LEDs MAGAZINE®

The New

Digital Magazine Experience

Use this button to toggle the new digital experience.

Use this button to view the table of contents.

The replica view is enabled by default.

NOVEMBER/DECEMBER 2017

PennWell

LEDs MAGAZINE®

TECHNOLOGY AND APPLICATIONS OF LIGHT EMITTING DIODES

LEDsmagazine.com

Wireless mesh
Bluetooth grows up P. 35

Street and Area Lighting
Conference report P. 41

Optical principles
Luminaire design P. 47

Offices get WELL

LED and natural lighting P. 21 & 31


www.osram.com/general-lighting
Inspiring greatness.
Illuminating greatness.
For us, technology is key to a better life.
And we pursue that vision with great effort. With a spectrum of infinite possibilities. From passionate hearts to smart minds. From the first idea to impressive illumination. From unprecedented atmosphere appreciated by art lovers to highly innovative and sophisticated lighting installations on thrilling grounds. From our first draft to your business success.
OSRAM
Opto Semiconductors

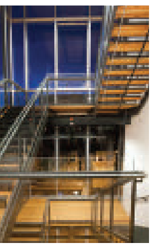
LEDs MAGAZINE® ISSUE 101

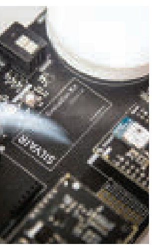
November/December 2017

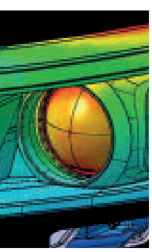
Cover Story

Solid-state lighting and controls contribute to human wellbeing and productivity in commercial projects (see p. 21–33; courtesy of Benya Burnett Consultancy/Eric Laingnal/ Perkins & Will Architects).

features







columns/departments

Horticultural Lighting Conference reveals complex SSL application sector

We held our second US Horticultural Lighting Conference (horticulturelightingconference.com) just days before this issue of the magazine went to print. An in-depth article on the conference will have to wait for a future issue. But here I offer some quick thoughts. It's a fantastic opportunity for LED and solid-state lighting (SSL) manufacturers, but also one with technical and logistic challenges.

Philip Smallwood, director of research at our Strategies Unlimited business unit, quantified the lighting opportunity. For 2017, Smallwood projected that the horticultural lighting market would total just over $4B (billion) in revenue and grow to the $8B range by 2022. But the bulk of the market is based on legacy light sources today.

For 2017, LED installations and hybrid LED/HID installations will represent less than 25% of the market. Still, there is plenty of opportunity for LEDs. Smallwood projects that revenue from LED-based products will approach $3B by 2022. Smallwood further discussed specific niches such as vertical farming and legalized cannabis. Those details and much more are in the new "Horticultural Lighting: Market Analysis and Forecast 2017" report from Strategies Unlimited (http://bit.ly/2tZOYhc).

Turning to the technical presentations, an unexpected theme arose throughout the day. In many ways, plants are way more complex than humans when it comes to characterizing the performance and efficiency of lighting. Now that statement may not be literally true. But in the plant world, there are so many varieties or cultivars, and most have different optimal light recipes. Moreover, plants have varying needs at different times through the growth cycle.

Still, there is one important commonality between lighting for plants and lighting for humans with respect to LED sources. We held our first Lighting for Health and Wellbeing Conference this past summer in Newport Beach, CA (http://bit.ly/2gj4ccX). A key theme then was the tunability in spectra that LEDs bring to human-centric lighting (HCL). That tunability will also be important in horticulture. Unfortunately, no one knows in either application exactly what the ideal spectrum is in terms of delivering tangible benefits — increased yield and better tasting produce, for example, in horticulture.

The complexity of the application extends to logistics issues with market transformation programs and the ability for buyers of horticultural lighting products to receive rebates or utility incentives. For example, the DesignLights Consortium (DLC) is a market-transformation organization that was originally formed by a group of utilities to facilitate the transition to SSL in general illumination. Over time, the DLC has developed a broad qualified products list (QPL) covering lamps and many types of luminaires. It ensures that qualified products are eligible for rebates.

The DLC would like to develop a QPL for horticultural lighting products. But the industry is still developing standards specific to horticulture, as we will discuss in our upcoming feature article. And tunability will further complicate the issue — as it does in HCL. It can be almost impossible to discern a parameter such as efficiency or efficacy when spectra are changing.

The technical challenges and the opportunities in the horticultural sector are both large. We need to solve the challenges — the positive impact on society and the environment depend on it.

Maury Wright,
EDITOR
mauryw@pennwell.com

LEDs MAGAZINE

Twitter @ledsmagazine
Facebook LEDsMagazine
LinkedIn Showcase LEDs Magazine Showcase Page

LEDs MAGAZINE | web exclusives

E-book

Materials matter in LED applications
http://bit.ly/2itj9gy

Webcasts

Horticultural lighting plays out in varied spaces
http://bit.ly/2gBnTAj

Faster and better – How optics help in achieving higher quality light and reduce LED system costs
http://bit.ly/2xZyh7v

Video Library

Watch the latest conference interviews and more
http://bit.ly/2wBvi4C

For more online exclusive resources, go to: ledsmagazine.com/resources

FEATURED *events*

LuxLive, co-located with lightspace.london
November 15–16, 2017
London, UK

Strategies in Light Europe Investor Forum
November 16, 2017
London, UK

Lux Awards
November 16, 2017
London, UK

China International Lighting Expo
November 20–22, 2017
Shanghai, China

LED Expo New Delhi
November 30–December 2, 2017
New Delhi, India

ForumLED Europe
December 13–14, 2017
Lyon, France

10th LED & Laser Diode Technology Expo
January 17–19, 2018
Tokyo, Japan

Strategies in Light 2018 – co-located with The LED Show
February 13–15, 2018
Long Beach, CA

Lightspace California
February 13–15, 2018
Long Beach, CA

LEDs Magazine Sapphire Awards
February 14, 2018
RMS Queen Mary, Long Beach, CA

MORE: www.ledsmagazine.com/events

ADVERTISERS *index*

ARCHITECTURAL LIGHTING

Ancient Church of Porza gets stunning yet non-invasive LED lighting retrofit

Dating to the 17th century, the Church of Porza stands on a hill in the Swiss district of Lugano, and while small in size, the church carries significant historical worth. The church recent underwent a solid-state lighting (SSL) retrofit that was intended to emphasize the beauty of the building without impacting the historic structure in any way. B Light has supplied a number of LED luminaires that have accomplished the goals as the nearby photo demonstrates.

The Church of Porza was dedicated to Saint Bernardino from Siena in the Tuscany region of Italy and Saint Martino from Tours in France. The building has a single nave and a bell tower with an octaganol drum. The baroque-neoclassical chuch is in a spectacular setting with views of the hills in the Lugano area.

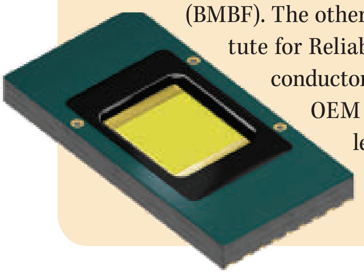
Lighting sacred and historic sites has been an important early application for the deployment of LED lighting. As was the case in Porza, such lighting projects must not imapact the structure for both religious and historic reasons. Small LED form factors and low power requirements have made an SSL retrofit the only option for projects where the desire is to improve the quality of the lighting design. For example, we covered the lighting in the » page 8

AUTOMOTIVE LEDS

Osram delivers prototype of 1024-pixel LED headlamp hybrid assembly

Osram Opto Semiconductors along with Osram Specialty Lighting has announced the demonstration of the Eviyos automotive LED headlamp module that could be the next advancement in automotive forward lighting beyond shipping adaptive drive beam headlights. The company recently showcased a prototype of the hybrid module at the ISAL (International Symposium on Automotive Lighting) event in Darmstadt, Germany.

Eviyos is the result of an R&D partnership coordinated by Osram and funded by the German Federal Ministry of Education and Research (BMBF). The other partners included the Fraunhofer Institute for Reliability and Microintegration (IZM), semiconductor-manufacturer Infineon, auto third-party OEM Hella, and auto manufacturer Daimler. We covered details of the R&D project called the μAFS Research Project last year (http://bit.ly/2f9pQNV) » page 10



SPORTS & ENTERTAINMENT LIGHTING

Martinsville Speedway gets LED lighting for fall NASCAR race

Eaton has announced an outdoor SSL installation at Martinsville Speedway located in Ridgeway, VA just south of the city of Martinsville. This past September, the new LED lighting bathed the track for viewers to watch the Late Model series NASCAR (National Association for Stock Car Auto Racing) series drivers duel in the ValleyStar Credit Union 300 race — the first night race in the 70-year history of the iconic raceway.

Seeing LED-based lighting installed for professional sports venues has become a fairly common occurrence of late, although just a few years ago it was quite novel. For example, we covered the first NFL (National Football League) Super Bowl played under LED lighting just two and a half years ago (http://bit.ly/1KqhVrQ). And MLB (Major League Baseball) teams made a big move into » page 8

interior of a neo-Gothic church in Germany (http://bit.ly/1tQsfkJ). And we published a feature-length article on an SSL project at the Durham Cathedral in England (http://bit.ly/1oVQ324).

In Porza, B Light was tasked to light the bell tower, the churchyard, and the outdoor area enclosed by low walls. The goal was to maintain a solemn atmosphere while enhancing the beauty of the site and making ingress and egress safer for worshippers.

To light the passage leading to the entrance of the church and portions of the churchyard, B Light installed Inserto Medium DO luminaires that are recessed into the surface in an asymmetrical pattern. The luminaires both light the passage and deliver some uplight to the front surface of the church and portal.

The bell tower, meanwhile, is lit with Linear Tube 112 Slim fixtures that, as the name implies, feature a tube-shaped form factor that can uniformly light such a structure while being hidden from direct view. The luminaires are installed inside the bell tower, making the bell clearly visible against the contrast of the night sky.

The remainder of the area lighting in the project was focused on benches located around the site and on the trees in the churchyard. Under the benches, B Light deployed Button 100 DO luminaires that have optics designed to reduce glare. More-directional and recessed Meropre 140 AD luminares provide uplight on the trees.

The Church of Porza joins a growing list of sacred sites where worshippers will enjoy the benefits of LED lighting. Indeed, the list includes among the most famous sites the Vatican's St. Peter's Square for example (http://bit.ly/2l9qCT3). ◂

Race from page 8

LED lighting for the 2016 season (http://bit.ly/28YaZ5u). Top European soccer teams have also been in on the SSL trend (http://bit.ly/2tq7eBQ).

Still, Martinsville has become the first major automobile speedway or motorsports facility to be lit with LEDs. International Speedway Corporation (ISC) owns the track and instigated the project called "Light Up Martinsville." Distributor Graybar also participated in the installation of the Ephesus Stadium 750 luminaires.

As is increasingly the case in sports venues, the choice of LED-based lighting was more about light quality than energy efficiency — although a track that previously had no lighting for night racing will surely appreciate energy-efficient lighting. But ISC said the lighting was selected to optimize the viewing experience for fans in the stands and those watching at home in HDTV.

Martinsville is one of the most popular venues on the NASCAR circuit for fans and drivers. The circuit is small relative to most NASCAR venues at just over 0.5 miles for the oval track. But fans in the stadium-like venue can see all the action. The track has been on the NASCAR circuit since the inception of that racing organization.

This season, fans and drivers are in for an all-new nighttime experience at Martinsville. "We were honored when historic Martinsville Speedway selected our Ephesus LED lighting solution to light up Martinsville," said Mike Lorenz, president of Eaton's Ephesus Lighting business. "It's especially rewarding to bring night racing to this remarkable venue. There is nothing like racing under the lights and with our industry-leading digital lighting system, drivers experience optimum conditions while fans will experience this venue in a whole new light." ◂

HORTICULTURAL LIGHTING

Seoul announces horticultural LEDs; Cree, Lumileds, and Osram show recent newcomers

The *LEDs Magazine* Horticultural Lighting Conference took place on Oct. 17 in Denver, CO, and the event yielded the public debut of a number of new packaged LEDs for the burgeoning application. Seoul Semiconductor used the event to launch its Horticultural Series LEDs across mid-power, high-power, and chip-on-board (COB) products, including LEDs that emit in the ultraviolet (UV) range. Osram Opto Semiconductors, Lumileds, and Cree, meanwhile, all used the conference as a venue to demonstrate new horticultural LEDs launched in the past few months.

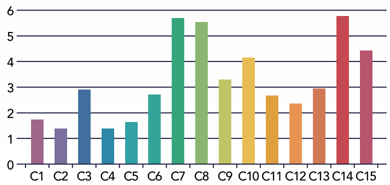
Seoul horticultural entry

The Seoul announcement became what was perhaps the broadest horticultural LED launch in the industry, even surpassing the Lumileds SunPlus announcement last year in breadth. Seoul is the only vendor offering horticultural-centric products spanning the UV range to the near infrared (NIR) bands. Moreover, the company is targeting some LEDs at horticulture that are based on its SunLike technology platform that debuted earlier this year with a uniform spectral power distribution said to mimic the sun (http://bit.ly/2sNvv2U).

In the high-power sector, Seoul announced deep-blue (449–461 nm), deep-red (646–665 nm), far-red (730 nm peak), and broad-spectrum-white LEDs. In each case, the company is specifying a photosynthetic photon flux (PPF) measure of performance expressed in micromoles per second (μmoles/sec). For example, the 650-mW deep-blue LEDs are rated at 2.6 μmoles/sec. For more on horticultural-centric metrics, see our feature article on the topic (http://bit.ly/2fwtLZB).

The high-power offering also includes horticultural LEDs in the UV-C, UV-B, and UV-A bands, which are marketed by the Seoul VioSys business unit. During the conference sessions, Peter Barber, product marketing

CITILED Vivid Series Brilliant Type



CITIZEN ELECTRONICS CO., LTD. JAPAN

1-23-1, Kamikurechi, Fujiyoshida-shi, Yamanashi-ken 403-0001, Japan
Tel:+81-555-23-4121

http://ce.citizen.co.jp/e/

CITILED is a trademark or a registered trademark of Citizen Electronics Co., Ltd. Japan

CITILED®
The Light Engine

Headlamp from page 7

and Osram said the partners completed the R&D work in 2016.

We have written quite a lot about adaptive drive beam headlamps at the component and module level. Osram has been a leader in the space. The company recently announced a module that combined multiple LED segments or pixels and a silicone optic to enable auto makers to use the technology in mainstream vehicles (http://bit.ly/2y3uDtm). Typically, the technology works with camera assistance to sense oncoming traffic and changes in the road topography to alter beam direction, eliminating glare for oncoming drivers and providing the driver of the auto with the adaptive headlamps to better view the roadway.

The Eviyos LED headlamp project takes beam control to another level with the ability of the electronics to independently control 1024 individual emitters or pixels as opposed to controlling three to a dozen groups of emitters that form larger pixels or segments. The key to the granularity is the integration of driver electronics and intelligence in the module.

"The hybrid LED is another example of our products making a major contribution to improving the quality of life in many different areas," said Thomas Christl, marketing manager at Osram Opto. "With Eviyos we are helping to make the roads safer and improve comfort and convenience for drivers. We are proud that we can present the first prototype so soon after completing the research project. We are now another stage further toward series production."

The usage of the word hybrid in the above quote is key to understanding the architecture of the module. In electronics and semiconductor industry parlance, a hybrid refers to a device that integrates multiple ICs and/or discrete semiconductor components on a substrate and that can be handled like a large IC, although it is not a monolithic device. In the case of Eviyos, the hybrid integrates the LED array, driver electronics, and intelligent control.

The hybrid LED headlamp module has a footprint of 4×4 mm. The prototype device can deliver 3 lm/pixel at a drive current of 11 mA. And Osram has demonstrated the ability to up the flux output to 4.6 lm/pixel.

Osram does not plan on selling the Eviyos LED headlamp modules commercially until 2020 — although with the long development cycles in the auto industry, development teams will be selecting 2020 components now if not earlier. Osram said some designs might utilize multiple Eviyos modules or combine one of the modules with more traditional LED headlamp components. ◂

Horticulture from page 8

manager for Seoul VioSys, explained that UV LED technology can be utilized at many stages of horticulture starting with treatment of seeds and extending to use in increasing shelf life of produce such as strawberries. We will have more coverage of the conference talks in an upcoming feature article.

In the mid-power sector, Seoul is also offering deep-blue, deep-red, and far-red LEDs, along with a broad-spectrum white LED based on the SunLike technology. And the COB offering is also based on SunLike with the components spanning the 6–25W range.

"By extending the spectrum of LEDs to include both ultraviolet and far-red light sources, Seoul Semiconductor provides horticultural lighting designers an entirely new spectrum of possibilities in developing lighting systems for specific plant growth and propagation," said Mark McClear, vice president for the Americas at Seoul Semiconductor. "Our Horticultural Series LEDs include high-power, mid-power, and COB devices, enabling the design of a wide range of lighting fixtures — from high-bay and directional lights to rack-mounted fixtures for vertical farming systems — all from a single LED manufacturer."

Horticultural Lighting exhibits

In addition to the new Seoul LEDs being on display in the tabletop exhibit area adjacent to the conference session, several other LED makers showed recently-released products. Osram, for example, demonstrated its Oslon Square LED family — 2W devices in a 2×2-mm LED. A few months back, Osram added a hyper-red (660 nm) LED to the Oslon Square family after previously offering deep-blue and far-red LEDs in the portfolio. The hyper-red horticultural LED is useful for controlling the growth of blossoms on a plant.

Recently, Lumileds added LEDs to its SunPlus family of horticultural-centric products (p. 14). At the Horticultural Lighting Conference, the company was demonstrating the new COB products in a directional fixture design for overhead lighting. And the new deep-red and far-red members of the mid-power SunPlus 35 portfolio were on display.

Cree, meanwhile, showed reference designs that integrated blue and red LEDs, and designs based on broad-spectrum white LEDs. The royal-blue LEDs in the demonstration were the XLamp XP-G3 LEDs that the company launched in the spring (http://bit.ly/2qBe9Fw). Cree says those LEDs deliver 81% wall plug efficiency.

OLEDS

FEP demos OLED's true colors

The Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology (FEP) said it has figured out how to make flexible OLEDs change colors.

The breakthrough comes about two years after the Dresden-based research institute first cracked the color changing problem, on rigid substrate OLEDs.

"Fraunhofer FEP now offers OLED emission systems featuring an adjustable color range integrated on flexible substrates," Fraunhofer said. "These types of OLED modules are able to switch the emitted color between two different color temperatures. In this way, a yellow-blue bi-color emission system can not only be switched between the pure emission colors of yellow and blue, but white light can also be generated through simultaneous activation of both colors."

Fraunhofer demonstrated the new technology at the ISALevent mentioned earlier.

LG, Samsung invest in German OLED company aiming at efficient blue

LG and Samsung have invested a combined €25 million (about $30 million) in a small German OLED specialist that claims to be solving a big shortcoming in OLED technology by developing an efficient blue emitter.

Cynora is focused on blue at the moment because that's where it sees the greatest need. "While efficient emitters for red and green are already commercially available, there is still no OLED material that efficiently converts electricity into blue light," the company says on its website.

In general lighting, one of the drawbacks of OLED is that it is not as efficient as LED. An improvement in blue efficiency could help to narrow that gap. OLEDs are materials that light up when excited by a current. They could usher in a whole new era of design in lighting, architecture, and clothing, but manufacturing costs have remained high and efficiency has not matched LEDs, which are single light points. Another challenge for OLED developers is that LED designers are embedding light strips in fabric to create effects similar to OLEDs.

Bruchsal, Germany-based Cynora said it will commercialize the product by the end of this year, using a technique called thermally activated delayed fluorescence (TADF).

Cynora explains that TADF focuses on "triplet excitons" rather than on singlet excitons. Excitons are the recombined positive and negative charge carriers that can be converted into light by emitter material. "For highly-efficient OLEDs, both types of excitons have to be converted into light," says Cynora. "This is less straightforward for triplet excitons."

The Series B investments by LG Display and Samsung Venture Investment Corporation call for both companies to work on separate Cynora projects advancing TADF materials for AMOLED — active matrix OLED — which is targeted at the market for TV screens and smartphone displays (http://bit.ly/2yC7T7J). Cynora, founded in 2008, is also positioning TADF for the general lighting market, where it promises leaps in efficiency and color temperature performance.

SSL BUSINESS

Cree names Gregg Lowe CEO to replace Chuck Swoboda who led focus on general illumination

Cree announced that Gregg Lowe (pictured) would take the position of president and CEO of the company effective this past September, ending the long-time reign of Chuck Swoboda, who guided the company's total focus on LED usage in general illumination applications. Lowe was previously CEO of Freescale Semiconductor, a company acquired by NXP Semiconductors in 2015; Qualcomm announced late in 2016 that it was buying NXP. Current Cree board member Robert Ingram will take on the role of chairman that was previously also held by Swoboda.

Swoboda had been Cree CEO since 2001 and chairman since 2005. He ran the organization with a razor-like focus based on LEDs becoming the primary light source for general illumination far quicker than most expected. We covered that philosophy after a presentation Swoboda made back in 2010 when LEDs could only serve in select lighting applications such as street lights (http://bit.ly/2x8zIkw). Swoboda's results were at times spectacular, although Cree missed the significant role that mid-power LEDs would play in general illumination (http://bit.ly/2in6cos).

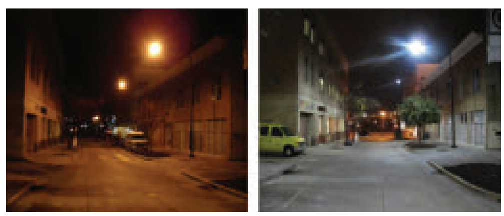
At Texas Instruments (TI), Lowe guided the company's analog components group to outstanding profits even while the company's digital technologies such as mobile phone ICs and digital signal processors (DSPs) garnered more coverage in the media. Lowe served at TI for 28 years before moving to fierce but smaller rival Freescale (a spinout from Motorola). Freescale was a $5 billion company under Lowe and the new CEO is decidedly qualified to lead Cree.

MORE: http://bit.ly/2yz4moP

ROADWAY LIGHTING

Knoxville taps Siemens, Acuity in straight-up $15 million LED street lighting job

The City of Knoxville, TN is replacing some 30,000 high-pressure sodium (HPS) luminaires with LED technology that officials

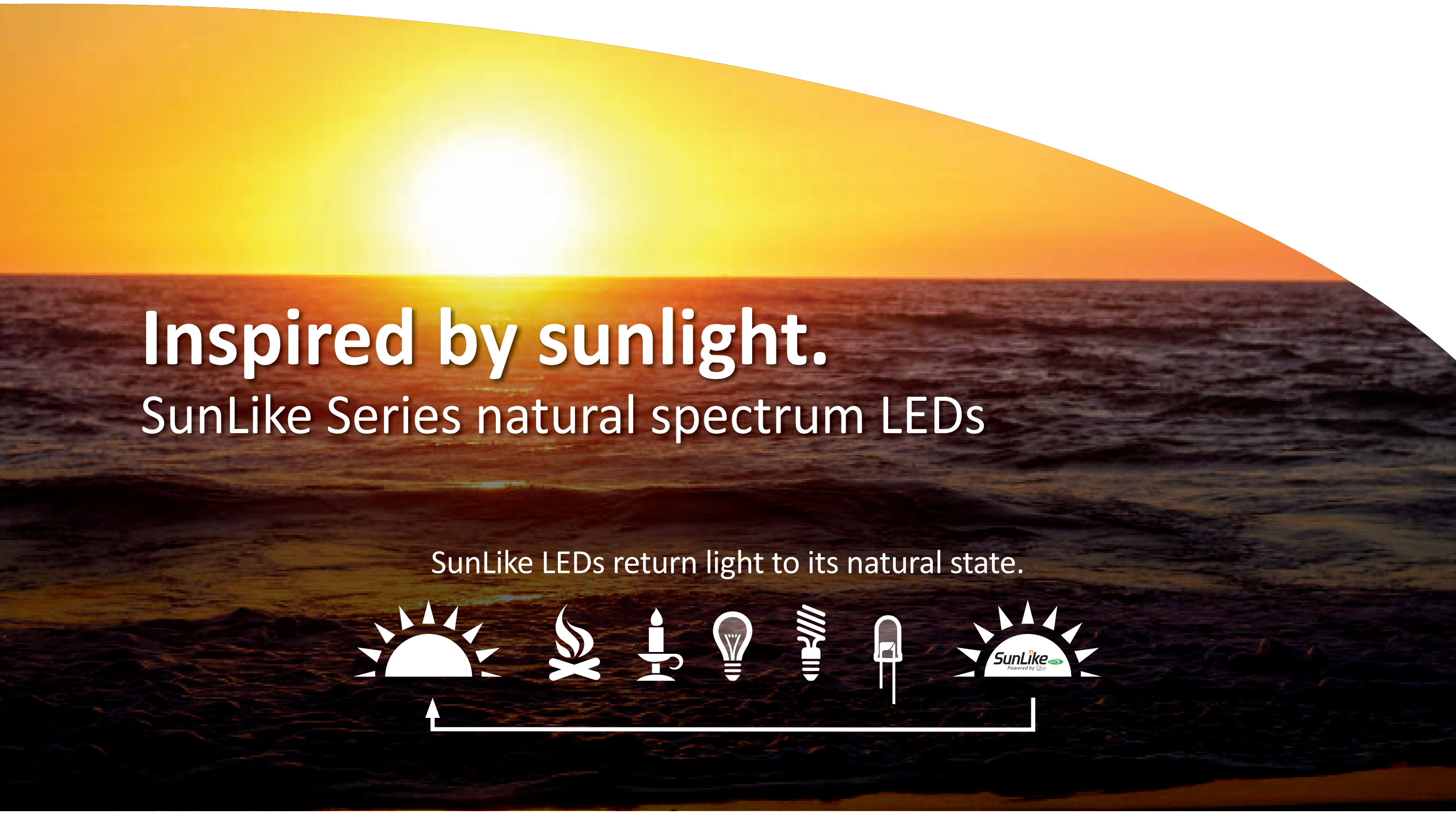


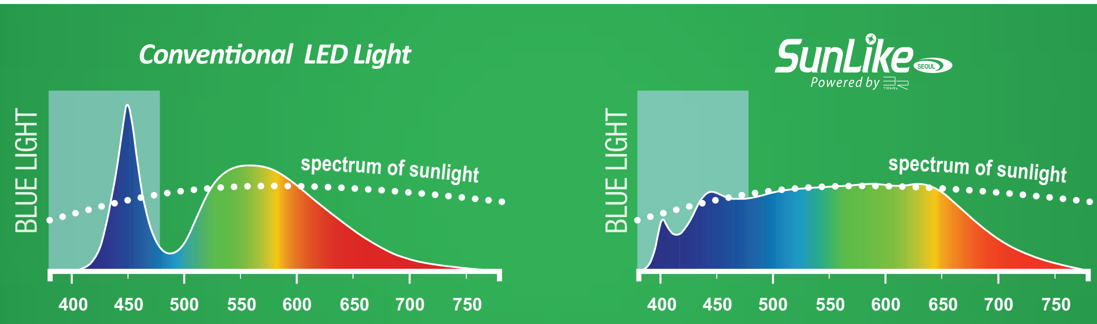
say will cut energy costs in half and will also improve light quality.

The $15 million installation calls for lead contractor Siemens to complete the job by June 2019, with Acuity Brands providing its Holophane luminaires and possibly its Roam wireless mesh control system (http://bit.ly/1LopMpT).

"Our street lights are one of city government's largest energy users, accounting for nearly 40% of our total municipal

SEOUL SEMICONDUCTOR





SunLike Series LEDs

- Closely matches natural spectrum of sunlight
- Minimizes negative effects of artificial light
- Accurately renders objects in natural light

.2W 3030 | 6W MJT COB | 10W MJT COB | 15W/25W MJT COB

SunLike Powered by

Visit **seoulsemicon.com** to learn more about the benefits of SunLike.

electricity consumption," said Mayor Madeline Rogero, noting that Knoxville expects to cut its annual street lighting bill from around $4 million today to around $2 million. The city also expects the LED luminaires to last 4× as long as HPS, at around 100,000 hours compared to 24,000 hours.

Knoxville is paying Siemens around $9.5 million as the main contractor, and is paying $5.2 million to local utility Knoxville Utilities Board (KUB) for past infrastructure investments in the lighting system. KUB owns most of the poles, while the city owns the brackets and lights that attach to them.

"This project will help us improve the overall design of our lighting system," said Knoxville office of sustainability director Erin Gill. "Instead of illuminating the sky and trees with an orange glow, we can focus light where we need it: on streets and sidewalks. The clear, whiter color of LED light provides better visibility and color rendering than HPS bulbs, making it easier to see people and objects in the roadway."

MORE: http://bit.ly/2hQVtPd

HORTICULTURAL LIGHTING

Dutch grower uses supplemental LED lighting to boost lily yield

Plessey has announced the results of a horticultural LED lighting trial at Alstroemeria grower Together2Grow located in Poeldijk, South Holland, the Netherlands. The grower

worked with Plessey to test LED lighting as a supplement to HPS lighting in a portion of its greenhouse dedicated to the Virginia variety of Alstroemeria. After seven weeks of supplemental SSL usage, the grower noted an increase in yield that has since been documented as a 20% improvement.

Alstroemeria, also called Peruvian Lily, Lily of the Incas, or Parrot Lily, is native to South America yet has become a popular flower around the globe. We covered the start of the Together2Grow trial back in the spring when Plessey announced several horticultural lighting trials, including one focused on tomatoes (http://bit.ly/2quYmJl). In each case, the tests are being focused on SSL as a supplemental energy source for the plants.

The control area of the trial relied just on the existing HPS lighting that delivered photosynthetic photon flux density (PPFD) of 70 μmoles/m²/sec. The SSL trial area used Plessey Attis 7 fixtures alongside each 1000W HPS fixture. The supplemental lighting increased PPFD to 130 μmoles/m²/sec.

MORE: http://bit.ly/2yuDzMA

Lumileds adds COB LEDs and new red options to SunPlus horticultural portfolio

Lumileds has announced an expansion of the Luxeon SunPlus family of horticultural lighting LEDs that first came to market one year back. The company has added COB LEDs in the portfolio that extend the type of fixtures that can be enabled to high-output directional products. Moreover, Lumileds has added deep- and far-red LEDs to the SunPlus 35 product line.

The SunPlus launch last year marked the first time any LED company had announced such a broad portfolio of LEDs, all targeting the horticultural lighting sector. The 3.5×3.5-mm SunPlus 35 LEDs are targeted at lower-power applications such as vertical farms where the LEDs are located relatively close to the cultivars such as lettuce and other greens. We termed those prod-

ucts mid-power LEDs in our original article because they are offered in what appear to be typical mid-power packages. Lumileds has since said that the company doesn't classify the products that way, and we have an interview from our October issue that further clarifies its position (http://bit.ly/2guXmVs). The SunPlus 20 LEDs are offered in a smaller 2×2-mm footprint, but appear to be based on high-power LED technology and packages.

The new COB products borrow a novel feature from some of the other members of the SunPlus 35 line. At the original announcement, Lumileds described purple LEDs that are produced using blue emitters and red phosphor that can cover the spectra that is known to maximize chlorophyll absorption in plants. The new SunPlus COB line consist of LEDs that emit the same mixes of red and blue spectra. Lumileds will offer the LEDs in three sizes with 15-, 19-, and 32-mm light-emitting surface (LES) diameters.

MORE: http://bit.ly/2x9EwGx

LIGHTING & CONTROLS

New York data center slashes energy usage with LED lighting and controls

Fairbanks Energy Services has documented the energy savings attributed to LED lighting and autonomous controls at a Chappaqua, NY data center at 244,000 kWh in one year of operation. Fairbanks worked with IT company vXchnge on the SSL project that delivered the significant energy savings in a 38,000-ft² center while meeting Illuminating Engineering Society (IES) recommended light levels.

For vXchnge, the LED lighting project was part of its continued commitment to being a green company. The company has stated that it is insistent on meeting the US Environmental Protection Agency (EPA) guidelines for "green data centers." In the case of the Chappaqua project, the partners said the occupancy- and daylight-sensing controls extended energy savings 20% relative to an installation with basic efficient SSL.

Still, as with all lighting projects, it's the quality of lighting for the people that work under it that is most important. Fairbanks reported that before the retrofit, light levels were 15–20 fc below fixtures and as low as 5–10 fc between fixtures. The retrofit can deliver 30–35 fc between fixtures, although that level depends on occupancy and natural light at any given time.

The LED lighting is set to dim to 9–10 fc when a space is vacant for 15 minutes. After 25 minutes, the lights are extinguished. The partners report that based on observations, the lights are on at full output only 10% of the time and even at that level are only 88% of full output. The observations would project that 40% of the time the lights are 50% dimmed and that 50% of the time the lights are off.

MORE: http://bit.ly/2ioczYS

INTERNET OF THINGS

Target gives the go-ahead on IoT lights at half its stores

The world's largest known deployment of lighting-based indoor positioning is finally going full speed ahead, as US retail giant Target plans to roll out a customer engagement system in nearly half of its 1800 stores by Christmas.

Using Bluetooth chips embedded in LED ceiling lights from Acuity Brands, Target will send signals to shoppers' phones. Drawing on a Target app, the phones will display an interactive map that guides individuals around the aisles, helping them find specific items and providing information about discounts.

Target has been piloting indoor positioning systems for several years, as *LEDs Magazine's* sister publication *Lux* first reported exclusively back in April 2015 (http://bit.ly/2xRfBf3). But like many early indoor positioning implementations, Target has held back from full-on deployment. As of two years ago, it was trialing the technology in about 100 stores (http://bit.ly/1JgkvCs).

Target is embedding Bluetooth transmitters in Acuity ceiling lights, the Target spokesperson said, noting that the system will only work with iPhones at first. Android support will follow later.

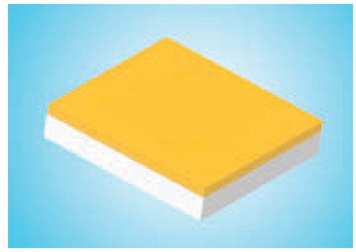
The rollout at Target could help boost the lighting-based indoor positioning concept and encourage further takeup of the Internet of Things (IoT) scheme, which has been characterized by one-off implementations in single or small groups of stores — such as at an EDEKA Paschmann store in Dusseldorf and E.Leclerc store in Langon, France; at the Dubai-based retail chain aswaaq; a Carrefour store in Lille, France (http://bit.ly/1GJqnTc), and elsewhere.

MORE: http://bit.ly/2gSR3Ia

PACKAGED LEDS

Samsung debuts CSP LEDs with top emission for directional applications

Samsung Electronics has announced a new family of chip-scale package (CSP) LEDs that the company refers to as Fillet-Enhanced CSP (FEC) LEDs. CSP LEDs are inherently five-sided emitters with no package covering the sides of the devices. The FEC products use a reflective coating on the four sides of the CSP device to reflect light and maximize the flux out of the top surface.



In many applications, five-sided emission is perfectly fine. For example, linear luminaires need wide beams and light in every direction. And other applications, such as the street lights we covered at LightFair International (LFI) this year, place the LED under a total internal reflection (TIR) lens, eliminating any issues with the side emission (http://bit.ly/2gvuiwP).

Directional lighting, however, requires maximum light output in one general direction. That's the application Samsung will address with the FEC family along with high-bay lighting. Moreover, Samsung said the new LEDs have higher efficacy than did previous Samsung CSP LEDs.

MORE: http://bit.ly/2yusnzF

Cree adds high-current COB LEDs based on a metal substrate

Cree has announced the XLamp CMA family of COB LEDs that mark the company's first foray into such LEDs manufactured on an aluminum substrate as opposed to a ceramic substrate. Cree is informally calling the new line a high-current family and positioning the portfolio to fit between previously-launched Standard Density and High Density ceramic-based LEDs.

In terms of product development, the CMA family will primarily be valuable as a way to move up from Standard Density products without paying the full price for High Density COB LEDs. The new line covers five LES diameters — 9, 12, 14, 19, and 23 mm. The 12-mm CMA 1825 delivers a range of 2150–7300 lm depending on drive current, CCT, and CRI. Cree said in general the performance numbers in terms of efficacy are on the order of 10% higher than second-generation Standard Density (CXB family) LEDs, although the company also said lumen density can be more than twice what the Standard Density products deliver.

The CMA LEDs are available across the 2700K–6500K CCT range and at 70, 80, and 90 CRI. Cree will also offer the CMA COB LEDs in what it calls Premium Color options with up to 98 CRI and custom chromaticity points. The company rolled out the Premium Color technology with chromaticities off the black-body locus when it announced the second-generation High Density line last year.

MORE: http://bit.ly/2xRvSM1

funding + programs

Circadian scientists who have studied light's impact win Nobel

For the second time in three years, a trio of scientists connected to lighting has won a Nobel Prize, as the Nobel Assembly has awarded three biologists with the Nobel Prize in Physiology or Medicine for helping to explain how the human circadian cycle works, including how light affects our daily rhythms.

To be clear, light was not the centerpiece of research by the three new Nobel Laureates Jeffrey C. Hall, Michael Rosbash, and Michael W. Young — in contrast to the lighting-centric work of Shuji Nakamura, Isamu Akasaki, and Hiroshi Amano, who won the 2014 Nobel Prize in Physics for their invention of the blue LED (http://bit.ly/1DCMmDS).

Rather, Hall, Rosbash, and Young over the years revealed the complicated cell-level mechanisms that literally make the circadian clock tick, in work on fruit flies that has since been shown to also explain the circadian processes in humans. Hall is affiliated with Rockefeller University in New York, and Rosbash and Young with Brandeis University in Boston, as well as the University of Maine for Young.

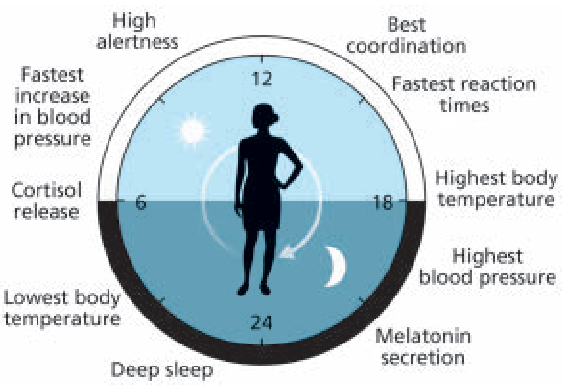


Image credit: Nobel Assembly at Karolinska Institute.

In investigations spanning a decade or more starting in 1984, they identified three genes, including the "period gene" that helps build a protein called PER, which accumulates in a cell's nucleus. PER also blocks the period gene from making more PER and then degrades during the day. Another gene called "timeless" assists the process by helping to build a protein called TIM that moves PER from one part of the cell into the nucleus, where it needs to be. A third gene called "doubletime" helps build a protein called DBT that delays PER's accumulation.

Together, those genes keep the circadian clock in sync, which is crucial because the clock regulates critical functions such as behavior, hormone levels, sleep, body temperature, blood pressure, and metabolism.

Messing with the clock could throw off any of those functions, which has ramifications for health and wellbeing, and has been linked in other research to diseases including cancer, diabetes, and more (http://bit.ly/2gj4ccX).

Light is one factor that can throw the clock out of rhythm, a fact not lost on the three new Nobel Laureates Hall, Rosbash, and Young.

"The paradigm-shifting discoveries by the Laureates established key mechanistic principles for the biological clock," the Nobel Foundation said in announcing the prize. "During the following years, other molecular components of the clockwork mechanism were » page 18

US DOE publishes Gateway research on tunable LED lighting in education

The US Department of Energy (DOE) has conducted a Gateway trial of tunable LED lighting in three Carrollton, TX classrooms, and teachers felt that the solid-state lighting (SSL) installation improved the educational environment. Interestingly, the school district has decided not to invest in tunable LEDs on a widespread basis at this point due to the cost premium relative to non-tunable LED lighting. However, the district did say it would reevaluate tunable technology as more data becomes available documenting positive impacts in student learning outcomes and teacher satisfaction directly attributable to tunable lighting. And the report lacks quantifiable detail on aspects such as productivity improvement that have been associated with so-called human-centric lighting (HCL).

The Gateway project took place in the Carrollton-Farmers Branch Independent School District (CFB). As with all DOE Gateway projects, commercially available LED lighting products were installed for evaluation in a working setting. The SSL installation included one 5th-grade math and science classroom, one 4th-grade reading and language arts classroom, and one 8th-grade science laboratory at three different CFB schools. In each of the schools, there was a very similar classroom nearby that was lit with legacy fluorescent lighting, and those classrooms served as comparative reference cases to the tunable lighting installations.

The DOE installed SSL and control products from Acuity Brands, including Lithonia-branded LED-based BLT Series troffers and nLight controls. Acuity has demonstrated such a system going back to at least LightFair International in 2016 when we covered the announcement of what the company called Mainstream Dynamic technology (http://bit.ly/1UyRcPf). The control system offers preset scenes for different » page 18

School from page 17 activities such as test taking or book study.

In the Texas schools, the DOE installed a control panel that supported four scenes and separately four different spectral power distribution (SPD) settings — General (4200K CCT), Reading (3000K), Testing (3500K), and Energy (5000K). The scenes included:

- Full — all luminaires on at 100%
- AV Mode — the luminaire near the front of the room off and others set to 40%
- Presentation Mode — the luminaires near the front at 100% and others at 50%
- Dim — All luminaires at 10%

Other controls provided overrides. For instance, an up arrow allows the teacher to raise light levels at every luminaire by 5% each time the button is depressed and a down arrow works similarly to reduce light levels. Occupancy sensors can also turn the lighting off.

The full DOE report provides intricate details on photometric data gathered under the lighting. And it compares that data with the fluorescent reference classrooms. Generally, the LED system delivered higher-quality lighting, although there are some interesting details that the DOE discussed in new human response metrics that it studied in the classrooms. You can find the full report on the DOE SSL website (http://bit.ly/2zeoLib).

But the summarized results are more focused on energy savings and whether the tunable lighting improved the educational environment. The energy efficiency angle is documented by facts, whereas the benefits of the lighting are generally limited to input from the teachers.

One of the teachers, who had suffered migraine headaches on a regular basis, reported no recurrence of migraines under the LED lighting. The report speculates that flicker from the fluorescent lighting may have been the culprit.

Photo credit: Acuity Brands.

Generally, the teachers felt that the tunable system empowered them to provide a better educational environment. But the DOE noted that the empowerment is impossible to quantify. Overall, the teachers reported using the scene controls far more often that the SPD controls.

In almost all cases, the teachers used the dimming controls via scenes or manual overrides throughout the day. The combination of energy-efficient LED sources and dimming that wasn't easily accomplished with the fluorescent systems resulted in the LED lit rooms using 58% of the energy used in the fluorescent-lit rooms.

The school district, however, balked at installing a tunable system on a more widespread basis after learning that the tunable system cost 25% more than an SSL system that just included dimming with a similar control strategy. Indeed, the scenes as implemented in the Gateway system were simply based on dimming with the SPD tuning handled separately, so a non-tunable system could deliver those scenes and perhaps better energy efficiency since tunable lights mix output from multiple LED channels.

MORE: http://bit.ly/2ztlxXU

Nobel from page 17 elucidated, explaining its stability and function. For example, this year's Laureates identified additional proteins required for the activation of the period gene, as well as for the mechanism by which light can synchronize the clock."

In a more in-depth summary of the trio's work, professor of neuroscience Carlos Ibañez from the Nobel Assembly, which awarded the prize, noted that "the building blocks of a circadian system consist of a self-sustained 24-hour rhythm generator or oscillator, setting or entraining mechanisms that link the internal oscillator to external stimuli (referred to as zeitgebers, i.e., timekeepers), such as light, and output mechanisms to allow the timely scheduling of physiological processes."

Certainly, there is now plenty of research looking into light's role — including that of artificial LED light — as both villain and hero in circadian health. And LED lighting vendors are in the early days of selling human-centric lighting (HCL) systems, also known as circadian lighting. *LEDs Magazine* has reported on many developments, including our two-part feature examining HCL in the workplace (http://bit.ly/2yRrodB and p. 21). That series follows last year's two-part report, when we looked at early successes of HCL in healthcare (http://bit.ly/2cL4Fnn) and in the office (http://bit.ly/2iEsGPI).

MORE: http://bit.ly/2yseQYt ◄

DOE publishes 2017 SSL R&D plan for LED and OLED technology

This year, the DOE's annual SSL R&D plan is split into two documents: the 2017 Suggested Research Topics and the Supplement to 2017 Suggested Research Topics. The latter contains the latest DOE projections on efficacy advancements and energy savings; the former succinctly defines specific areas where more research is needed in the SSL sector.

The new document structure marks the second time in recent history where the DOE has changed the structure of its R&D planning and reporting. The agency has published the annual R&D Plan since 2015 (http://bit.ly/2lt6u9Z). Prior to that year, the agency published separate Multi-Year Program Plan (MYPP) and SSL Manufacturing Roadmap reports (http://bit.ly/28IXyX9).

The 2017 supplement projects energy savings based on the SSL industry's current path as well as on the DOE's more aggressive goals — both relative to a scenario in which no LED lighting had been installed. Based on the current industry path, the DOE said the LED transition will save 42 quads of energy cumulatively from 2015 to 2035 in the US. A quad is approximately equivalent to 293 TWh or a quadrillion BTUs. The DOE further said that if the industry can meet DOE goals, the cumulative savings could reach 62 quads with the additional 20 quads being enough energy to power 90% of US homes for a year.

The 2017 research topics document shows the efficacy gap between cool- and warm-white phosphor-converted LEDs narrowing. By 2020, the DOE says the gap will be 10 lm/W with typical cool-white efficacy of 218 lm/W at the package level. By 2025, the agency expects cool-white efficacy to reach 240 lm/W with only a 3-lm/W gap to warm-white LEDs.

The news is not so good in the OLED sector, which the DOE said has not been able to crack the 100-lm/W barrier outside the lab. Back in 2014, the DOE had projected that such panels would have been widely available by now.

Going forward, the research topics document suggested that study of efficiency droop in blue LEDs will remain a priority.

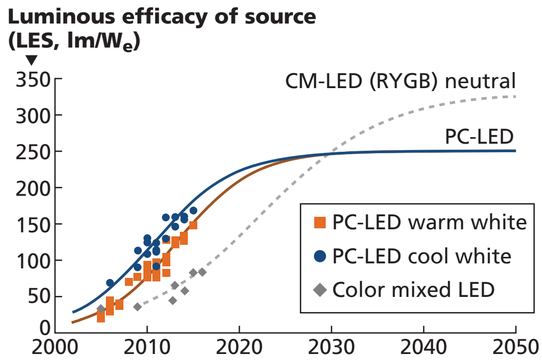


Image credit: US Department of Energy.

You can read the full details of the new SSL R&D Plan on the DOE website (http://bit.ly/2yorwOp).

MORE: http://bit.ly/2xJsS4o

Lighting the World
ONE LED AT A TIME
Z Series
High Density
B-V2 Series
High Efficacy
COB Series
Single 3 step color bins with various retail CRI options
High lumen density
Low thermal droop
Simple assembly process
Request Your FREE Samples Now!
www.bit.ly/FLSNichiaSamples
NICHIA
www.NICHIA.com
FUTURE
Lighting Solutions
Making LED Lighting Solutions Simple™
www.FutureLightingSolutions.com

Human-centric lighting in the workplace: It's not just about color temperature

While it might make sense to turn up the Kelvin settings during the day and down toward night, it's not always that simple. **MARK HALPER** discovers the virtues of spectral power and natural light at offices from coast to coast in the US.

As our modern lives emphatically defy the planet's natural day/night cycle we are, plainly put, messing with our bodies' circadian clocks. Our physiology has evolved over millions of years to conform with 24-hour patterns of sunrise and sunset, yet our contemporary non-stop work and play habits fight brutally against that conditioning.

And there is perhaps no greater symbol of our new clock-defying norm than electric light, which has generally kept the gates wide open to nocturnal land for well over a century in the developed world.

Many efforts are now underway to study the impact of light on the circadian rhythm, and how to engineer lighting systems to be good circadian citizens. Those efforts are intensifying now that LED lighting has arrived. LEDs' digital nature makes them relatively easy to tune to settings that might support circadian needs.

LED lighting has gained a reputation for both good and bad on the circadian scene. On the good side, the blue frequencies that tend to be common in white LED light can stimulate, which is desirable, say, in the morning, or at a math class when you need to pay attention. But blue can keep you awake at night when you need to sleep. Conversely, ambers and reds can help you relax. More bad: Blues at the wrong circadian time have been linked to serious health issues such as cancer and diabetes, and so on.

The scientific understanding is still evolving. It's very much in its early days and is subject to debate. For a basic understanding of some fundamental precepts: Blue frequencies stimulate the brain's master clock because they stoke up a pigment called melanopsin which resides in the retina's non-visual photoreceptors (non-visual photoreceptors are different from the visual photoreceptors known as rods and cones); and blue suppresses melatonin, a hormone associated with helping us fall asleep.

With that in mind, offices around the world are beginning to deploy lighting systems that try to make the most of our circadian rhythm. *LEDs Magazine* has written many articles over the past couple of years on the subject, including last year's two-part special looking at deployments in hospitals (http://bit.ly/2cL4Fnn) and in the workplace (http://bit.ly/2iEsGPI). We've followed that with another two-parter this year. The first installment ran in our last issue (http://bit.ly/2yRrodB), looking at buildings in the US and in the UK, at the impressive research and field studies by Rensselaer Polytechnic Institute's Lighting Research Center, and at control systems from Casambi.

Here in Part 2, we delve deeper into the science, discovering the important distinction between correlated color temperature (CCT) and spectral power distribution (SPD), and the importance of natural light. And we

Photo credit: Benya Burnett Consultancy/Eric Laingnal/Perkins & Will Architects.

FIG. 1. Employees at ASID headquarters work in finely tuned spectral power conditions.

MARK HALPER *is a contributing editor for LEDs Magazine, and an energy, technology, and business journalist (markhalper@aol.com).*

Photo credit: Benya Burnett Consultancy/Eric Laingnal/Perkins & Will Architects.

FIG. 2. ASID employees benefit from natural light as well as artificial. And the office's north-facing windows provide ample natural light but less glare than if they were facing south.

peek into the lighting design at a couple of different award-winning buildings.

Whatever you want to call this subject — it goes by the names human-centric lighting and circadian lighting, or lighting for health and wellbeing — rest assured that it will continue to gain attention and help drive the lighting industry. It's a pillar in the field of human circadian studies, the general importance of which is growing, as evidenced last October when Nobel judges awarded the Nobel Prize in Physiology or Medicine to three US scientists for their work in explaining how the circadian clock works (p. 17).

Lighting is not the only factor of modern living that is disrupting circadian cycles. Heating and air conditioning (temperature), physical activity or lack thereof, eating habits, and much more all play a role. But along with temperature and food intake, light is one of the three or so primary influences — circadian scientists call them "zeitgebers" from the German word for time giving, or timekeeper. Zeitgebers like light can turn gene functions on and off. They have a huge impact on health, mood, energy level, and all sorts of other things.

In a world where most people spend more time indoors than out, and where nighttime tends to be light time whether outside or not, it's imperative to gain a better understanding of lighting's circadian effects — and what to do about them. Here are some people and places that are trying.

* * * *

ASID HQ has the power — The spectral power

As the concept of human-centric lighting gains credibility, the common wisdom is that blues stimulate, ambers relax. Thus, designers are tending to specify systems that deliver those frequencies at the desired time of day or in the desired setting. Typically, they might focus on the correlated color temperature, prescribing systems that adjust the CCT. For example, lights might deliver cool-blue 5000K and 6000K temperatures to stimulate in the morning, while resetting to the warmer 2700K zone of amber colors at rest time. (In case you need a reminder, temperatures in the counterintuitive "K" or "Kelvin" scale are cooler at higher numbers.)

But it's not quite that simple, noted Deborah Burnett, principal and partner at lighting design firm Benya Burnett Consultancy. While different CCTs are indeed associated with different biological responses, it is not the CCT per se that elicits the different reactions.

Rather, notes Burnett, it is the energy released by light, a quality characterized by SPD. As that energy hits human eyes and human skin, it will trigger biological responses. SPD accurately defines the energy in light across the range of human visual sensitivity. The fact is that even if two light sources have the same CCT, they can have decidedly different SPD curves.

"If you rely on CCT, you are ignoring the main basic tenet of human-centric lighting, circadian lighting, biology of plants and humans," said Burnett. "CCT is a correlated color temperature, a Kelvin temperature. It's how you represent an average of the CCT of a light source. You take 2, 3, 5, 10 different 3500K LEDs and you line them all up, and you use a spectrometer and you take an image shot of each one, of the illumination emanating from that light source — you will have 2, 3, 5, 10 different spectral power distributions. Every single one is different.

"And in order to specify lighting that's intended to deliver a behavioral or a biological response, you must specify the spectral power distribution. You can no longer rely on CCT or Kelvin temperature."

Thus, Benya Burnett carried out thorough SPD evaluations at one of its showcase client sites — the headquarters for the American Society of Interior Designers (ASID) in Washington, DC — before prescribing what type of lights to put where, and how much to rely on the office's considerable amount of natural light.

The refurbishment, on the ninth floor of a 12-story downtown office building, opened in September 2016. Benya Burnett specified a combination of LED and fluorescent artificial lighting, in combination with the daylight provided by the windows, which are about three-quarter ceiling height at the mostly north-facing facility.

The result was nothing less than two prestigious design distinctions for the project, which in July 2017 became the first space in the world to garner a Platinum certification in both the LEED (Leadership in Energy and Environmental Design) environmental building assessment from the US Green Building Council and the WELL healthy building assessment from the International WELL Building Institute. (Learn more about how WELL status can be achieved on p. 31.)

A better night's sleep

Such honors are impressive. But how is it all performing in actual practice?

"It's actually working very well," said ASID CEO Randy Fiser, basing his appraisal on ongoing anonymous surveys of the 35 employees. "We've asked staff how the office that we're in currently makes them feel, and how they're sleeping, and things along those lines. All of those variables that we were looking to measure have improved with this office in comparison to where we were before.

"The idea of the lighting system was to drive health, wellness, and wellbeing within the staff, knowing that light is such an important part of managing our circadian rhythms and our circadian systems, knowing that staff is spending more and more of their time indoors and we need to maximize their exposure to light as if they were outdoors."

And according to Burnett, the results relate to a steadfast engineering decision. "We ignored CCT, and instead, we focused on spectral power distribution," she said.

But here's the challenge: Determining the correct SPD level was not easy. Burnett described an assiduous evaluation, considering a dozen or so factors. Among them: employees' average age as well as their gender, body mass index, general state of health or infirmity, and even their reproductive stage of life; the latitude and longitude of the building; the largely northern exposure of the windows; the height of desks in an office where many workers prefer tall standing desks; sunrise and sunset times; even the curvature of the Earth.

"It's so complicated," said Burnett. "Many manufacturers will say, 'Just go ahead and buy this product at a specified CCT and it's a slam dunk.' But that's just not the case. If they're just looking to specify 4000 or 3500 [K] CCT and a CRI of 90-plus, they're missing the boat. Especially if they want to have a behavioral or biological response. They're 100% missing the boat."

No one solution

Burnett declined to reveal the precise SPD figures and measurements deployed at the ASID offices. She noted that every potential location will be different, and that it could thus be misleading to publicize the prescription at one site such as ASID. Suppliers included Soraa for light sources and Finelite for luminaires, among others, as well as Lutron for the controls system, which, in addition to lighting, ties into other systems such as window shading.

But one key to the design: Benya Burnett aimed to minimize the exposure to short-wavelength blue frequencies (around 455 nm).

"We don't know all the answers scientifically or medically, but it seems to be that light at night with a short-wavelength presence of 20% and over seems to be the catalyst of what is directing a lot of the negative health impacts," Burnett said, adding that the industry needs to establish guidelines for circadian lighting implementation of what she noted is essentially a drug (http://bit.ly/1l9Xc2d).

FIG. 3. At the recent Lighting for Health and Wellbeing Conference, Dr. Martin Moore-Ede presented compelling data about the ability to reduce the negative effects of blue light on human biological rhythms during evening shift work — including metabolic conditions such as insulin resistance and obesity — by reducing blue energy in circadian-friendly lighting.

ASID's Fiser described the setup on the sixth-floor office. About 70–80% of the lights are fluorescent, primarily the ceiling troffers starting on the outer edge near the windows and coming into the office. Further away from the windows, the ceiling can lights are LED. All the ceiling lights change their spectral settings, and are tied into the Lutron controls system, which also permits overriding.

In addition, the office has deployed LED task lamps that are dimmable but are not tunable for spectral power, although Benya Burnett's design would have factored in their spectral setting, Fiser said.

About those fluorescents

It might come as a surprise that an office on the vanguard of tunable human-centric lighting is using such a high percentage of fluorescent products, given that LEDs with their digital nature are known to be easier to tune than fluorescents.

Fiser explained that when Benya Burnett

evaluated the premises over two years ago, LED pricing was too prohibitive.

"The original design was LED, but the price point of that was just so much more expensive than our budget, that we needed to reengineer the design and use fluorescent light," he recalled. "LED with circadian lighting, the ability to change the lightwaves and colors and all those things, there were only one or two lighting packages that had that capability. Many lighting companies have that package now, which is why pricing is dropping."

The emphasis on fluorescent came with tradeoffs, such as the clumsiness of having to use two bulbs to get the desired spectral effect that LED could accomplish with one, Fiser noted. Additionally, even though ASID managed to win LEED platinum certification, the fluorescent sources are not as energy efficient and will probably not last as long as LEDs.

Nevertheless, it's doing what ASID wanted it to do. "There has been a definite articulation by the staff of improved health and well-being and wellness, including sleep," he said, noting that other factors have also played a role, such as air quality.

While the Benya Burnett lighting design emphasized SPD, ASID staff still notices varying CCTs, which ultimately are the result of the SPD curve of the light source. Cooler CCTs will be associated with an SPD with more energy in the blue end of the human visual range.

Fiser said the system is programmed in the summer months to start turning to bluer shades at 5:30 in the morning, and to revert to red shades at around 7 p.m. — a shift in color temperature that is perceptible to the eye. In one aspect of circadian programming, he said the shifts do not occur all at once. Rather, they take place over a 30-, 40-, or 50-minute period. "If it goes straight from blue to red, without a transition period, it's actually startling, and actually creates a shock within the body, and you don't want that," said Fiser.

It hasn't all been perfect — nor would one expect it to be given the pioneering nature of the deployment.

"There have been times when things have not been operating as exactly as they're supposed to, and we needed to do a recalibration," Fiser said. But the big picture has so far been a success.

"This whole lighting component, which is early on in its creation of using light to keep our bodies calibrated — since we're not spending as much time outdoors as indoors — is new, so we are doing a lot of studying of this, and ensuring that this lighting package is truly doing what it is intended to do," said Fiser. "We're seeing our office as a living laboratory, if you will. We will report out to the rest of the world, both positive and negative — if it doesn't do anything for us, we will report that out, as well as the fact that it is doing something for us, which is what we're finding right now. We will continue to do that on an annual basis."

ASID will be a human-centric lighting installation to watch for some time to come.

* * * *

Circadian Light: Don't get the blues — not at night, anyway

Dr. Martin Moore-Ede was a Harvard Medical School professor for 23 years and has been investigating circadian science for a long time. He led a team at Harvard in 1980 that he says was the first to identify the human brain's circadian clock — known as the suprachiasmatic nucleus or SCN — and its control of 24-hour rhythms of sleep/wake, body temperature, and hormones. Even back then, experts like Moore-Ede knew that light falling on non-visual photoreceptors in the retina was stimulating the SCN.

It wasn't until 20 years or so later, owing to further research at Oxford University, the University of Surrey in the UK, and elsewhere, that scientists began to understand that light in the blue frequency range in particular fiddles with the clock, and that a retinal cell pigment called melanopsin (not to be confused with the hormone melatonin, which, when suppressed by blue frequencies, can cause disturbed sleep) had a lot do with it.

Fast-forward to today. Moore-Ede, now CEO of

Photo credit: Nic Lehoux.

FIG. 4. Is it the view or the natural light that makes a difference? Probably both. From this conference room at the Bullitt Center, employees see the downtown Seattle skyline.

FIG. 5. Skylights and windows bring in the light at the Bullitt Center. There would be more skylights if not for the solar panels on the roof.

Stoneham, MA-based circadian health consultancy Circadian and its Circadian Light group, pins a lot of human maladies on the way blue frequencies in the 430–500-nm range mess with the circadian clock. Not that blue is outright evil; it can be desirable during the daytime. But it "causes havoc" when applied at nighttime, which Moore-Ede outlined at the Lighting for Health and Wellbeing Conference this past July.

"There are certain wavelengths in the blue part of the spectrum that boost alertness, performance, and mood during the daytime hours, but during the nighttime hours they disrupt circadian clocks and now have been shown through hundreds of research studies to cause a 65% increase in breast cancer, a 37% increase in diabetes, a substantial increase in cardiovascular disease, an increase in prostate cancer, and a variety of medical problems," said Moore-Ede. The list of risks goes on, including diabetes related to blue's instigation of insulin resistance, and obesity connected to blue's stimulation of appetite.

It almost sounds as though LEDs at night are the new tobacco.

But it doesn't have to be that way. Moore-Ede's company, Circadian Light, makes a suite of office lighting products including ceiling lights, troffers, and suspended fixtures that cut out the harmful, bio-active blue frequencies at night. Circadian's system, based on LED chips from Plessey, "delivers a timed dosage, and independently varies the bio-active blue content," Moore-Ede explained.

But doesn't that reduce the brightness of the light, since bright white light tends to be associated with CCTs around 5000K or more that have a high content of blue frequencies?

Absolutely not, said Moore-Ede, noting, "You can do it without jacking up the color temperature. You can do it all in the 3000K to 4000K range — in other words, in the normal, comfortable range of light color temperatures. You don't really want a high CCT. You don't want a light that's harsh and bright and looks like a typical car headlight. This is where lighting is going — engineered spectrum. We are spectrally engineering light."

Circadian's engineering tricks include using violet emitters, which Moore-Ede said deliver even more of the stimulating effect of blue but without the harmful consequences.

Like Burnett at Benya Burnett, Moore-Ede said tunable lighting systems should focus on light frequencies, and not on CCT per se.

"There's been a huge misunderstanding in the industry that somehow color temperature is the issue," said Moore-Ede. "It isn't. It is actually the spectrum that matters. And it's regulating that component of the spectrum that is bio-active, and has this effect, both the beneficial effects as well as the negative effects."

A number of Fortune 500 companies are already working with Circadian systems, Moore-Ede claimed, although he declined to identify users. They should be easy enough to spot — they'll be the ones with the healthy employees.

* * * *

Seattle's ultra-sustainable Bullitt Center: Au naturel

If the idea of any human-centric artificial lighting design is to mimic the patterns of natural light as much as possible, then it stands to reason that having natural daylight would be even better. And since most office workers by definition work indoors, that means it behooves lighting designers and architects to allow in as much natural light as possible.

"From our perspective, the daylighting component winds up playing the largest role in human-centric lighting," said Zachary Suchara, design director at Portland, OR-based Luma Lighting Design. "The access to views, and the access to quality daylight, is by far the biggest driver."


In control...
Future Lighting Solutions' Philips Lighting zero lead-time initiative gives you the confidence of knowing parts are ALWAYS IN STOCK
FUTURE
Lighting Solutions
Making LED Lighting Solutions Simple™
PHILIPS
Authorized Distributor
www.FutureLightingSolutions.com/ZeroLT
*Offer is based on certain marketplace assumptions and, as such, changes in the marketplace may invalidate this offer. Offer may end at Future Lighting Solutions' discretion at any time. Offer is valid in North America only. Please contact your local Future Lighting Solutions representative or visit www.FutureLightingSolutions.com/ZeroLT for details on this offer and its terms and conditions.

So that's what Luma helped to do at the six-story Bullitt Center in Seattle, which opened in April 2013 and is home to the Bullitt Foundation, an environmental protection and advocacy firm, among other groups.

The commercial office building was designed to last for 250 years, and has won a number of accolades including *World Architecture News*' Sustainable Building of the Year, and, in 2015, the Illuminating Engineering Society's Lighting Control Innovation Award.

Natural light is a significant contributor to the lighting there. It will come as no surprise that one of the main design elements that allows natural light in is windows. To help optimize their effect, city planners permitted the six-story building to range slightly taller than normal — not to add floors, but to increase the ceiling height of each floor from around 11 ft to around 14. Thus, noted Suchara, with the 11-ft windows, "almost 100% of the occupiable spaces have quality daylighting access." The space adheres to what Suchara noted is a rule of thumb — any distance from the window should not be more than twice the window height in order to benefit from the daylighting. An office with typical 8-ft windows on one side can thus go 16 ft deep without losing benefit, or 32 ft with 8-ft windows on both sides.

"That ability to sense the daylight through the space, and keep us in tune with the natural environment, that's the human-centric portion," he said. "The ability to stay in tune with the ever-changing condition of nature throughout the day — the daylight — that's the human-centric part of lighting design."

Suchara noted that the human-centric benefit relates both to the circadian effect of natural light, as well as to the psychological boost of having a good view. Some experts believe that the view factor is the more important of the two. "I think it's a balancing act between them," noted Suchara.

In addition to the windows, the Bullitt Center also includes a generous helping of skylights. There, though, the lighting designers had to compromise with the green aims of mechanical and electrical engineers, who put solar panels on the roof in some places that could have housed even more skylights.

With natural light in mind, architects also came up with what's known at Bullitt as the "irresistible stairs" — a glass-enclosed stairwell along an outside wall that provides views of the Olympic Mountains, Puget Sound, and the downtown Seattle skyline (the Bullitt Center is in the Capitol Hill neighborhood of Seattle).


Photo credit: Nic Lehoux.

FIG. 6. The "irresistible staircase" at the Bullitt Center is glass-enclosed on three sides, providing views of downtown Seattle, the Olympic Mountains, and Puget Sound.

Luma also specified some artificial human-centric lighting touches. For example, task lamps at some of the desks use Philips Hue technology, changeable by the individual user in both CCT and in color.

"You'd come in and find someone who had their light tuned to pink, and you're like, 'Really?'" Suchara mused. "But it's just personal preference. And it's a really simple way to do it. And very cost effective."

He said that, in general, Luma is increasingly adding CCT tunability on its lighting design jobs. While dimming remains a more popular user request, CCT is beginning to gain attention.

Suchara cautioned, though, that offices sometimes want different color temperatures in different portions of an open-plan setting, which can cause problems.

"The biggest issue we run into is white constancy," Suchara said. "If one space is 4000K and someone else has decided that their space needs to be 3000K, it makes the 4000K space feel colder, because someone can see the warmer space. Also, it just looks odd. We mocked it up once, and it was like you're kind of walking into a David Lynch space."

Moral of the story: Go for natural light as much as possible.


Design Freedom Made Easy
72,000+ Lutron-enabled fixtures from over 350 manufacturers deliver guaranteed dimming performance
Wired or wireless systems
Fixed or variable color temperature
Performance dimming from 100% to 0.1%
Render the right environment
LUTRON
lutron.com/designfreedom
24/7 Tech Support: 1-888-LUTRON1
© 2017 Lutron Electronics Co., Inc. | P/N 306-0192 REV C


Making LED
Lighting Solutions
Simple™
We Accelerate Time to
Revenue by Providing
▶ The Most Comprehensive System-Level Product Portfolio
▶ Solid-State Lighting Expertise
▶ Design Support Services
▶ Global Supply Chain and Business Solutions
FUTURE
Lighting Solutions
www.FutureLightingSolutions.com

A building well lit and well controlled is WELL certified

MICHAEL JOUANEH and **SHAUN TAYLOR** describe how to leverage lighting controls to support WELL building certification and invest in the most valuable commercial asset — people.

By now, the 3/30/300 story is probably familiar to you. As a general rule, organizations spend approximately $3 per square foot per year for energy, $30 for rent, and $300 for personnel. Since people are your most valuable asset, improving their overall experience delivers the greatest return on investment (ROI). Furthermore, investments that focus on wellness and sustainability are proving to have exponential results in terms of employee satisfaction and productivity. The WELL Building Standard, administered by the International Well Building Institute, provides a model for space design and construction that integrates performance-based systems to positively impact the built environment (https://wellcertified.com). Lighting and lighting control are an essential piece of this proverbial puzzle.

Many organizations that were early supporters of Leadership in Energy and Environmental Design (LEED) certification are also turning their attention to the WELL standard as a guideline for design focused on wellness, comfort, and productivity. WELL Building Certification can also help to address another pressing need — the ability to attract and retain top talent in an increasingly competitive environment. Beyond a simple ROI, the WELL Building Standard offers a value proposition that includes:

- Improved environment for employees and clients
- Thought leadership
- Increased productivity
- Improved employee satisfaction and retention

The Washington, DC-based headquarters of the American Society of Interior Designers (ASID) is the first space in the world to achieve Platinum Level Certification for both the WELL v1 Building Standard (WELL) and Leadership in Energy and Environmental Design (LEED), under the LEED ID+C rating system v4. ASID leadership, along with architectural firm Perkins+Will, lighting designers Benya Burnett Consultants, and electrical engineers GHT Limited, were committed to making the new ASID headquarters a showcase for progressive design, and prioritized the goal of achieving dual Platinum certifications. A centralized light and shade management system — Quantum Total Light Management System and Sivoia QS shades with Hyperion solar adaptive shading software — was essential for helping to achieve these important goals.

In this article, we use the ASID project as an example to look at the structure of the WELL Building Standard, examine the WELL features that lead to certification, and delve into the role lighting controls can play in how a building or space is configured to achieve WELL requirements.

Photo credit: Benya Burnett Consultancy/Eric Laingnal/Perkins & Will Architects.

FIG. 1. The ASID project incorporates circadian-optimized electric lighting as well as daylighting as part of its WELL certified design.

WELL features used to evaluate building performance

Certification starts with seven concepts that influence human behaviors and define a wellness-focused environment: Air, Water, Nourishment, Light, Fitness, Comfort, and Mind. Under these concepts there are

MICHAEL JOUANEH, *CEM, LEED AP, is manager – Sustainability and Energy Standards, and* SHAUN TAYLOR, *LEED GA, GGP, CGP, is sales supervisor at Lutron Electronics (lutron.com).*

"features" or provisions that have requirements to be met. Some features are mandatory and are called preconditions. Others are optional, known as optimizations. There are three levels of WELL Certification: Silver, Gold, and Platinum. Silver level certification is achieved by meeting 100% of the WELL preconditions applicable to the project type in all concepts. Gold level certification is achieved by meeting all of the WELL preconditions, as well as 40% or more of the optimization features. Platinum level certification is achieved by meeting all of the WELL preconditions, as well as 80% or more of the optimization features.

The Light concept area provides illumination guidelines to minimize disruption to the human body's circadian system, enhance productivity, and provide visual acuity. The WELL Building Standard promotes lighting and shading systems that increase alertness, enhance the overall occupant experience, and even promote healthy sleep. In designing lighting and controls to meet WELL requirements, the lighting professional will consider standard strategy categories including activity-based light levels, color quality, daylighting, and glare control for any given space.

For the ASID project, James Benya and Deborah Burnett of Benya Burnett Consultancy created a lighting design incorporating all these strategies to ensure circadian-optimized lighting and daylighting, critical luminaire placement, and annual lighting schedules and sequences. To maximize points in both WELL and LEED programs, the Quantum system automatically adjusts shades and light to provide appropriate spectra, light intensities, and exposures throughout the year while saving as much energy as possible (Fig. 1). Because LEED and WELL certifications provide complementary, but different benefits, designing a lighting control system that effectively supports both certifications demands intricate knowledge of both the lighting control system capabilities and the certification requirements.

Preconditions and optimizations in the WELL Light concept

Fixture selection and fenestration play a role in all preconditions and most optimizations in the WELL Light concept. A smart, integrated lighting and shade control solution can specifically help achieve precondition features in Visual Lighting Design (#53), Circadian Lighting Design (#54), and Solar Glare Control (#56), and is essential for optimization features in Automated Shading and Dimming Controls (#60) and Daylight Modeling (#62; see http://standard.wellcertified.com/light for more on Light features).

Visual Lighting Design, Feature #53, defines required average light levels of 215 lx on the horizontal plane, measured at 30 in. above the floor, as well as independently controlled zones of light no larger than 500 ft^2. Also, this feature requires the appropriate brightness and contrast ratios on different surfaces among spaces (e.g., no greater than ±10× in main room than ancillary rooms) and among surfaces within a space (e.g., surface cannot exhibit 3× greater or lesser luminance than an adjacent surface) to avoid dark spots or excessively bright spots in a room. Tunable lighting (setting maximum lighting output to the appropriate illuminance level) helps designers meet the contrast ratios.

A lighting design can meet required lux levels with fixtures alone, but this strategy can result in very bright light, which is acceptable earlier in the day but considerably less desirable in the late afternoon when it can negatively affect sleep patterns. Designing an integrated light management system with usable daylight enables the shades to help regulate daylight, provide the required footcandles, and prevent glare, while the drivers/ballasts automatically dim to help save energy.

In addition, the lighting zones must be no larger than 500 ft^2, or 20% of an open-office floor plan. Digitally addressable ballasts and drivers can accommodate zoning requirements without the need for complex wiring, and when the furniture or layout inevitably changes, zones can be easily adjusted from a computer with no need to rewire.

Tunable-white fixtures and controls allow lighting to be adjusted automatically and unobtrusively over the course of the day. For

Photo credit: Benya Burnett Consultancy/Eric Laingnal/Perkins & Will Architects.

FIG. 2. Indoor sunlight exposure and views to the outdoors, managed in part by a software-programmable shade system linked into the daylight-responsive lighting controls, boost the WELL qualifications of the ASID facility.

example, short wavelengths of light (the violet/blue end of the visual spectrum) can be included earlier, then scaled back in the afternoon and evening to prevent sleep disruption. While WELL certification does not focus on energy efficiency, energy savings is a consideration in most commercial buildings. Lighting control solutions that integrate with daylight and occupancy sensors, or daylight responsive shading, can play a significant part in tuning the light for the right environment, significantly reducing energy use.

With digital control, the lighting design not only complies with certification requirements, but easily facilitates integration with timeclock control. With a single button or command, all lighting zones can be turned on or off, and still deliver zone-based occupancy or daylight control.

Feature #54 addresses Circadian Lighting Design. This aspect of WELL certification is designed to provide lighting conditions that reinforce natural patterns of the human circadian cycle with appropriate melanopic light intensity in work areas. At least one of the following requirements must be met:

- 250 equivalent melanopic lux (EML) is present at 75% or more of workstations, at 4 ft above the finished floor, for at least four hours per day.
- Ambient lights provide maintained recommended illuminance of EML greater than or equal to lux recommendation from the Illuminating Engineering Society (IES).

EML is calculated by measuring the visual lux and multiplying it by a ratio that correlates to the impact the light has on the body's sleep/wake cycle. Shorter-wavelength light (blue) has a stronger biological response than longer-wavelength light (yellow or red). The ratio of shorter-wavelength light will be higher due to the impact on the body's circadian system. The ratio for a 6500K fluorescent light might be 1.02 because it has a lot of stimulating blue light, while the ratio for a 2950K fluorescent light may be 0.43 because its spectral power distribution (SPD) contains lower amounts of stimulating blue light. (For more on SPD and how it relates to human-centric lighting design, see the feature on p. 21.)

The Melanopic Light Intensity in Work Areas option requires at least 250 EML on the vertical plane facing forward for 75% of the workstations for at least four hours each day. If a light meter measures 275 lx and you multiply it by the ratios listed above, that yields 280.5 EML for the 6500K lamps, and only 118.25 EML for the 2950K lamps. Since the WELL Building Standard requires 250 EML, the 6500K lamps meet the requirements while the 2950K lamps do not.

The blue light that helps meet EML during the day can have a negative impact on sleep at night. This is one motivator for the enhanced use of color tuning fixtures — they can provide biologically active light during the day at lower power consumption, and adjust to deliver less biologically active light in the evening and night.

The third precondition feature that can be met with light controls is Feature #56, Solar Glare Control. This feature helps to mitigate glare from the sun by blocking or reflecting harsh, direct sunlight away from space occupants. A key requirement is to provide controllable or automatic window shading, and this feature cannot be met with a static glare inhibitor such as overhangs. By using an automated shading solution, the lighting control design can also help meet optimization Feature #60, Automated Shading and Dimming Controls.

Feature #62, Daylight Modeling, supports circadian and psychological health by setting thresholds for indoor sunlight exposure (Fig. 2). Manual shades can be used to meet this WELL feature, but automated shades that respond to changing daylight conditions and integrate with daylight responsive lighting control also increase spatial daylight autonomy. Using this control strategy, you are better able to meet the requirements for LEED Daylight credits in addition to the WELL Daylight Modeling feature.

Achieving WELL and LEED Platinum certifications

The ASID project set a very high bar for sustainable, wellness-oriented, energy-efficient lighting design. The design helped to achieve all the lighting Features in the WELL Light Concept with the exception of daylight fenestration. By including automated shades that used a sheer, GreenScreen Evolve low-VOC-emitting fabric, ASID was able to use the shade fabric to help meet the mandatory preconditions for Feature #4: VOC reduction, Feature #74: Exterior Noise Intrusion (shades can help reduce the sound coming in through the windows), and Feature #88: Biophilia (shades can preserve the views to the outside, which helps provide a connection to nature for the building occupants).

Ultimately, the ASID headquarters met the stringent requirements of both WELL and LEED certifications, with the integrated lighting and shading control system contributing in three WELL concepts and four LEED categories, including almost all the energy efficiency points.

Sometimes the different certifications' performance goals might appear to be at odds — LEED is very energy focused and WELL is tailored specifically to human performance and health — but together they deliver a truly versatile, responsive space. The lighting and shades in the ASID headquarters provide automated, solar-responsive daylight and shade control, astronomic time clock, manual overrides, precise control of several types of electric light sources, compliance with the energy code, and the data needed to prove LEED and WELL certification requirements.

Benya Burnett co-principal Deborah Burnett addressed the need for the right service as well as the right product: "The manufacturer's field service team was critical on this project. We were able to program all the wellness protocols and transitions, as well as provide everyday functions like personal task light dimming. The programming automatically adjusts light intensities and durations for seasonal solar angles, changing weather conditions, available daylight, and occupancy." The result is a lighting design for all seasons, all conditions, and everyone in the space.

In the ASID offices, every light is controlled, and the solar-adaptive software silently and seamlessly adjusts the shades over the course of the day, minimizing glare, reducing heat gain, and enhancing comfort throughout the space. Adjustments can easily be made using the software's graphic user interface to ensure the space remains dynamic, and the facilities team is able to quickly make adjustments to meet changing space requirements.

The lighting, controls, and shade design in the ASID headquarters creates a dynamic "living laboratory" for the design community, offering an opportunity to engage in pre- and ongoing post-occupancy research. Achieving WELL and LEED Platinum helps to change the conversation about how to design a space that promotes both wellness and sustainability.

Mesh standard adapts wireless technology to professional lighting needs

SZYMON SLUPIK and **SZYMON RZADKOSZ** explain what you should know about the architecture of the Bluetooth mesh standard and why the IoT network technology is an optimal match for connected SSL.

With Bluetooth mesh networking, entire building systems can communicate in an orderly fashion especially when lights are used as the primary network nodes.

Bluetooth mesh networking technology is finally here. Was it worth waiting for? Can it really drive widespread adoption of connected solid-state lighting (SSL)? And what exactly does it mean that it has been designed for professional lighting applications? As one of the leading contributors to the development of this new wireless standard, Silvair has answers to questions you might be asking yourself today. Let's review the development of the standard and consider the impact it may have in bringing LED lighting into the Internet of Things (IoT) movement.

A pinch of history

For Silvair, the interest in Bluetooth all started back in 2013 when Google rolled out Android 4.3 with API level 18 (http://bit.ly/2xUccvh), introducing support for Bluetooth Low Energy (BLE). At that time, the company wasn't too familiar with Bluetooth, but already knew that IPv6 over the 802.15.4 standard (used by ZigBee, for example) was a pipe dream. Even with the 6Lo compression (6LoWPAN — Ipv6 over Low Power Wireless Personal Area Network, a lightweight protocol envisioned to bring IP networking to embedded or IoT devices; http://bit.ly/20t1qRN), IPv6 was simply too heavy to fly, and 802.15.4 turned out to be too slow to give it a lift. Back in 2012–2013, Silvair was experimenting with something very similar to what Thread is today (http://bit.ly/2t4mCGn). But eventually we found this combination (IPv6 + 802.15.4) incapable of addressing the needs of professional wireless lighting. Hence, Silvair kept looking for a suitable radio technology.

SZYMON SLUPIK *is CTO at Silvair and chair of the Bluetooth mesh working group.* SZYMON RZADKOSZ *is a technical writer at Silvair (silvair.com).*

Google's announcement of support for Bluetooth Low Energy in Android sparked hopes. BLE was already supported by iOS, so with Android on board, it seemed like a good candidate to try. But it did not fly, either. The single-hop range was very limited and the hub-and-spoke topology was far from anything usable for lighting needs; it could provide only a handful of point-to-point connections. Great for linking a heart rate monitor to a phone but certainly not to control a ceiling with 500 lights in a hotel lobby. There was hope, though.

BLE offered the physics

The underlying physics of BLE was very promising. Within a couple of months, Silvair managed to build a BLE module capable of communicating over a 500m single-hop distance. The company also discovered that with proper software engineering, it was able to run multiple Bluetooth roles (a GAP Observer and a GAP Broadcaster) at the same time (GAP stands for General Access Profile). This experiment was carried out in early 2014 and you can see it now being the fundamental requirement of the Mesh Profile specification (http://bit.ly/2yrrbgN; see the last paragraph in Section 3.3.1).

This could be described as the conception of Bluetooth mesh networking. After all, if the software part of an off-the-shelf Bluetooth SoC (system-on-chip) could be modified in a way that allowed receiving and retransmitting messages, building a mesh network on Bluetooth would be possible. It was "just" a matter of nailing down the details of this software and documenting it as an open specification, so others could do the same.

This "just" step took more than three years and resulted in the publication of three specifications, approximately 1000 pages combined. Indeed, it is a complex solution. But along the way, it turned out that a solid technology for connected lighting simply could not be outlined in a dozen pages and delivered within several months. The nature of wireless mesh networks is complex. Jet engines are complex, too. Cars are complex. So are cellular networks and many other technology wonders we're using every day. They are all successful because they are complex and solve the intricate nature of problems. This is what Bluetooth mesh is doing, too — trying to address the complex challenge of low-power communications in the resource-scarce IoT environment while ensuring wire-like performance in connected lighting networks. Many technologies have promised that, but none of them has delivered so far.

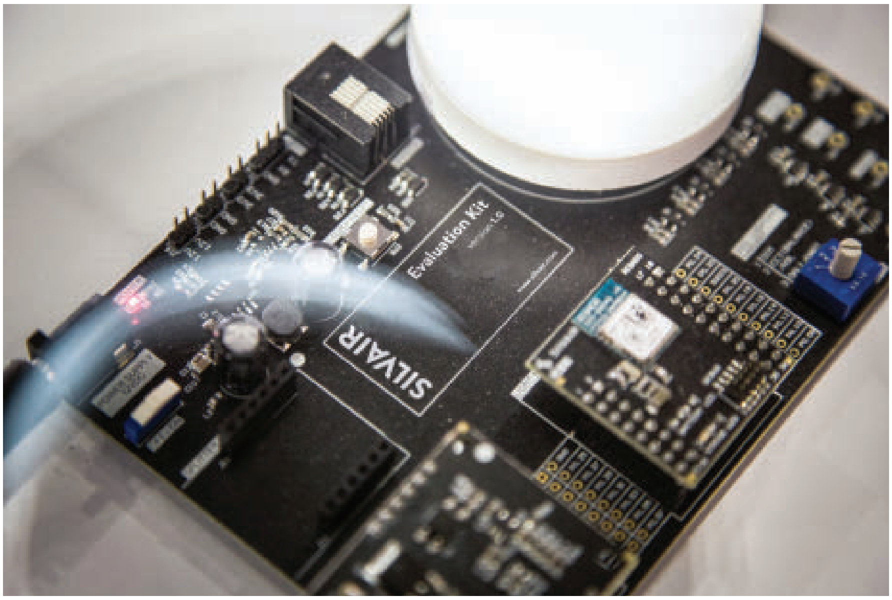
It's all about the packet

Why should we trust that Bluetooth mesh will be different? As the Bluetooth mesh networking specifications (http://bit.ly/2yrrbgN) are now public, we can start dissecting and discussing various building blocks of this new wireless standard. There are many novel and unique concepts in mesh, but perhaps the key asset and differentiator is the packet. It is extremely compact. This compactness contributes to the spectral efficiency (and throughput) of Bluetooth mesh networks.

Radio is a shared medium and data-packet collisions are one of the key problems to address. This is what makes scalability such an enormous challenge in connected lighting networks. The math is simple: A shorter packet means fewer collisions. But how short can it be? The answer is up to 29 bytes, as described in Section 3.4.4 of the Mesh Profile specification.

Of course, such design begins with the basics: compressed binary payload instead of a text representation. Covering a broad set of use cases (including connected lighting, building automation, and sensors), 11 bytes for the application payload seems appropriate. The standard allows 1–2 bytes for an opcode and up to 10 bytes for parameters, such as a value measured by a sensor, or a multidimensional light (light level, hue, saturation) with a transition time.

On top of that, there are two items that may be considered overhead, but it is an absolutely necessary overhead: addressing and propagation control (SRC, DST, CTL+TTL: 5 bytes in total) and security (IVI+NID, SEQ, AppMIC, and NetMIC). The IVI+NID is 1 byte. This byte helps identify a network (is this a network I know and have keys to interact with?). SEQ is 3 bytes and together with the unique concept of a slowly propagated IV Index, forms a 7-byte-long sequence number. Each packet sent on a mesh network has a unique sequence number, per given SRC address. The smart part here is that only 3 bytes are included in the air interface packet. The remaining 4 bytes are slow changing and are "known" to the network. Sequence is essential in two areas: detecting replayed packets (very trivial security attack) and also being the key ingredient of both network and application nonces — see Section 3.8.5 of the aforementioned spec.



A Silvair evaluation kit enables SSL product developers to experiment with the capabilities of Bluetooth mesh, and accelerate the connected SSL product design cycle.

Securing the system

MICs, or Message Integrity Checks, define the level of security of the system. Bluetooth mesh has dual-layer security — it includes the network layer and the application layer. Messages may be secured with two independent keys. This is useful for relay nodes to authenticate a message on a network layer without enabling tampering with the application payload. A lightbulb that relays a message to a door lock cannot change the payload from "open" to "close," but it does check whether the packet belongs to its own network. The network layer MIC can be either 8 or 4 bytes long. In its shorter form, it is combined with the application layer MIC that can again be 8 or 4 bytes long.

The end result is an application payload that is sufficient for almost any building automation, lighting control, and sensor application, with strong security and flexible addressing. And this all comes in an extremely compact form factor. Combined with the modulation scheme offered by BLE, it is also feather light. Including all necessary radio interface fields, such as a preamble, an access address, and a CRC (cyclical redundancy check), it totals 47 octets. As a result, a single transmission on a single frequency lasts less than 400 μs. This is 10× less than it takes to transmit a comparable message using other existing wireless technologies. And when using the new 2M PHY introduced by Bluetooth 5, this advantage can potentially be doubled.

The success of any wireless system fundamentally relies on the spectral efficiency. It is similar to how the success of an airliner fundamentally rests on its fuel efficiency. In the low-power, ultrashort-message category, Bluetooth mesh delivers an order of magnitude more than other wireless solutions. As far as data transmission is concerned, it is the first wireless standard capable of meeting the enormous expectations of the IoT era.

Why lighting?

Still, you may wonder why a technology from the IT and telecommunications field is right for lighting. When working on the architecture of the Bluetooth mesh system,

the Bluetooth SIG's (Special Interest Group's) Mesh Working Group kept on diving deep into the roots of problems it was aiming to solve. In particular, the team of contributors has focused strongly on addressing the many challenges of the smart lighting environment. There are many reasons to treat lighting as the primary application for a mesh system. Most important, lights are everywhere and they are powered. So depending on how you look at it, a lighting control system may be the goal itself or may just be the initial step to develop more services that are based on a mesh-connected infrastructure.

Imagine an airport, a hospital, a company campus, or a high-rise, multi-tenant office building. Now imagine you want to roll out a service that requires a dense infrastructure of radio nodes — perhaps thousands of them. Rolling out adequate hardware would be very expensive, as each component would require a mounting point and power supply. Now suppose that each light is already mounted and powered, and is capable of supporting your wireless application. Suddenly, you realize the hardware is already there: a mesh network of thousands of low-power wireless computing nodes.

This is why the lighting category is so crucial for Bluetooth mesh technology. And to be a winning solution in that category, the new wireless standard had to be outstanding for connected lighting applications. Everything else comes afterward.

A tough world of lighting controls

There are many important details that contribute to why a given solution is good for lighting. Let's take a closer look at two simple examples.

First, consider eliminating the so-called popcorn effect. There are two challenges for wireless lighting control systems here:

- They have to be absolutely reliable when it comes to delivery of control messages. If any light in a ceiling doesn't turn on, it will be immediately noticed and considered a system failure.
- The execution of a control command must be synchronous — any popcorn effect simply disqualifies a system, being a clear step backward compared to smooth and synchronous operation of traditional lighting controls.

A lot of effort has been put into ensuring that Bluetooth mesh networking can effectively address both of these challenges. First, it is primarily optimized for multicast traffic. So regardless of whether there are ten, a hundred, or a thousand lights in a ceiling, they can all be addressed with a single message that goes out. This message, in real life, may reach around 90% of lights. To ensure that all of them are eventually reached, the message is repeated a couple of times. With two messages, the probability of delivery of at least one message goes up to approximately 99%. With five messages in a row, the reliability jumps to five nines, or 99.999%.

Now, some lights will receive the first message, while some lights will receive one of the later messages. But we want all of the lights to turn on at exactly the same time, since this is how lighting controls have worked for us for decades. How does the new standard ensure that? Here comes the Delay parameter to the rescue. Let's say that five messages are spaced 20 ms apart. The first one goes out at T=0 with the Delay set to 100 ms. The second is sent at T=20 ms with the Delay set to 80 ms. The scheme repeats until the fifth message is sent at T=100 ms with the Delay set to 0. Now, regardless of which one is picked by a given light, all lights will turn on at exactly the same time. Of course, there is the overall execution delay of 100 ms, but that is below the human perception level. The speed of the underlying radio, combined with multicast transmissions and time-compensated retransmissions, guarantees that the final effect matches application requirements.

The second example is simpler but nicely illustrates the attention to details characterizing the Bluetooth mesh specifications. How does a lighting system behave when the power is cut off and restored later on? How should it behave? The answer is that it depends. Of course, it depends on the type of lights, what purpose they serve, etc. In some cases, you might not want a power cycle to turn the lights on (this is unfortunately the case with some popular home lighting systems). But in many other scenarios, this may be the desired behavior.

In Bluetooth mesh networking, there is a configuration state called OnPowerUp (Section 3.1.4 of the Mesh Model specification). It can be set to Off, Default, or Restore (to the last value before the power was cut off). It works in tandem with another configuration state, the Light Lightness Default (Section 6.1.2.4), which can be any arbitrary level, or the last non-zero value (e.g., if you dimmed the lights down to 20% and then turned them off, after a power cycle they will turn on but at 20%, not at their full brightness). Again, the attention to tiny details presented by the design team seems to be going much deeper than in the case of other wireless solutions.

Scaling it up

Scalability was the initial reason why Silvair turned to BLE when trying to find a foundation for a robust low-power mesh networking technology. Its wireless capabilities were simply much better than anything else available. This was primarily due to the extremely compact packet structure, which flies over the fastest low-energy radio. But, of course, every solution has certain limits. So what are the limits of Bluetooth mesh? The answer is, as always, it depends. It depends what the network is doing (how many and what types of messages it keeps sending around) and how it is set up. Bluetooth mesh has many parameters that may be fine-tuned to adjust its performance to specific requirements.

As a general rule of thumb, one can assume that at 200 devices (or fewer), there is no need to worry about any tuning at all. The likelihood that any two communications will collide is pretty low. So let them loose at will.

Above 200 devices, depending on how talkative they are, some collisions might occur. This is why Bluetooth mesh provides a number of tools that help optimize the network and let it grow significantly while maintaining an excellent packet delivery ratio. The most important ones include the following.

TTL, or Time To Live. It defines how many relay hops a message is allowed to travel. It is rarely the case for large networks that every sender has to be heard across the entire network. An occupancy sensor, for example, usually needs to report only to light fixtures in the same room. And maybe to a gateway, but not across the entire building, to locations where nobody is interested in its status. Setting the Default TTL to a low value (even to 0 in some cases) is a good way to significantly increase scalability.

Relays. They retransmit received messages, obviously multiplying traffic in a given space. Usually, the default setting for the relay function is "on" in order to make setting up small networks seamless. In large networks, it pays to carefully select how many devices are designated as relays and disable relaying where it is not needed. Ericsson Research has recently published a thorough case study (http://bit.ly/2xV2XLm) modeling an office floor with close to 900 talkative mesh devices. It is based on real data captured from a live network. It shows that for a case like an office floor, it is enough to assign about 1.5% of nodes as relays.

Subnets. Mesh networks can be significant in size, spanning entire multi-story buildings. But it is extremely rare that devices on separate floors need to communicate with each other. Except for administrative tasks like re-keying the entire network or shutting down the whole building, typically each floor is self-contained. This fact is why subnets are a great mechanism to confine network traffic. A mesh node can be a member of multiple subnets, so it is a good practice to have the base network spanning all floors and then have a subnet defined for each floor. And to configure the nodes to transmit only on subnets they belong to, not on the main network (except the administrative tasks). A single mesh network can have more than 4000 subnets. We have yet to build a structure that vast. Until then, subnets should help in scaling up any network you imagine.

Is this the beginning of a new era?

According to wireless architects from Silvair, the v1.0 of Bluetooth mesh is much more capable than anybody has anticipated. It is a complete system for low-power, fully-interoperable mesh networking, with a deep and flexible application layer addressed in the Mesh Model and Mesh Device Properties specifications. By defining basic functionalities of network nodes, mesh models make devices aware of what function they perform, what other nodes they can connect with, and what actions can be performed upon them.

To enable maximum design flexibility, models include multiple properties that can be adjusted in accordance with specific applications. In addition to covering a full range of standard lighting functionalities, mesh models fully support additional functionality such as advanced lighting control strategies including occupancy sensing, daylight harvesting, or time scheduling. They also come with multiple tunable parameters and properties, effectively future-proofing buildings against increasingly stringent environmental requirements that we can expect to see as the world strives for a low carbon future.

With the Bluetooth mesh networking specifications already published, we will soon be able to see how these networks perform in practice, and whether this new wireless standard has what it takes to move connected lighting to another level. What already seems certain is that no other technology has fostered such a comprehensive approach to challenges typical for lighting applications. Time will tell whether this is enough.

Smart city applications enabled by LEDs dominate the discussion at SALC 2017

The transition to LEDs in street lights is happening rapidly, but it's the symbiotic network and control technology that can enable smart city applications which excited the IES SALC crowd, reports **MAURY WRIGHT.**

The Illuminating Engineering Society (IES) Street and Area Lighting Conference (SALC) took place in Austin during September, and as always was a great place to learn about recommended practices for LED-based outdoor lighting. But as has been the case in recent years, the presentations leaned more toward smart interconnected lighting, the Internet of Things (IoT), and how solid-state lighting (SSL) can enable and empower smart city applications ranging from parking control to environmental monitoring to security. There were real examples of networked lighting being installed, although it appears at this point that those installations remain in the minority. Still, smart city applications hold tremendous potential.

As is commonplace at SALC, the conference kicked off with presentations from outdoor lighting stakeholders within organizations local to the venue. Elaina Ball (Fig. 1), COO of Austin Energy, opened the show, saying, "We like many other utilities in the room have some bold and ambitious objectives. We have a plan that is setting forth objectives to reduce our carbon emissivity and improve our affordability and competitive position. And those can be very challenging — both of those activities sometimes compete with one another. LEDs and outdoor lighting are a wonderful nexus where we can achieve both of these objectives."

FIG. 1. Elaina Ball of Austin Energy described how the city raises light levels at 2:00 AM in the entertainment districts so revelers can get home safely.

Austin has a program in place that will strive by 2027 to reach a point where 65% of supply side resources will come from renewable sources. "We also have some bold objectives to reduce 900 MW of consumption side energy by 2027, and that's really where our lighting program comes in," said Ball. The city currently has 59,000 street lights and about 25% have been converted to LED sources.

Ball also said the city has deployed controls to monitor performance, whereas before authorities relied on customers to report outages and had to roll trucks out to investigate, although she did not say how many lights the control network is installed on. She added that they are controlling light levels in some cases. Rhetorically, Ball asked if anyone in the room was planning to visit the notorious 6th Street entertainment district while in Austin. She said, "You don't have to admit it. What happens in Austin stays in Austin." Then she described what one might witness if they happen to be on 6th Street at 2:00 AM when the entertainment venues start to close. "We actually brighten our lights in the entertainment districts in order to promote safety for folks to walk back safely to their hotels," said Ball.

Don't pitch efficiency first

Next up from the local area was Ted Lehr (Fig. 2), a data architect with the City of Austin, who delivered the SALC keynote. And Lehr immediately got to the issue that manufacturers in the room were keen to hear — how to sell street lights to municipalities in the LED era. Lehr said saving money is always a secondary goal and that something else is always first for the stakeholder contemplating a street light tender.

Lehr answered a question that many in the audience may have wondered about when he noted his job title and suggested that there was no direct connection to street lighting. But he said, "Nearly all of the new technologies have something to do with data." And Lehr counsels the mayor and city on data issues relative to systems such as lighting.

But Lehr said he has learned that city executives are overwhelmed by technology and that's where he got back to the message that cost savings come second, because he translates technology stories into business cases for the executives. He said, "Know that you are talking to the second priority of the executive" when you address cost savings. He continued, "You probably should address the first priority."

Relating the message back to Austin, he said the city cares a lot about being a technology hub in areas such as wireless communications, so the city authorities would naturally be interested in technology-focused smart city and smart lighting initiatives. Moreover, Austin remains a very artistic-driven community and aesthetics are very important to the city.

Factors include sensitivity and latency for outdoor data transmission tasks.

	Frame rate	Resolution (pixels)	Avg. sample size (Kbyte)	Transmission rate
Car	15 frames/sec	1600 × 1200	330	4.9 Mbytes/sec
People	15 frames/sec	1024 × 768	150	2.3 Mbytes/sec
Parking	1 frame every 30 sec	1600 × 1200	330	11 Kbytes/sec

Aesthetics matter

Regarding LED lighting in the city, Lehr said, "It's not just the safety, [although] the safety is very important, but the aesthetics." Based on his experience with projects, he said, "The lighting proposals that have a community touch, not just a cost-savings touch, or a public safety touch, but the 'light the community' [angle] gets the attention of our city council, gets the attention of the policymakers." He said that if the proposal talks about the aesthetics for the community, the impact and the size of the installation grows in magnitude.

One other surprising concept mentioned by Lehr was augmented reality (AR) technology. He noted, "It is appealing to us." What he meant was the use of AR in a way that allows the community and municipal officials to see what a lighting project might look like once it's completed. He said AR can get buy-in from the community in that the motivation for a project is doing something good for the community. He said AR was also being evaluated as a maintenance tool for city services including street light maintenance.

As for smart and connected street lighting, Lehr said Austin is looking for places to locate intelligence, and street light poles or what he called a "multipurpose lighting infrastructure" are an excellent candidate. The city wants to monitor vehicle and pedestrian traffic, among other applications. But again, he said the smart pole has to be pretty.

Interoperable controls

Lehr's talk hinted at smart interconnected lighting, and soon the conference would move decidedly in that direction for the bulk of the presentations. One of the most compelling came from Isabelle Lessard, an engineer and project manager with the city of Montreal, QC, Canada. And the compelling point was interoperability, as you will soon learn.

At the onset of an LED conversion program, Montreal had what you might term a dysfunctional situation in street lighting. The city had around 133,000 fixtures and 146 different models installed. Around 96% were high-pressure sodium (HPS) luminaires. Lessard said the city needed to streamline the system and at the same time move to LED technology. Moreover, the city decided to install wireless controls at the same time it retrofitted to LED sources; Lessard said the city wanted to eliminate the need to visit each pole twice and controls were clearly in their future.

The challenges ranged from simple to complex. For instance, Lessard said 45,000 of the fixtures are decorative in nature. And she pointed out that most wireless nodes that are unobtrusive on top of a cobrahead luminaire mounted 30 ft in the air are just ugly on a decorative fixture mounted at pedestrian scale. The city had to find controls that could be mounted inside the fixture.

But it was the city's insistence on a multi-vendor interoperable smart-lighting system that garnered the most notoriety. Lessard said controls vendors discussed future interoperability but in reality were expecting customers to be reliant on their proprietary technology, and added, "That was in contradiction with the city's open data mindset." And the city wanted to be able to scale up the deployment later without being tied to a vendor.

FIG. 2. Ted Lehr of the City of Austin warned manufacturers not to sell street lighting based on energy or cost savings but on whatever the primary priority would be for the customer at hand, such as aesthetics or smart city capabilities.

Changing the market

Lessard said there was no solution on the market that met the project goals. “What was the next step?” she asked. “We changed the market.” Because Montreal authorities were entering the market with the potential procurement of 135,000 fixtures, they felt that they could have vendors make concessions and they asked for interoperability on all functionality. Moreover, the interoperability would have to be proven in bench tests.

They sought a distributor or energy services company that could deliver three vendors that would supply field gear — both network nodes for the luminaires and network gateways. And the bidding company would select one company to supply the central management software that had to work with the varied gear in the field. Ultimately, the city got four qualified proposals and selected the best one based on criteria including cost, but also the interoperability testing, experience of the bidder, and technical compliance.

The installation began at the beginning of this year. Thus far the city has 100 gateways installed and has moved into a year-long phase of commissioning and testing the system. Lessard said there will be 10,000 nodes up and running by the end of the year, and work with the software management platform is going well so far. Once the system is functional, the additional 120,000 poles will be retrofitted over five years.

Lessard said that as a customer, you should demand the capabilities you need and vendors will work harder than you might expect to meet your requirements. For Montreal, the payoff is flexibility and independence from relying on a single vendor. And the city expects to add more functionality to its street-light network going forward through sensors for snow level, pollution, and more as depicted in Fig. 3.

One other aspect of the Montreal project that’s interesting is the inclusion of energy metering in the luminaires. Lessard said the city was working with utility Hydro Quebec to validate the metering capability and have it accepted as a utility grade meter, so the city pays only for the energy it uses. That sounds like a perfectly valid idea and another valuable benefit for smart connected outdoor lighting, although there are some challenges to it.

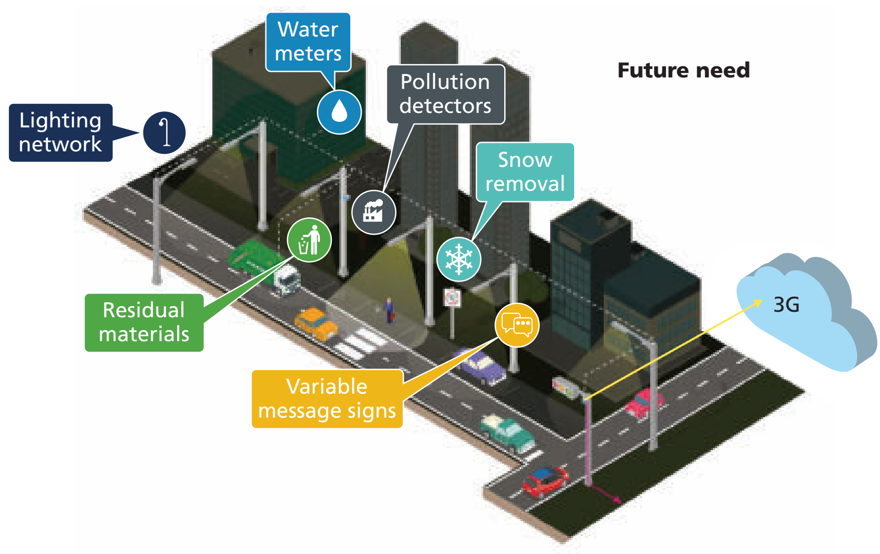


FIG. 3. Montreal’s interoperable street-light controls supplied by three vendors will allow the company to layer on additional sensor-based applications such as air-quality monitoring and the need for snow removal services.

Energy metering in luminaires

There was another presentation made jointly by Jack Hanley, vice president for the Americas at Telensa, and John Walter, manager of outdoor light for New York at National Grid, that focused specifically on metering — both as a benefit enabled by connected lighting and the perils that await adopters.

Many of the wireless nodes on the market can be equipped with a revenue-grade metering chip. There are many reasons for metering street lights and providing tariffs based on the meter, starting with public pressure on utilities to provide transparency into their billing. Traditional street light tariffs are based on a flat calculation of hours multiplied by rated wattage multiplied by rate, but citizens want more accuracy and municipalities are looking to acquire and own their street lights and need accurate energy data. With meter chips, you can potentially even monitor energy use in real time.

Hanley described a case study with an unnamed utility that had agreed to tariffs based on a meter and a time of use rate. He said the utility agreed to ±1% meter accuracy for all outdoor lighting. The tight accuracy specification is due to the fact that the in-node meters measure relatively low Wh (watt hours) per fixture as opposed to utility-grade meters measuring aggregate power in a facility at the kWh level and requiring ±2% accuracy. The utility in the case study is relying on a modification to the ANSI C12 standard to guide the process. Hanley further described testing in a meter shop that showed the street-light-based chips can meet the accuracy requirements.

Of course, the utility has a logistics problem in terms of moving to such metered billing. Hanley described the procedures the utility in question went through to gather the meter readings and ultimately produce the energy report and bill at the end of a billing period.

Not so fast

Walter then took the podium to examine the issue from the utility perspective and asked if solid-state metering is ready for prime-time. The perception, he said, is that it’s a plug-and-play problem but at the end of his talk he would describe it as “plug-and-pray.” He said that in reality it’s complex with ownership, operation, security, and many more issues.

The data in Walter’s talk came from a solid-state metering accuracy project undertaken in Rhode Island at the behest of the Rhode Island Public Utilities Commission. The test involved three manufacturers of wireless nodes with meter chips from three different manufacturers and 18 luminaire models from four different manufacturers. The test included varied load and operating schedules and even sought to develop the back-end interface to the billing system.

The project included bench testing in what they call a meter farm in a controlled environment, where accuracy at various loads could be assessed. Then the test moved to a full-scale field deployment with environmental factors present and multiple operational schedules.

Walter presented some preliminary observations that alone aren't positive for the metering proponents. He said the meter chips did not come with the independent laboratory testing documentation that is considered a requirement in utility-grade meters. Furthermore, he said few independent laboratories are even capable of testing the wireless nodes with meter chips integrated.

He then showed some performance observations (Fig. 4). The accuracy ratings specified by the manufacturers for each of the meter chips are shown in the key on the upper right of the graph. Clearly, the meters from Vendor A did not perform as specified, while the others did quite well at full load.

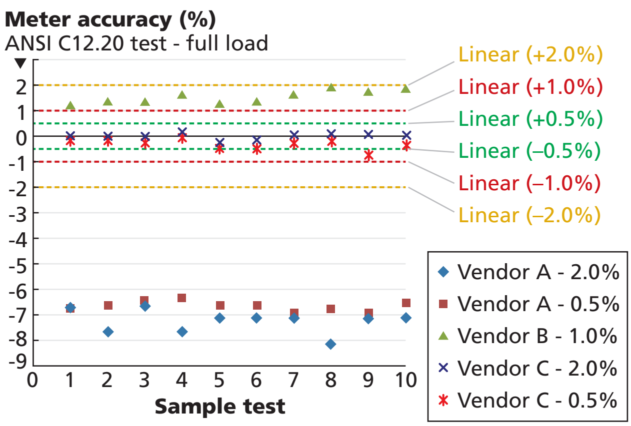


FIG. 4. The accuracy of energy metering chips in street-light wireless modes remains problematic for tariffs based on actual energy usage.

Beyond accuracy, Walter noted other issues. The meter chips will ultimately come from many vendors and the utility may or may not know the source of the meter chip or even the luminaire. Moreover, agents or distributors may supply the products and other entities may install the luminaires and node controls. The potential for finger pointing when problems occur is enormous. While there are some instances of metering being carried out today, the point made by Walter is that the industry is a long way from plug-and-play.

Smart city applications

Of course, there are many other potential applications for interconnected outdoor lighting. Most involve adding sensors to poles that can send data back to the cloud for processing. Ricardo Alvarez (Fig. 5), a PhD candidate at MIT and researcher in the university's Senseable City Lab, addressed some of the applications that are commonly discussed relative to smart street lighting, but that may yet pose some unexpected challenges.

Alvarez said, "Cities around the world are reinventing themselves — are trying to understand how they migrate from what is considered to be the physical cities of the 20th century, cities that are built of bricks, of buildings, of roads and streets to digital cities, cities that have layers of information embedded to them." The data comes from a variety of systems and transactions inherent in the digital cities. "We are sort of figuring out what that data means and scale, and what that data can be used for," said Alvarez. "And there's a role for that if we think about street lighting."

But Alvarez warned that we have to think differently about street lights. He said that while the lights are ubiquitous, the focus has always been about cost and quality of light. He stated that data is now a third variable that is a source of urban knowledge.

Now you may have heard much of what Alvarez had to say to this point before. But where he went next was a bit unique, because he began to discuss the sensor architectures and computational architectures that would be required to enable some applications that have been discussed relative to street lights. He said, "Street lights may be worth more because of the real estate they hold rather than the light that they provide."

He did cite some advantages street lights offer in enabling the vision he would espouse. We've heard these before. They are ubiquitous and powered. The size is right. Cameras can ideally be mounted up top and sensors for air quality and other things can be mounted 8 ft above the ground. He said the pole is an optimal form factor for sensors.

Technical sensing challenges

Still, the technical challenge may be tougher than many have suggested. Alvarez's lab has been working with Philips Research on trial projects in Cambridge to find use cases that make sense.

Part of the work is getting multiple uses out of one sensor such as a camera. If you install a camera on a pole, you should be able to use it to monitor pedestrians, automotive traffic, parking, and more. You have to decide what an application needs in terms of accuracy and other characteristics such as latency.

For example, consider a safety crossing application. Alvarez said it requires 100% detection capacity with zero latency. He said, "You need to be absolutely sure that you detect every person crossing the street." Parking, on the other hand, requires a high degree of detection accuracy but is a slow-moving system and a delay of a minute or two won't break the system.

Consider the numbers. To monitor moving cars on a roadway, you need to capture data at 15 frames/sec, which equates to a data throughput of 5 Mbytes/sec. To process that data, Alvarez said you need a "pretty beefy computer on board," which would be expensive; or you need an architecture to transmit the data, which may create latency problems. With parking, you may only need to sample one frame every 30 seconds. That takes the data throughput down to 11 kbytes/sec (see table). But both applications utilize the same sensor.

Smart city architects will have to carefully select the combination of sensors that might be deployed and how they are used. Temperature sensors are cheap and generate little data. You can install them anywhere. Cameras are also getting very cheap, but dealing with the output stream can be expensive. Thermal sensors, which can be a surrogate for a camera, are much more expensive but can lower the data rate and also eliminate privacy concerns that are common with cameras.

Alvarez's team is working on applications such as parking and the idea that a standard 20×8-ft parking space is not an optimal use of real estate given the diversity in car sizes.

FIG. 5. Ricardo Alvarez of MIT is researching smart city applications including parking control and enforcement, traffic control, environmental monitoring, and more.

Acting on that fact may take a while, but the team can already detect occupancy and measure the size of cars. The system can further be used to detect parking violations.

Alvarez also discussed the control of traffic intersections. For example, a city might dynamically change traffic flow based on pollution measurements at one or more intersections. That type of capability might be mined by cities from the gathered data.

CCT and SPD

There was, of course, much more discussion of smart city applications enabled by connected street lights. But here we need to address some light quality issues as we close our coverage. Everyone at the event agreed that glare is bad and that we need better fixture and lighting design. And protecting the dark sky is important. Yet the recommendation made by the American Medical Association that municipalities install warm-CCT street lights (http://bit.ly/2eW91WB) hung like a pall over SALC.

No one at SALC wanted to admit that the AMA has had any impact on street light installations. For example, Kevin Fitzmaurice and Jessica Tolley from Georgia Power presented an update on that utility's LED retrofit project, which by the way includes controls on all new installations and replacements. As we discussed in our SALC coverage two years ago, the utility believes that it can justify controls just through the benefits in automatic commissioning (http://bit.ly/1ZzgAme). The utility has now installed more than 200,000 LED luminaires, all with controls.

But the SALC presentation this year included a lot of talk about CCT. The Georgia utility has transitioned to 3000K-CCT lighting for streets. It said it came to that decision based on some complaints by customers and not due to any influence from the AMA. It made the switch in both street and roadway fixtures last fall. For now, area lighting such as parking lots remains a standard 4000K install. Residential security lights will transition to 3000K later this year.

Back to the Montreal project we discussed earlier, it was delayed by 18 months after the CCT issue arose. Now the controls issue may have delayed the project anyway, or maybe the delay made the controls decision an easier one. But the city ultimately decided to install 3000K lights rather than 4000K lights. The trend is clear despite the fact that multiple SALC speakers reminded the crowd that spectral power distribution (SPD) and not CCT is the proper way to contemplate light issues, and that the best data on the topic of object detection under street lights indicates 4100K is safer (http://bit.ly/1saaZU6).

Current IES president Cheryl English made it clear at SALC that the IES considers the AMA's activity inappropriate. The AMA did not have outdoor lighting experts on the committee that issued the recommendation. And the AMA has refused to collaborate with the IES. But perhaps the AMA has gotten its way nonetheless.

Back to a more positive topic, let's hope that the optimism surrounding smart cities and smart lighting is in fact going to lead to broad deployment of connected street lights. It's clear today that a lighting manufacturer can't get in the door at a potential customer site without a network and controls offering. But conversation around the SALC lunchtables indicated that the controls are often still eliminated late in the purchase process as a way to cut costs. Our own Strategies Unlimited market research business has also questioned just how prevalent connected street lighting will be, despite the potential benefits. For more information on their projections for connected lighting, see our coverage of talks at Strategies in Light from earlier this year (http://bit.ly/2rDik5q).

LEDs MAGAZINE SAPPHIRE AWARDS 2018

Don't miss the big reveal!

The winners will be announced at the

Fourth Annual

Sapphire Awards Gala

Celebrate Innovation Aboard the RMS Queen Mary

February 14, 2018 | 7:30 PM – 11:00 PM | Long Beach, CA

- Entertainment provided throughout the evening
- **NEW!** Bring your **Sapphire Sweetheart:** Treat your valentine to a spectacular evening out with our special spouse rate - use code **LOVE** at checkout
- Black tie encouraged

BOOK YOUR TABLE NOW!

Tickets can be purchased at **ledsmagazine.com/sapphireawards**

Contact Leslie Brown for more information - leslieb@pennwell.com | 918-831-9851

Held in conjunction with:

Strategies in Light | THE LED SHOW | lightspace california 2018

Sponsored by:

ERP POWER | OSRAM Opto Semiconductors | LEDs-ON™ www.ledson.eu

Plastic light diffusion systems match LED lighting needs – Part 2

Understanding optical systems phenomena such as reflection and transmission enables SSL development teams to choose proper additives and production techniques to achieve desired beam patterns, explains **GABI BAR**.

In recent years, LEDs have gained wide attention as a very low-power-consumption alternative to conventional indoor and outdoor light sources. Due to the LED's small size, an extensive range of design options is available for constructing the indoor and outdoor light fixtures. Nevertheless, when using LEDs to replace conventional light bulbs and fluorescent-tube lamps, the requirements to meet light intensity and light emission uniformity specifications remain in place. Part of that challenge relies on effective optical subsystem design, and this second article of a two-part series will describe the optical effects that can be achieved in solid-state lighting (SSL) systems.

To grasp where we are headed here, consider a baseline requirement for most LED-based luminaires. Although LEDs are spot sources, a "spot-like" light emission is not desired in most cases. Therefore, one of the main challenges in LED design is to be able to create uniform diffused light while minimizing loss of light intensity. Furthermore, the diffusing agent should be lightweight and allow for both high and low environmental temperature conditions. Finally, it should be economical to manufacture in high volumes.

Part one of this two-part series was published in the July/August edition of *LEDs Magazine* (http://bit.ly/2xYjmht). There we discussed light diffusion solutions from the perspective of selecting the optimal polymer carrier, and various techniques to measure light diffusion properties were presented. The current part will focus on the light diffusion agent itself, which in turn is incorporated into the selected carrier in order to provide optimal light diffusion properties of the complete system.

GABI BAR *is the global polycarbonate manager for Tosaf Compounds Ltd. (tosaf.com).*

FIG. 1. The image illustrates specular reflection of clouds on the surface of a pond. A still pond would deliver a mirror-like effect and would be considered regular reflection. The ripples in the water depicted in the image results in what is called diffuse reflection.

Optical system phenomena

In order to understand the light diffusion mechanism, the interaction between light and translucent material needs to be understood. When visible light interacts with translucent matter, several phenomena simultaneously occur. The most predominant for the systems of interest in LED coverings are reflection and transmission.

Reflection occurs when light bounces from a surface to the eye. Reflection may be specular (regular) or diffuse. If the surface is very smooth, like a mirror, the reflected light can form a very clear image. This is known as regular or specular reflection.

Consider the surface of a lake as an example. If you see a lake with perfectly still water, you will likely see a specular reflection of trees or clouds that rivals what you might see from a mirror. Conversely, when light is reflected from a rough surface, the waves of the light are reflected in many different directions, so a clear image does not form. This is called diffuse reflection. As seen in Fig. 1, even minute ripples in the water cause diffuse reflection of the clouds.

Transmission of light occurs when light passes completely through matter. As light is transmitted, it may pass straight through or it may be refracted or scattered as it passes through. When light is refracted, it changes speed and direction as it passes into a new medium as shown in Fig. 2. Moreover, the difference in the refractive index of air and the transparent material shown in the figures results in a discontinuity of the object viewed through the material. You can see a similar effect if you look at a straw in a glass of water and see the discontinuity between the portion of the straw below the water and the portion above the water in air.

Diffuse transmission occurs when light passes through transparent media that contains small transparent particles; a portion of the light no longer travels in a straight path, since when the particles are encountered, the light may be refracted or scattered or both. The result is dispersion of the transmitted light, also referred to as diffuse transmission. In fact, this is the mechanism of the light diffusion system.

The extent of light diffusion is based on many parameters and is discussed in depth in this article. An everyday example of a light diffusion system is shown in Fig. 3. Light from automotive headlamps in rain is an example of a case when light encounters tiny particles and spreads out in many directions.

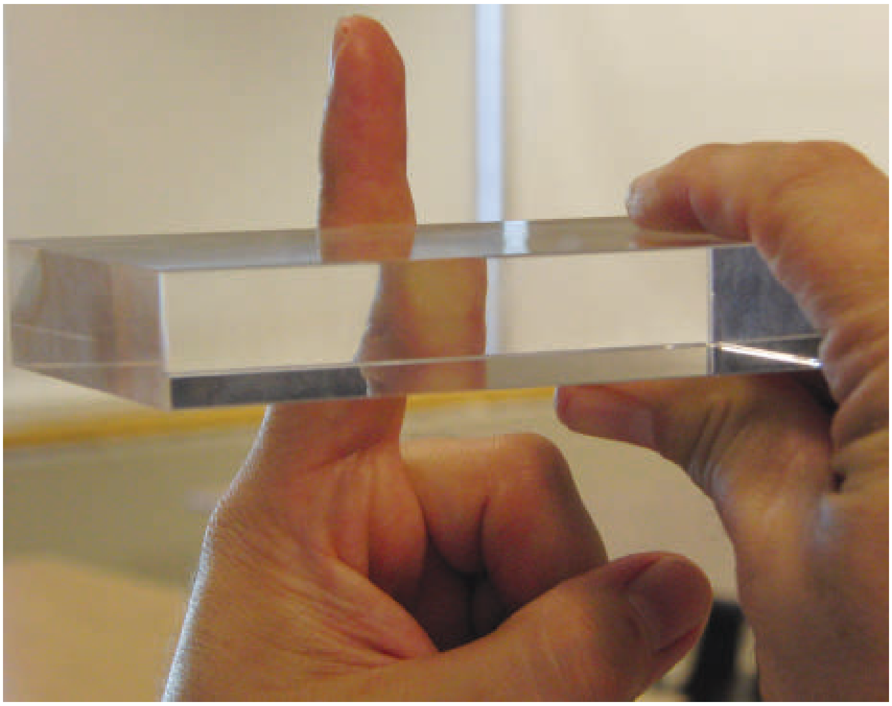


FIG. 2. Light travels at a slower speed in varying materials such as plastics, water, and air. The difference in refractive index (RI) between the plastic and the air causes the apparent discontinuity in the image of the finger.

Classifying matter by its interaction with light

Any matter can be classified by its interaction with light. In fact, there are three basic options for interactions of matter with light:

- Matter can be transparent to light
- Matter can be translucent to light
- Matter can be opaque to light

Light diffuser systems fall within the second category. In other words, the resulting materials are translucent to light. Translucent materials can be characterized by:

- The total amount of light that passes through the matter (as opposed to absorbed or reflected)
- The extent to which the transmitted light is diffused
- Parameters of the matter that affect translucency

Now, let's discuss the relationship of characteristics of optical matter and translucency. In order to understand this section, the term of refractive index must be further explained. The refractive index, *n*, also known as the index of refraction, is a dimensionless number that describes how light propagates through a particular medium, based on the following equation:

$$n = \frac{c}{v}$$

In the equation, *c* is the speed (velocity) of light in a vacuum and *v* is the velocity of light in the medium. For example, the refractive index of polycarbonate (PC) is 1.58, meaning that light travels 1.58 times faster in a vacuum than it does in PC.

Media and particles

So now the optimal diffusion system can be discussed, and we see that it takes two to tango. For quality light diffusion systems, both transparent media and transparent particles embedded in the media are needed. The aforementioned case of water droplets in the air is a good example of this combination.

In the case of a light diffuser system, the transparent media previously explained corresponds to the polymer, as discussed in depth in the first article of this series. Practically, there are only two options for a carrier for light diffusion systems: PC or poly-methyl-methacrylate (PMMA). The more challenging question is what kind of particles should be used to give the water-droplet-like diffuser effect in the host (or carrier) polymer.

The types of light diffuser (LD) additives in use over the last 20 years have been revolutionary if we compare recent additives to the type of additives used before. The first light diffuser additives in transparent plastics were quite primitive in terms of technology and performance. Nevertheless, they were satisfactory for roofing applications with PC or PMMA sheets.

Sheets producers, via their compounders, were using various materials to add LD properties into the sheets. Most of the additives were based on minerals, like $BaSO_4$ (barium sulfate), ZnO (zinc oxide), ZnS (zinc sulfide), $CaCO_3$ (calcium carbonate), and even TiO_2 (titanium dioxide). The latter is still in use today, but only for white coloring. The main advantage of using minerals as a light diffusing agent is the low cost. Often the costs of the LD additives were lower than the polymer itself.

State-of-the-art additives

Today, with the new LD additive technology, the LD additives by themselves can cost even ten times more than the host polymer on an equal weight basis. Still, you may be surprised at the reason for the transition because cost isn't a direct factor.

While the mineral approach offered a significant cost advantage, using minerals as a light diffusing agent required a relatively high dosing level to get acceptable moderate diffusing properties. But the high loadings consequently led to a reduction in mechanical properties and a significant reduction in total light transmission (LT). Where LT of the natural polymer is 90%, the mineral additives could lower LT down to 60%–65%. In comparison, today's systems can maintain an LT level of 80%–85%.

Why is there such a difference? The answer lies in the parameters that affect the LD performance while maintaining the LT. The most notable parameters are as follows.

LD additive concentration seems an obvious factor and is. Increasing the LD additive concentration in the polymer will increase light diffusion properties. On the other hand, it will also reduce the total amount of light transmitted (http://bit.ly/2hJcWN6). The term luminance is a measure of the intensity of the light emitted from a surface. The reduction in luminance versus concentration is shown in Fig. 4. Therefore, with any type of LD additive, concentration must be optimized to account for the tradeoff between LD and LT.

LD additive reflective index (RI) also is a key parameter. When selecting the RI of the LD additive, the RI of the host polymer must be taken into consideration. As the difference in RI between the carrier and the LD additive increases, the extent of light diffusion will increase. Thus, a lower concentration of LD additive can be used to give the same light diffusion level. On the other hand, light transmission will drop faster. The dependency of luminance on RI is also shown in Fig. 4. In other words, an LD system with a small RI difference between the host polymer and the LD additive will require a higher additive loading, but will result in a higher luminance as compared to an additive with a larger RI difference.

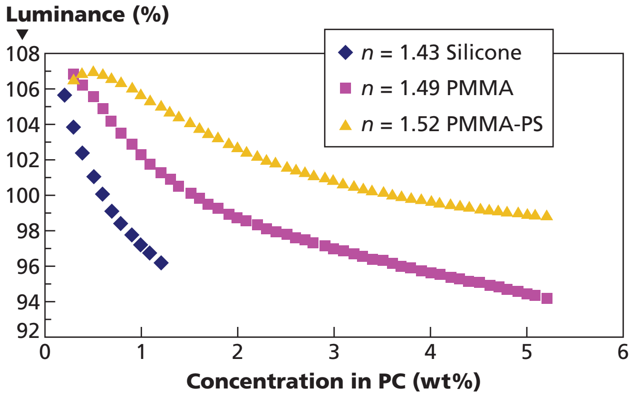


FIG. 4. The graph shows the dependence of luminance on the concentration and type of LD additive in polycarbonate. The RI of PC is 1.58. Microbeads with a higher RI difference (relative to the host polymer) are more effective in diffusion properties, but luminance drops much faster.

LD additive particle size comes into play in scattering. A smaller particle size will be more effective in scattering the light. This makes sense, since for the same LD additive concentration by weight, light will pass from the polymer media to the LD additive media a higher number of times in the case of smaller particle size. This will result in a greater light diffusing effect. However, when considering LT, experiments indicate that there is an optimal particle size of 2–3 μm (microns). A particle size that is larger or smaller than this range will result in lower LT. A luminance experiment based on different particle sizes is shown in Fig. 5.

LD additive particle size distribution is a concern, as might be expected. For a given average particle size, experiments indicate that a uniform particle size allows for higher luminance as compared to having polydispersity of the particle size.

LD additive shape also comes into play. Let's assume that the LD additive is composed of pure water, but not in a tiny spherical shape; rather, it is crushed ice in the form of small, thin irregular plates. Would the level of transmitted light will be the same? Also, here, the answer is no. Although ice has the same

Photo credit: Ruth E. Hendricks, via http://bit.ly/2kk9rxC.

FIG. 3. Scattering occurs when light encounters tiny particles of matter and spreads out in many directions. Here beams of light from a car's headlights are shining through fog. The water droplets in the air disperse the transmitted light thereby creating a natural light diffusion system.

chemical composition as water, the shape and form of the particles impacts the LT level. The reason is that when light meets a smooth surface of transparent material, most of the light will be transmitted through the object. This is the case with a spherical shape like the water droplets. But when the LD additive is in an irregular form, light will be reflected or scattered to a greater extent.

Light transmission through the LD additive is the final parameter we will discuss here. If instead of water droplets, the same light beams were projecting on cola droplets with the same droplet size and concentration, would the level of light reaching our eyes from the car beams be the same? The answer is clear: The level of light transmission will be lower. Thus, the extent of light transmission of the LD additives is also of importance.

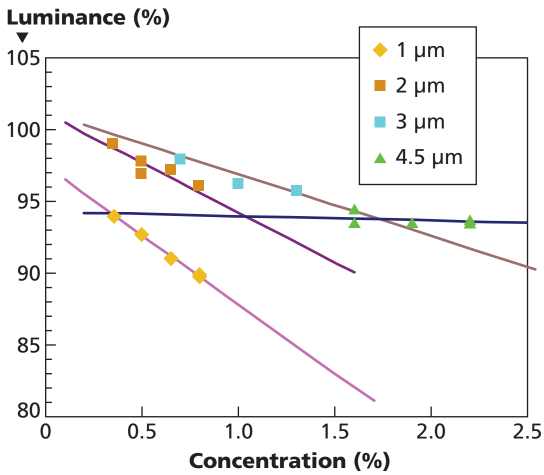


FIG. 5. The graph shows the dependence of luminance on particle size for the same type of LD additive. Optimal size range is between 2–3 μm. Smaller or larger particle size results in lower luminance levels. For particle sizes of 4.5 μm or higher, the luminance level has a very low dependency on concentration.

Industrial water droplets

After understanding the required properties of the LD additive, we can now discuss what we call industrial water droplets that might be used as light diffusing agents. For the last two decades in the PC sheets industry, the traditional minerals used as LD additives were replaced by cross-linked polymeric microbeads. Microbeads are also used in the production of flat LCD screens. Originally, polymeric microbeads were developed for the cosmetic industry.

Fig. 6 is a microscopic image of some Tosaf microbeads. The microbead diameter ranges from 0.8 μm up to 40 μm in some cases. The image is a picture of typical pure microbeads and not compounded microbeads.

These microbeads are the ideal light diffusing agents in PC and PMMA. The additives are transparent, spherical, uniform in size, and available in a range of RI's based on the type of polymer utilized. In addition, unlike in cosmetic use, the polymeric microbeads must be thermally stable to survive the extrusion process. Therefore, microbeads are subject to a cross-linking process when they are produced. The process involves a chemical reaction that converts the polymer from a thermoplastic to a thermoset. The microbeads are subsequently stable to heat when compounded into the host polymer and thereby maintain the original spherical shape.

It is important to mention that converters of PMMA and PC articles such as producers of profiles, lenses, covers, and sheets cannot introduce the LD additive directly into their process. The LD additives have a very low bulk density, and therefore specialized equipment is needed in order to dose them into the machines. Also, dedicated processing tools are required to disperse the additive in the polymer uniformly. Therefore, LED cover or optic manufacturers must acquire LD additive that is already compounded into the host polymer, as produced by compounding companies that specialize in this unique segment.

LD additive cost

Of course, cost is also an important parameter when selecting an LD system. On the one hand, LD additives with higher purity, improved thermal stability, and narrow particle size distribution will cost more. On the other hand, such additives will perform much better in terms of light diffusing quality and luminance level. The cost impact of the LD additive on the PMMA or PC cover part is limited, as its concentration in the carrier is very small: 0.3%–1.0%. Therefore, even if there is a $20/kg cost difference between two types of LD additives, the final difference can be acceptable. In an average LED cover, the weight is 0.5 kg, resulting in only $0.10 difference per unit.

Moreover, experiments indicate that the optimal level of LD additive in a polymeric cover depends on both the LD additive concentration and the cover part thickness.

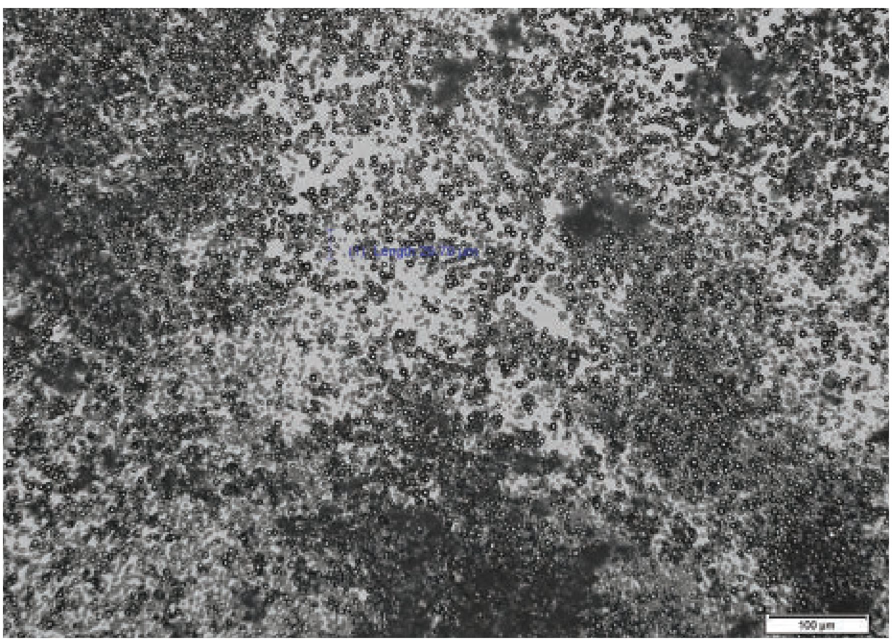


FIG. 6. The microscope picture of pure microbeads shows an average particle size of 4 μm.

The concentration, to a good approximation, is inversely proportional to the thickness. Thus, for example, if a part of 1-mm thickness requires 0.6% of LD additive. Then for a part of 2-mm thickness, approximately only 0.3% is needed to get the same extent of light diffusion.

Compounded LD additive in PMMA or in PC is offered by the compounding companies in two forms:

- Ready-made compound — with the main advantage that the LD converters can use the compound as is. Use as is means direct dosage into the injection molding or extrusion line without any additional actions.
- Masterbatch (MB) form — in this case, the converters need to blend the masterbatch with PMMA or PC at a certain dosing level. They can pre-mix the MB with the host polymer prior to introduction into the machine or perform the mix in-line by using dosing systems.

Ready compound is easy to process without any dispersion problems; however, it is much more expensive in comparison to the MB option. Therefore, converters that deal with large quantities should consider using MB rather than ready-made compound. Moreover, use of MB provides flexibility and control for the converter by allowing them to increase or reduce the LD additive level in the product according the product thickness and customer specification.

Summary

LED lighting systems are everywhere today — in private houses, shopping centers, train stations, factories, businesses, street lighting, and more. Attention should be paid to the performance of the light diffusion system. In particular, questions should include: Is the light diffusion uniform in the product? Can the light source shape be seen? Is it a high luminance system?

High-quality materials for these applications depend on the choice of light diffuser additive systems, so that they contribute to maximum energy utilization of the LED device. As we have discussed, on one hand, optimal systems allow a high level of light to be transmitted and at the same time, they provide for high diffusion of the transmitted light.

Government regulations and consumer preference for more environmentally-conscious, energy-efficient products have caused manufacturers to develop solutions for the marketplace that offer new levels of energy efficiency, based on LED technology. This trend will lead to a continuous increase in the LED technology market share among other light technologies. As a result, there will continue to be more demand for light diffusion systems with high-quality performance.

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance and helpful comments of Moira M. Nir, PhD, of Tosaf Compounds R&D Department in preparing this article.

Driving down automotive headlamp costs at Renault with LEDs

PAUL-HENRI MATHA explains how thermal analysis using computational assessment is guiding the development of LED-based headlight assemblies that will serve across many models in the company's automotive portfolio.

Automotive headlight design is an important part of the Renault brand these days, and our "C-shape" LED-based headlights are a signature part of the appeal of our cars. About 30% of the cost of automotive headlight assemblies can be found in the mechanics and 70% in the electronics. Hence, any savings that can be made on the electronics side will have a profound influence on the overall cost of these units. This article outlines how we have broken down our headlamp costs and used thermal analysis tools to incrementally optimize headlight design, achieving a 50% cost reduction in the two years from 2014–2016, and how we intend to halve it again in the next few years while relying on solid-state lighting (SSL) technology.

In Generation 1 of our full LED headlight assemblies, we looked at six of our C- and D-segment vehicles (medium and large vehicle classifications in Europe) from the Espace to the Koleos. We first standardized all platforms to one common height sensor, one common static leveler, one common DRL (daytime running light)/low beam/high beam driver, one common central connector, and common low- and high-beam modules with two suppliers for each. We did this in one year by examining the partition of costs and standardized about 60% of the components of our headlights (Fig. 1).

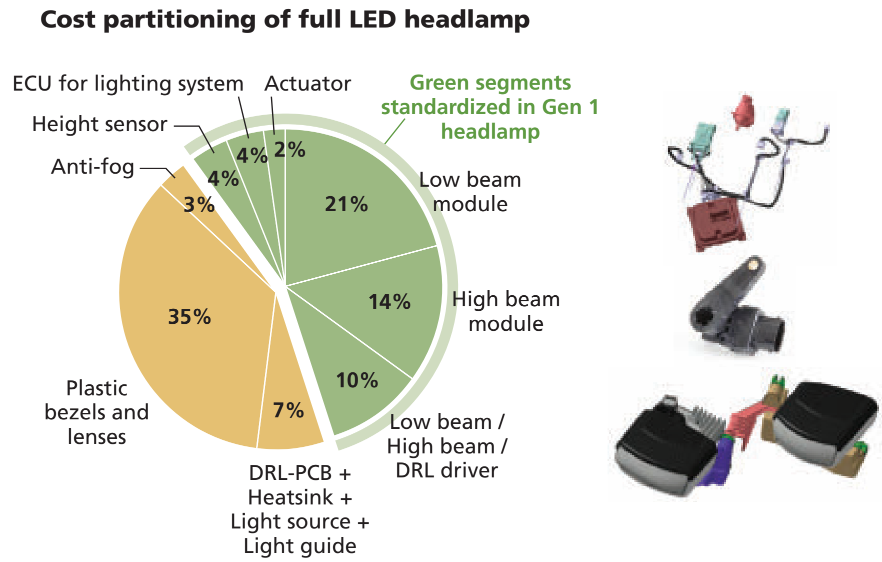


FIG. 1. The charts show headlight components standardized in Generation 1 versus the overall cost partition of a headlight assembly.

The plastics we used only made up about 30% of the overall assembly price. The volume effect is the main cost factor for a headlamp's part price, as is its supply entry ticket. However, by moving from halogen headlights in 2012 to LED-based headlights in 2014, the overall costs went up four-fold. This gave us the impetus to see if we could cut costs in Generation 2 of our headlight evolution.

Second-generation design

We focused our Generation 2 headlamp effort on our popular segment-B car (small car), the Renault Clio, which was going through a facelift and stylistically we wanted to move it to our LED-based, C-shape DRL lighting.

There were four pillars to our Generation 2 strategy:

- Be the first generalist automotive OEM with full LED headlights in this B-segment car
- To reduce by a factor of two the headlight part price between Generations 1 and 2
- To have a better LED lighting performance than the Clio Initiale (which had 25W xenon lights)
- To reduce overall headlight assembly depth by 50 mm

We standardized the Clio on a common LED electronic control unit (ECU), a common height sensor, and a common leveler. We then focused on the LED low-beam light and reduced its price to 30% by reducing the number of LEDs and the size of the heatsink

PAUL-HENRI MATHA *is a French engineer educated at École des Mines, and he is the lighting expert at Renault SA in Technocenter, France. He has been working at Renault for 17 years, with 15 years' experience in the lighting department.*

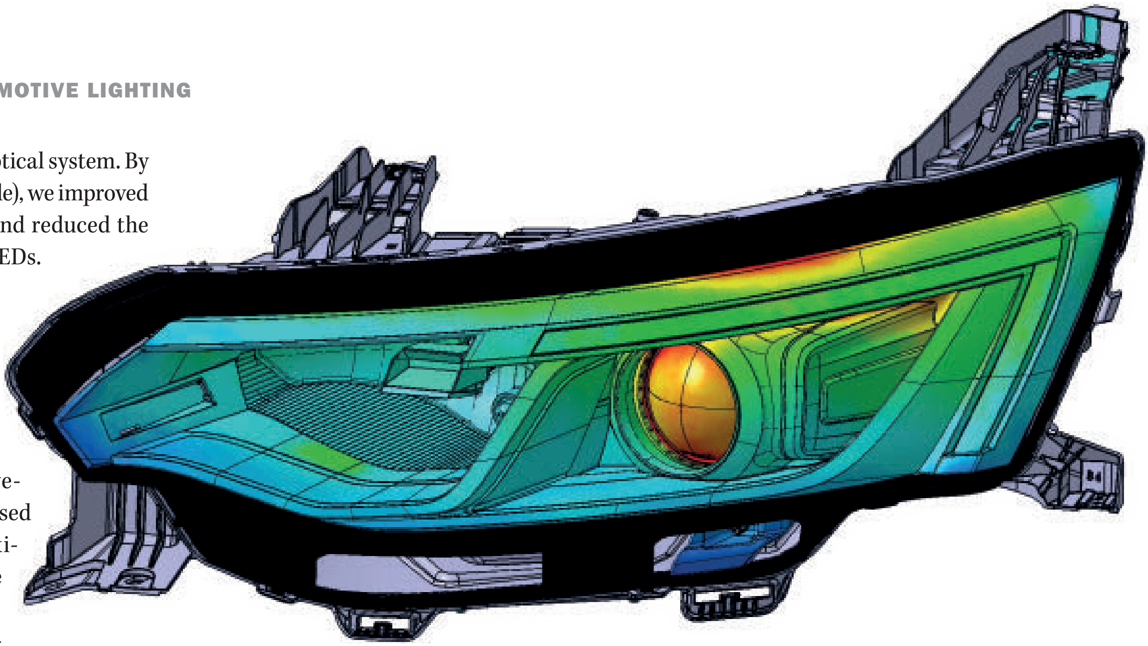


FIG. 3. FloEFD thermal predictions project performance for a Renault halogen headlamp assembly.

by 30%, and improving the optical system. By doing all these things (see table), we improved the LED light flux by 33%, and reduced the assembly from eight to five LEDs.

System-level benefits

We also increased optical efficiency by 25% and produced an overall assembly size reduction of 50 mm. With the thermal improvements to the LEDs, we increased the LED current, the maximum junction temperature usage, and the flux derating at a lower ambient temperature as shown in the table. Similarly, with the associated heatsink design, we were able to better manage junction temperature and derating through our detailed thermal simulations (Fig. 2).

With respect to the overall headlamp package size, we saved 50 mm in depth between Generation 1 with a halogen headlamp and Generation 2 with an LED headlamp because of a better-designed assembly. Fig. 3 shows typical CFD (computational fluid dynamic) simulations for a halogen headlamp in the computer-aided design (CAD) software, FloEFD, illustrating the complex airflow and thermal effects to be found on the surfaces in the headlamp assembly.

Digging into the details

Looking deeper at our general CFD-based thermal analysis approach that typically is used to optimize headlamp designs, we would normally be interested in predicting lighting performance at 23°C outside the headlamp in ambient air and up to a maximum of 70°C for the outside temperature for the outer boundary of LED reliability. To validate our simulations, we performed some experiments where we fixed the ambient temperature outside the headlamp at 23°C and installed eight thermocouples outside the assembly for a car with its engine on and off.

It is clear that the temperatures can reach over 50°C inside the headlamp when the engine is idling and the lighting is on for a prolonged period. In addition, headlamp surface temperatures can rise to 65°C in certain idling conditions.

With other tests, we found that with just a low beam on for an hour, the temperature inside the headlight went to 20°C, and with both low and high beams on for an hour, an extra 5°C in temperature was measured.

Thermal analysis

We also performed a series of tests in which we evaluated the effects of engine idling and lights either on or off by looking at the R_{jth} (thermal resistance) of an Altilon LED assembly (3 K/W) and three chips driven at 1A and a $\Delta(T_{junction} - T_{case})$ temperature differential of 20°C. We were able to show that for ambient temperatures of 70°C and with both low- and high beams on, together with the engine on, the junction temperature of the LEDs comes very close to the worst-case scenario of 150°C.

We concluded that it was not possible to design an LED system if we were to take into account all the use cases. The OEM must

Solution	Current (mA)	Flux/LED (lm)	Number of LEDs	T_j at 23°C (T °C ambient)	Start of derating (T °C ambient)
LED low beam Gen 1	800	200	8	120	60
LED low beam Gen 2	1000	270	5	130	50
LED high beam Gen 1	800	200	4	120	60
LED high beam Gen 2	1000	270	4	130	50

TABLE. LED solution evolution from Generation 1 to 2 for the Renault Clio headlamp.

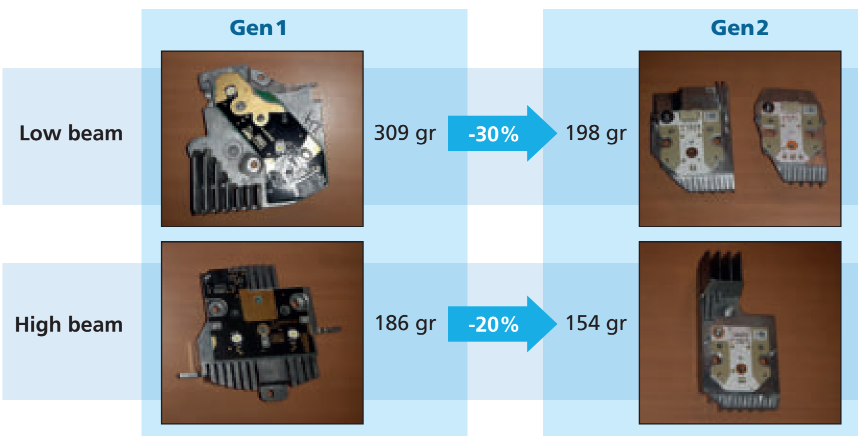


FIG. 2. Comparative images show the Renault Clio headlamp heatsink-weight evolution for Generations 1 and 2.

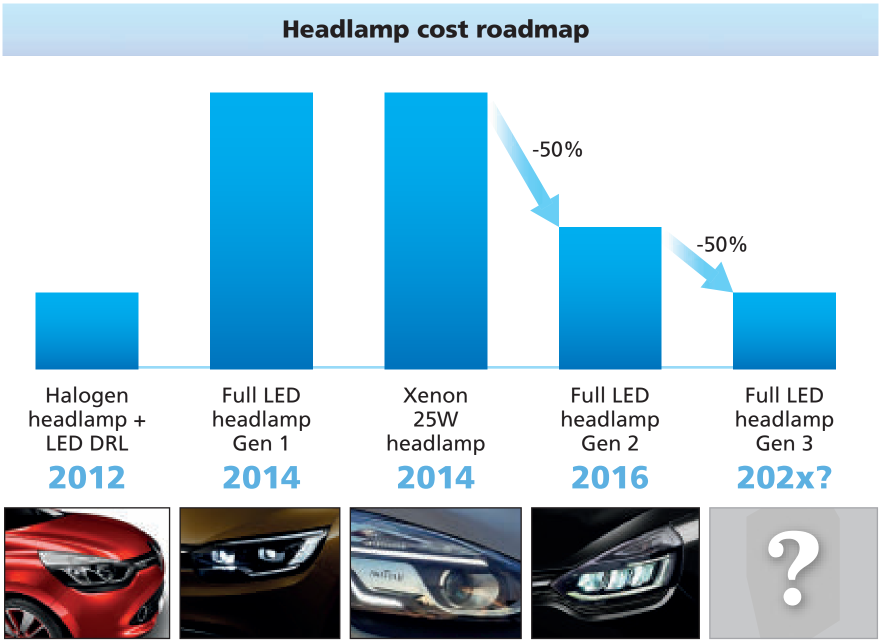


FIG. 4. Renault Clio headlamp changes and cost reductions from 2012 to 2016 from Generation 0 (halogen headlamp and LED DRL) to Gen 1 (full LED headlamp), then xenon headlamp to Gen 2 (full LED headlamp), and finally the cost reduction roadmap to Gen 3 LED headlighting.

therefore define the best compromise. For example, at 23°C after one hour of engine idling, lighting performance was shown to be at 100%, but if the ambient temperature rose to 50°C for the same situation, the lighting performance would go down to 80%. To respect this specification, we concluded that a thermal sensor had to be added to the PCB (printed circuit board) so the current could be reduced if the temperature at the LED was greater than a threshold we would define. We could then do a thermal derating and a flux derating of the full LED headlamp.

Moving to production design

Going forward, we are putting in place an action plan to deal with simulation and testing of lighting in transient drive cycle modes. As an OEM, we want to be able to simulate the impact of car speed on its lighting's thermal performance, and in particular the thermal variation due to speed of each of our engines. This will make thermal CFD software crucial for lighting engineers in future.

We also need to be able to model the nearby engine bay's thermal behavior in parallel with the headlight simulation because they affect each other. And we also see the need for thermal management inside the headlamp when thermal inductors will be present. In short, Renault believes the OEM should be responsible for the complete thermal system associated with headlamp design. To do so will make the OEM a system market leader.

Our immediate goal in the Renault Lighting Team with Generation 3 of our project is to increase the LED flux of headlamps from 270 to 320 lm by 2018–2020 (Fig. 4) and introduce new LED drivers to deal with higher power, plus we are aiming for the introduction of turn indicators and AFS (adaptive front-light system, sometimes called adaptive drive beam) functionalities, as well as overall assembly size reduction. Finally, we are aiming for a height sensor regulation evolution. Our eventual target is to reduce the price of our full headlamp assembly to by another 50%, bringing it to the levels we saw with halogen headlamps five years ago.

Should you buy or finance your LED retrofit?

LeaseQ CEO **VERNON TIREY** breaks down financing options available for an LED upgrade and lends expert advice on the savviest route.

LED lighting uses 75% less energy and lasts 25× longer than incandescent lighting (http://bit.ly/2wzvfHl), so it's no surprise that companies across industries are making the switch. While the benefits of upgrading to LED are clear and proven, the upfront cost deters many companies from pursuing a full upgrade. Building owners may struggle to justify an LED retrofit when their facility already has working lights, and lighting is rarely a priority when weighing other capital investments.

So what's an LED vendor to do? Build a strong case for capital spending to reduce costs and boost profits. There are two ways building owners can upgrade to LED. Each option has its unique advantages and disadvantages that energy managers should explore in each proposal.

Cash purchase. Purchasing LEDs outright is a great option for companies who have cash on hand to pay in full at the time of installation. The greatest advantage of paying cash is avoiding debt or interest. However, an investment this large will likely use funds allocated for other initiatives, and may postpone other projects or erase cash on hand. Although an LED retrofit will return energy savings, savings will not offset the initial investment for a few years.

Equipment financing. This is the industry catch-all term for equipment loans and leases. This is the best option for building owners who do not have the cash on hand for an LED upgrade, and whose focus is capital preservation — securing the upgrade with the lowest upfront cost. Equipment financing enables building owners to pursue an LED retrofit, while maintaining cash for other planned projects or unexpected costs and simultaneously enjoying energy savings.

Equipment financing presents an undeniable win-win scenario: Building owners who use equipment financing preserve cash flow for a rainy day or strategic investment, get the equipment they need, and maximize energy-efficiency savings while simultaneously improving the bottom line. Generally, financed LED retrofit projects are "net cash-flow positive." This means that the upgrade generates monthly savings that are greater than the monthly loan payments.

VERNON TIREY

Put another way, building owners can choose to finance an LED project for $0 down, use someone else's money, and generate immediate positive cash flow in the very first month. By counting the equipment as collateral for the loan or lease, equipment financing offers some of the best interest rates and payment terms for LED upgrades, regardless of a business owner's time in business or credit score.

All of this is music to an LED vendor's ears. LED vendors have long faced an uphill battle in closing deals for commercial spaces, due to the high upfront cost. With automated equipment financing solutions, vendors can quickly summarize the project economics and cash flows for a building owner. This might include cash spent to start realizing improved efficiency, estimated efficiency savings, any applicable rebates or incentives, and instant, online financing quotes.

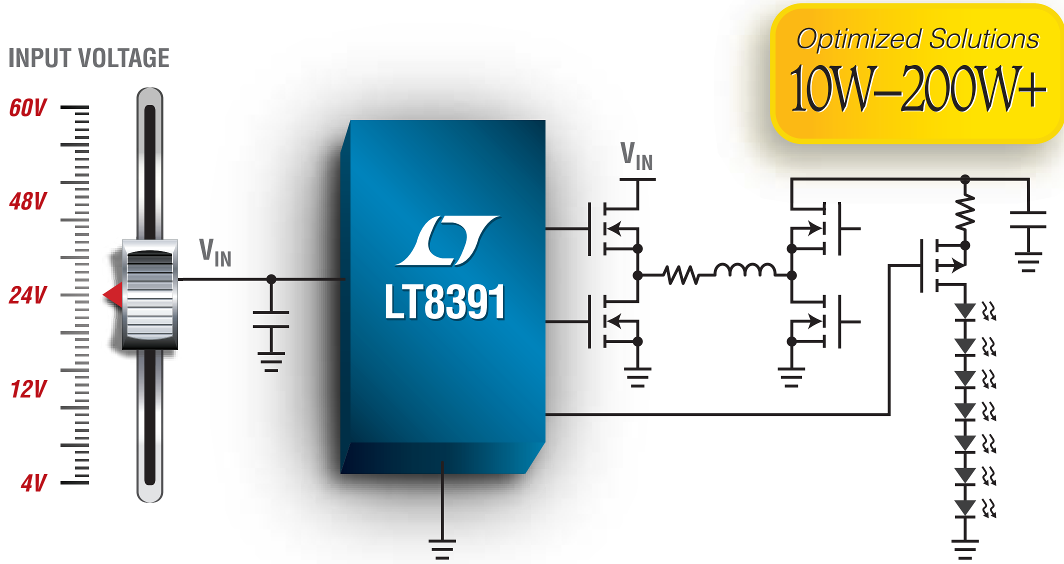
Equipment vendors should establish cost first, be realistic about future savings, and work with the building owner's finance department when necessary. The result is a "no-brainer LED retrofit."

Creating a strong business case with equipment financing enables vendors to position and sell more cash-flow positive LED projects. For example, consider the owner of a California Chevron gas station who was looking to increase his store sales by providing customers with better illumination of his store and merchandise with new LED lights. While he wanted to realize the energy and maintenance savings of energy-efficient bulbs, the owner did not have the budget for new lighting, as he was saving for an upcoming project.

The vendor, Hi-Def Lighting and Electrical, provided him with an alternative way to pay for the LED upgrade: equipment financing. With competitive terms from Hi-Def and the ability to save cash for his other project, the owner proceeded with a full LED upgrade. This Chevron station is expected to be 58% more efficient and save the owner close to $3000 per year.

Vendors who implement equipment financing capabilities will differentiate themselves from competitors and become a trusted advisor in the LED industry. On the forefront of automation, vendors can make upgrading to LED effortless, ensuring building owners have the best and brightest, without breaking the bank.

60V Synchronous Buck-Boost LED Driver



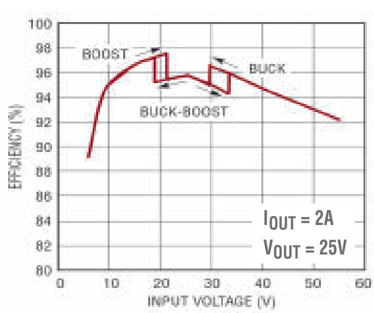
Flexible Power Range, Low EMI Design & Robust Performance

The LT8391 is a synchronous 4-switch buck-boost DC/DC LED controller that regulates LED current from input voltages above, below or equal to the output voltage. It can deliver 10W to over 200W of LED power with efficiency as high as 98% and ±3% LED current accuracy. Its 4V to 60V input voltage range is ideal for a wide range of applications including automotive, industrial and architectural lighting. Similarly, its output voltage can be set from 0V to 60V, enabling it to drive a wide range of LEDs in a single string. The LT8391 offers 128:1 internal dimming and 2,000:1 dimming using an external PWM signal. Its unique topology incorporates direct inductor current measurement at all times, offering robust performance under all conditions while spread spectrum frequency modulation minimizes EMI concerns.

Features

- 4-Switch Single Inductor Architecture Allows V_{IN}, Above, Below or Equal to V_{OUT}
- 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}



Info & Free Samples

www.linear.com/product/LT8391

1-800-4-LINEAR

LINEAR TECHNOLOGY | NOW PART OF ANALOG DEVICES

Find your local sales office: **www.linear.com/contact**