JOURNAL CIBSE

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SPIRIT OF NEW YORK

Light lifts city workers at World Trade Centre's new transport hub

Lightening the workload
LG7 focuses on saving energy in the office

The future is light
How LiFi will revolutionise telecommunications

LIGHTING SPECIAL

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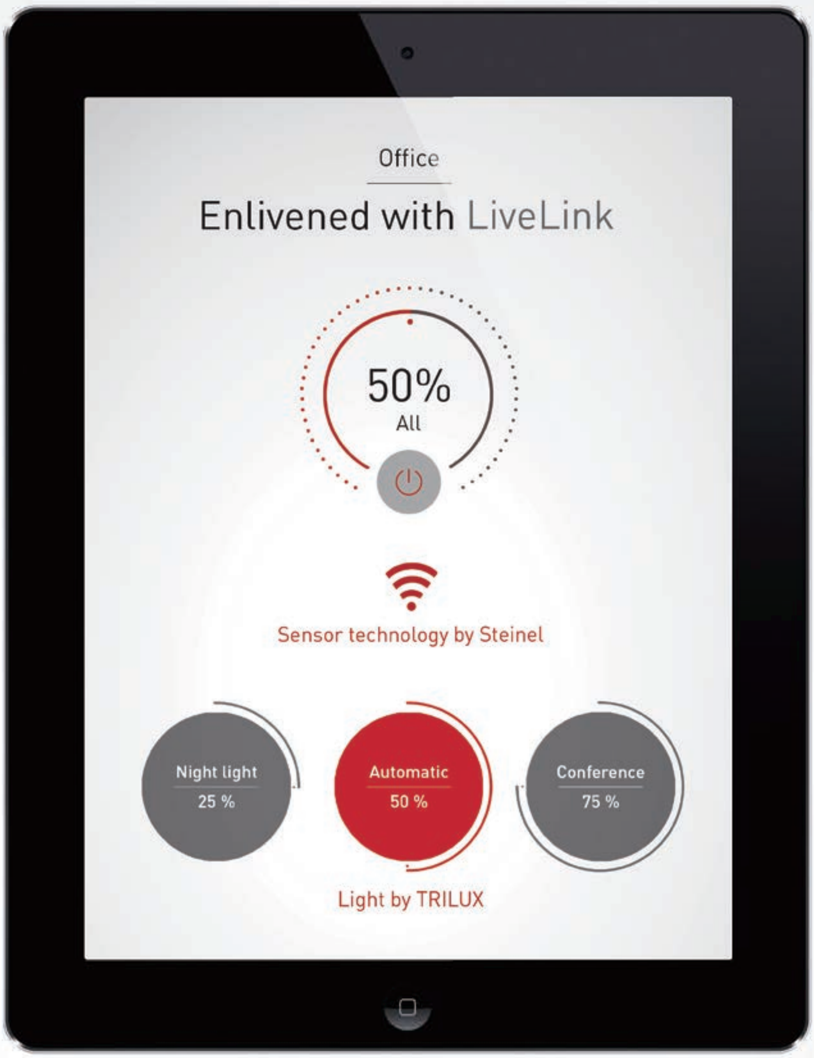

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The light fantastic

Fourteen years after the 9/11 attacks in New York, a key element of the rebuilding of the World Trade Center has opened to the public. The Fulton Centre transit hub is an uplifting space, thanks to a huge glazed reflector that amplifies sunlight into the heart of the three-storey pavilion building.

The Sky-Reflector Net illuminates the way for the 300,000 commuters that pass through the subterranean network every day. We explain how art, architecture and engineering came together to produce a unique landmark building for Manhattan (page 4).

Mankind has always known about the benefits of daylight, but it is only recently that researchers understood that light waves could be used to carry data. With an estimated seven billion mobile phones on the planet, and a shrinking number of free wavelengths on the radio frequency (RF)spectrum, our wireless communication systems are being stretched to the limit. But, according to Professor Harald Haas, lighting has the potential to hugely increase the capacity to send data (page 12).

He explains how LED sources could be turned into high-speed communication devices to form a new layer of wireless networking. Dubbed LiFi by Haas, the system uses light waves instead of RF to deliver data and will supply 10,000-times more bandwidth, providing the next 5G and 6G networks.

The future is nearer than we think – the first LiFi luminaire is about to be installed at the Paris headquarters of property developer Sogeprom.

As LED becomes more commonplace in office lighting, Dominic Meyrick gives a timely review of the new Lighting Guide 7 (page 8).

The guide has a greater emphasis on energy use and how to get the best out of lighting designs, including the 'hot desking' approach and dealing with tablets and touchscreens.

Don't miss our special CPD on page 19, in which Tim Dwyer explores the evolution of lighting systems and the impact of hybrid systems on the industry.

Liza Young, deputy editor
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TRAVEL LIGHT

The main transport interchange at New York's World Trade Center has been transformed into a soaring, light-filled space thanks to a striking daylighting feature at the nexus of art, architecture and engineering. **Jill Entwistle** reports

While the *Guardian*'s review of Grimshaw's Fulton Center in New York was somewhat tepid, architectural writer Jimmy Camp did single out the Sky Reflector-Net as a redemptive feature. It is 'an achievement of artistic and technical virtuosity,' he wrote, '...a practical and elegant union of art, engineering and architecture that pulls Fulton Center from the brink of glossy banality'.

One of New York's key transit hubs, the building forms part of the regeneration of the World Trade Center site and its environs. The three-storey, glazed pavilion structure, incorporating a retail element, was designed to crown the new underground pedestrian network and form a landmark gateway to Lower Manhattan. Sitting on the corner of Fulton Street and Broadway, one block east of the World Trade Center site, it is where 11 city subway lines converge, carrying more than 300,000 people daily.

The Fulton Center project involved untangling what had become a knot of inefficient connections, creating a light, airy and more intuitively navigated environment. The ambition was to rethink public transportation, with a concept

CREDIT: JAMES EWING

inspired – according to New York Grimshaw partner Vincent Chang – by the soaring space of the city's Grand Central Terminal, which is famously lit by slanting rays of sunlight through its clerestory windows.

An eight-storey dome is the centrepiece of the building. Its canted 16.15m-diameter circular skylight – known as the oculus – forms a striking focal point, and brings sunlight and daylight down through the building to the subterranean levels.

'From the inception of the project, light and daylight played a critical role in this re-envisioning of the transit hub, by acting as a key wayfinding element,' says Arup lighting associate Matt Franks.

This natural light is amplified by an integrated artwork, the Sky Reflector-Net, which acts as a functional, but also strikingly aesthetic element.

A steel cable-net structure with custom-designed, aluminium-coated panels, it forms an independent reflective lining, offset from the dome's interior and directing sunlight downwards. Together, the oculus and reflector-net generate enough illumination in the building interior to allow electric lighting to be turned off during the day.

The reflector-net concept was created by James Carpenter Design Associates (JCDA), a cross-disciplinary design firm specialising in the crossover between architecture, art, design and engineering. The design and development of the structure was a collaboration between JCDA, Arup and Grimshaw.

View of electric lighting of the Sky Reflector-Net during fixture aiming

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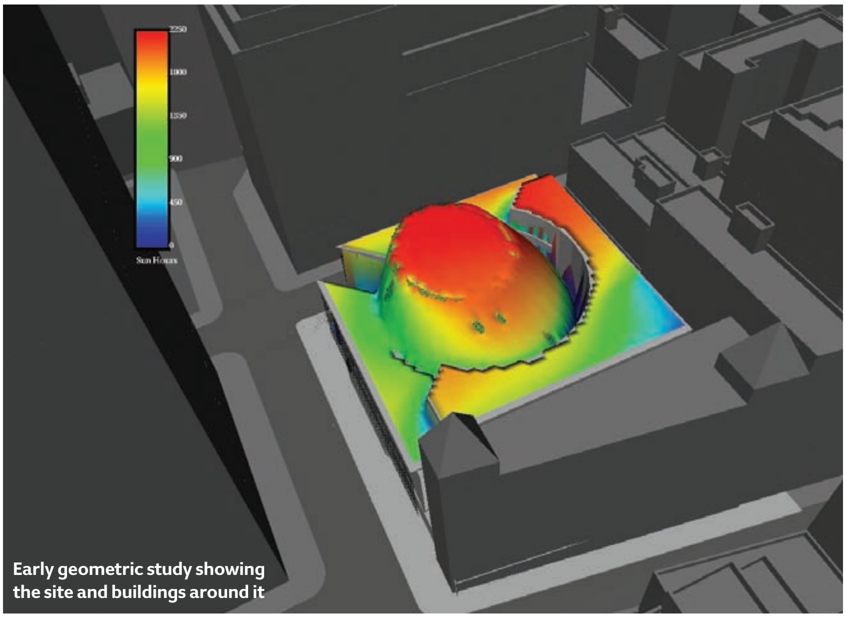


Early geometric study showing the site and buildings around it

The structure comprises a stainless steel cable net with nearly 1,000 perforated reflective panels made from a custom-designed, semi-specular aluminium coating, on a 3.2mm aluminium substrate. This dynamically reflects the direct sun and diffuse light according to changes in exterior conditions and the viewer's position. The coating has been specially designed to avoid the accumulation of dirt and dust, to preserve the integrity and visual quality of the installation.

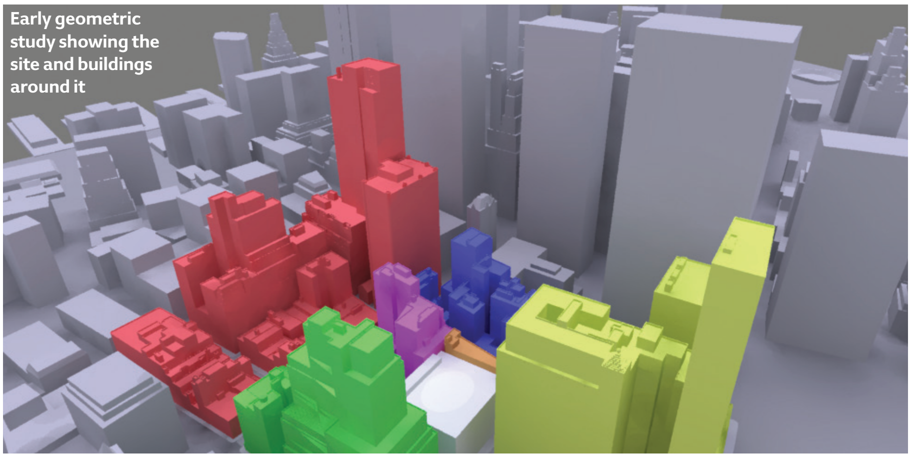
The surface finish also allows for subtle direct reflections while avoiding direct glare from reflected sunlight. The perforations in the panels range from 30% open at the top of the structure to 70% open at the bottom, so reflectance is optimised where it is needed most.

They also allow heat and smoke to pass through the structure, for comfort and safety purposes.

There are additional glass panels, known as parasols, which reflect small amounts of direct sunlight onto the interior of the reflector-net structure. These are designed to add a dynamic sparkle when sunlight penetrates the oculus.

Crucial to the efficacy of the oculus was determining its location in relation to both the sun and surrounding buildings. The design team studied the solar geometry of the site to find out to what degree it would be overshadowed by the surrounding buildings. Daylight studies helped determine the location, height and angle of the skylight.

The team began with a three-dimensional model of the site to determine

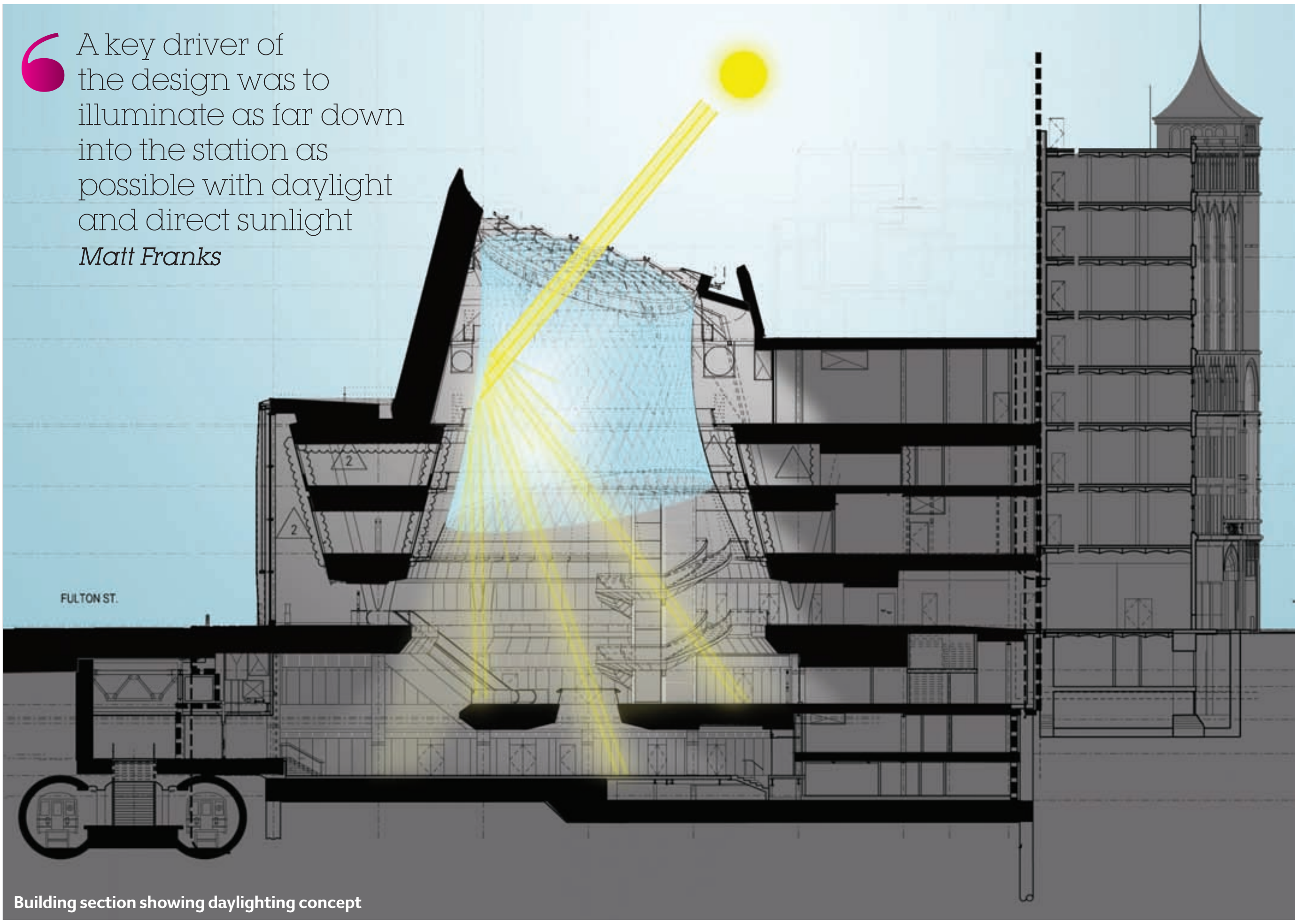


Early geometric study showing the site and buildings around it

PROJECT TEAM

- **Client:** New York Metropolitan Transit Authority (MTA)
- **Architect:** Grimshaw Architects
- **Artist:** James Carpenter Design Associates
- **Structural engineer and daylight analysis:** Arup
- **Contractor:** PSJV
- **Specialist sub-contractors:** Enclos; TriPyramid Structures; Durlum; STS Steel

> A key driver of the design was to illuminate as far down into the station as possible with daylight and direct sunlight
> *Matt Franks*



Building section showing daylighting concept

solar access. Investigating the sunpath geometry around the site using inverted sunpath diagrams allowed them to determine at which times the sun could potentially be blocked by other buildings.

The designers produced solar animations for three key days – 21 March (equinox), 21 June (summer solstice) and 21 December (winter solstice). These provided an understanding of the shadow patterns throughout the day and year. This was further developed by looking at an annual analysis of potential solar exposure.

The outcome was to locate the structure towards the northern corner of the site, tilting it gently towards the south to allow more direct sunlight to enter. In summer, sunlight penetrates as far as two levels below ground, so that passengers step off subterranean platforms into daylight. The skylight is also open to diffuse light so that adequate natural light is provided when the sun is obscured by clouds.

The next step was to understand the solar exposure in the interior of the building, as well as exposure to diffuse daylight when no direct sunlight is available. This confirmed that daylight alone would be sufficient on most days, without the need for supplemental artificial lighting.

'A key driver of the design was to illuminate as far down into the station as possible with daylight and direct sunlight,' says Franks. 'Further daylight analysis confirmed that – for portions of the summer months – direct sunlight would reach down to the concourse level of the station, two storeys below street level, reinforcing a key wayfinding element in the space.'

Artificial lighting

Because of the protracted nature of the project – Arup's involvement began in 2003 – metal halide light sources were specified rather than LEDs. 'Had it been a quicker project, we probably would still have used metal halide since it is much easier to maintain,' says Matt Franks. 'If we used LED, failed fixtures would likely need to be replaced with what's available on the market today, rather than just replacing the lamp.'

Artificial light fittings had to be located very precisely. 'Computer studies determined the aiming of interior lighting for the reflector-net structure and how the qualities of the material impacted illumination,' says Franks. 'By modelling the floodlight aiming in 3D lighting-simulation software – and recording aiming azimuth and altitude angles of each fixture directly onto construction documents – the design team also ensured a smooth installation.' To help with the fixture aiming, the design team created custom-designed brackets with multiple points of adjustment.

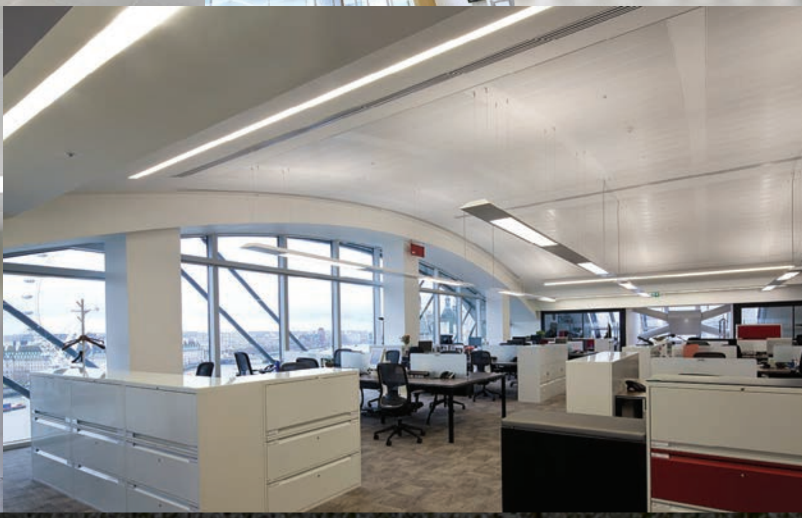
'The result is an even illumination of the interior of the reflector-net, which illuminates the interior of the space with indirect light, providing all of the illumination required in the centre of the space at night,' says Franks.

FUTURE DESIGNS

LED LIGHTING SPECIALIST





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Lighting Guide 7 is an essential manual for anyone designing office lighting. Hoare Lea's **Dominic Meyrick** reviews the publication and considers the changes that have taken place in the sector in the decade since the last guide

DESK RESEARCH

The new Lighting Guide 7 (LG7) is out and its 144 pages are well worth a read. It is twice the length of the original LG7 on office lighting, which was published in 2005 after the demise of LG3 in 2002.

The 2005 LG7 was ambitious in its desire to move the industry away from an obsession with glare on computer screens, pushing the reader to think about the whole lit office environment – particularly walls and ceilings – as well as the illuminance levels on desks.

LG7 2005 helped form the core guidance in the European Standard BS EN 12464-1 Lighting of Work Places, which was revised in 2011. The new LG7 takes the BS guidance further and is now more aligned with BS EN 12464-1 on many key issues.

The most important is the move away from an energy-guzzling, manufacturer-loving (because it means more fittings) uniformity over the total working area of 0.7, to the more environmentally friendly 0.4 – with 0.7 now confined to a specific task area (0.5m x 0.5m) on the desk.

Another positive is that the document mentions lighting design a lot. As a lighting designer this is very good news, and in the text we are told that: 'In some instances, it may be appropriate to have a dedicated lighting designer to provide the design direction' (just 'some' instances?).

It should be remembered, however, that the guides are written to help those for whom lighting engineering is only a part of what they do – who are willing to learn and, for whatever reason, can't afford a lighting designer.

Of course, the new guide is highly technical. This is necessary, but I sometimes

Dublin Yahoo offices by Dlight Lighting

> For many of those who work in an office environment, their workspace is more than just somewhere to carry out a task. The space has to try and meet a number of requirements: to be safe, comfortable, visually stimulating, efficient and productive. Lighting plays a large part in trying to achieve those goals and some of the demands on the lighting installation have changed considerably in the past 10 years
>
> *– Simon Robinson, author of LG7*

feel it gets a little too 'techy', without reference to how lighting design can affect the health and wellbeing of a user. For example, in Section 9 – *Control of lighting* – there is no mention of the fact that light intensity and patterns change the mood in the office environment, although there is a nod to this in Section 8.4, *The Energy balance*, which discusses energy versus well-designed lighting.

Study after study has concluded that allowing individual control of the lit environment – rather than imposing it on office users - is beneficial to user wellbeing.

Both the 2005 and 2015 guidance sing the praises of task lighting. In 2005, the focus was on user satisfaction, while the new LG7 stresses the advantage of task lighting as part of an energy-reduction strategy, where background illuminance – especially with mobile devices unheard of in 2005 – could be as low as 200 lux. The question, however, is why – when it was so enthusiastically discussed in 2005 – has task lighting, accompanied by a background illuminance, failed to take off in standard office environments, despite being much loved in offices where design creatives congregate? Does the new guidance signal a relaunch of this under-used way of lighting in general office environments? I appreciate this is a complex area, but perhaps the next revision might address it in more detail.

Continuing the compare-and-contrast approach, there is a welcome expansion of the guide's coverage of daylight design. This is an enormous area, but the author, Simon Robinson FCIBSE MSLL, valiantly tackles the subject. He builds on the 2005 guidance by including helpful sketches to show typical window configurations, and how daylight can be brought into an interior.

He also recognises the need to introduce a daylight designer early in the architectural process, to ensure that reduction in electrical energy use by daylight harvesting is both meaningful and measurable. Trying to introduce the perfect light spectrum of daylight, as an afterthought, seldom delivers either advantage with any great satisfaction.

LED revolution

However, the most dramatic change during the 10-year period between the two publications is the rise and rise of LEDs, and their influence on the emphasis on glare. In the 2005 guidance, LEDs are not mentioned – not once. So Robinson has done an amazing job of trying to cram the past 10 years of explosive technological change into the document, while being careful not to make statements that may prove obsolete in the next few years – or even months.

This leads me to the new office lighting bogeyman – LED efficacy glare influence. In the past, glare was about veiled reflections on screens from both natural and artificial light. In the new guidance, this has shifted to the potential glare, for users, from the ever-increasing luminous efficacy of LEDs.

As the new LG7 states: 'The introduction of LEDs into mainstream office lighting has brought the issue of glare back to the fore'. And the reason is simple – although LED efficacy is now commonly more than 100lm/W, the area over which that light is emitted – for example, from the ubiquitous 600mm x 600mm square recessed fitting – has not increased. This means that fitting luminance, or the subjective 'brightness', is now a major concern.

I am pleased to report that Robinson has not budged on the perceived wisdom – built up over years of research and anecdotal evidence – that the glare rating for an office is unified glare rating (UGR) 19, although I am sure that some in the manufacturing community chasing a tick-box energy efficiency number would like to move the glare goalposts.

To solve the challenge of what to do with LEDs, the latest ranges of office luminaires have gone retro. These comprise the swinging 1960s-style flat, glowing diffuser panel, which ignores the glare issue altogether and, instead, relies on the user dimming the fitting to an acceptable brightness. More worrying are the luminaires that, through cunning optical control,

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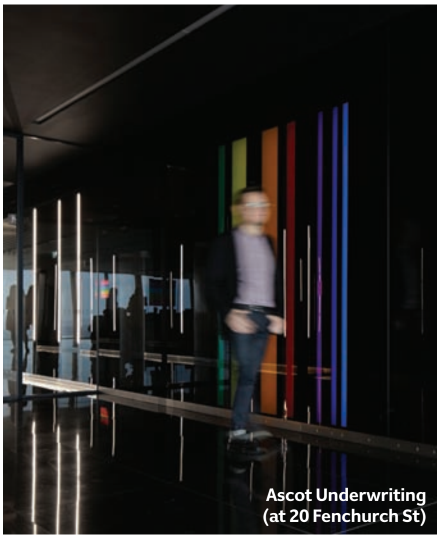
Paul McNulty Lighting Design



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concentrate light on the floor. This allows them to hit the UGR19 value, but at a price – the creation of light patterns reminiscent of the 1990s, the old Cat 2 visual impression of a dark environment with a cave-like ambience. In short, a visual nightmare.

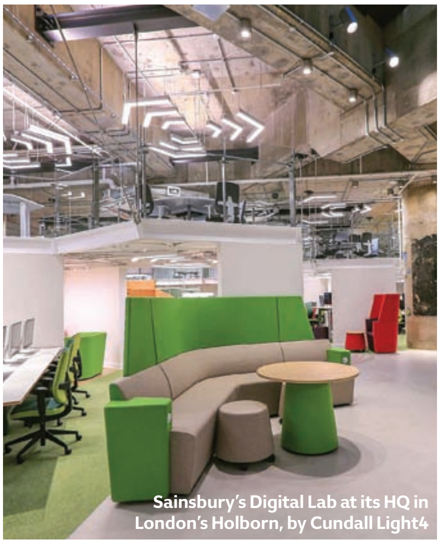
On the plus side again, the 2015 Guide is littered with comments encouraging specific lighting to vertical surfaces and ceiling, to prevent unacceptable contrast ratio. For example: 'Both the general and localised approaches to illumination have to address the need to provide illumination of walls and ceilings.' I take comfort from the fact that Robinson is aware his 'beware of glare' warnings could result in poorly lit environments, and so he encourages the reader not to 'throw the baby out with the bath water'.

As the document mentions frequently, this is particularly important now, as we move towards more face-to-face communication over mobile devices, with cylindrical illuminance and carefully controlled contrast ratio now key.

While I applaud the singling out of LEDs and related glare issues, I am concerned that the new LG7 may inadvertently be ignoring the genie that has already escaped its bottle – that is, poor-quality LED luminaires with mediocre binning, lamps that will colour shift over time, and with dubious light lose maintenance factors (LLMF). However, tackling the issue head on and placing LEDs into a visual environment context – as the guide has done – is far better than giving special dispensation to this new technology by arguing that LEDs represent a paradigm shift in artificial light.

To explain further, there are some who believe that the wisdom of the past should be scrapped and rewritten, as LEDs are – they believe – a 'destructive' technology, destroying all other artificial light sources.


Yahoo offices by Dlight Lighting


Sainsbury's Digital Lab at its HQ in London's Holborn, by Cundall Light4

These are mainly manufacturers that only make LED products and have no legacy products in more established lamp technologies.

Fortunately, the author has not been swayed by this argument and, in LG7's foreword, emphasises that technical requirements should not be achieved at the expense of the user. This should always be the key driver for any lighting guidance, and LEDs should not be treated differently – they are a lamp, like any other artificial light source.

The future

I do wonder, by following Illuminance and luminance recommendations slavishly, whether we create spaces in which people actually want to work? Note the word 'want' rather than 'have'. But let us wait and see where the next 10 years of advances in understanding of our visual system – and how we actually see – take us.

I would love the next edition to have even more images; in fact, loads more pictures and diagrams, as explaining some issues requires 'showing' – and, with more pictures, the word count might come down. Perhaps any future guides should aspire to create a design bible – something beautiful to behold, packed with information and with exceptional imagery. But well done to the author of the 2015 version. It has addressed important lighting design and engineering issues, and represents a valiant attempt at explaining complex areas – especially difficult in a time of rapid change. I am sure this updated document will prove a useful addition to the industry.

● *Lighting Guide 7: Offices*, by Simon Robinson FCIBSE MSLL, is available at no cost as a member benefit at **www.cibse.org/Knowledge/CIBSE-LG/Lighting-Guide-07-Offices-NEW-2015**

● **DOMINIC MEYRICK** is a partner at Hoare Lea Lighting

Key areas of revision and new guidance in LG7:

- A new chapter on the approach to design
- A greater emphasis on energy use and how to get the best out of lighting designs, while being mindful of the need to reduce energy use
- A revision to guidance on how to approach speculative offices
- Guidance on how to deal with the 'hot desk' approach to office use
- A new chapter discussing the interaction with mechanical systems and their effect on lamp colour and efficiency
- Guidance for new and refurbishment projects
- How to approach cylindrical illuminance and the application of modelling ratios
- A new chapter on how to deal with tablets and touchscreen use in offices
- A new chapter that gives some practical examples of how lighting could be considered for an office space

FACTS OF LIFI

Using light waves to carry data has the potential to transform the telecommunications industry. Professor **Harald Haas**, who coined the term LiFi, examines the technology and outlines its implications for LED lighting and broadband communication

Have you ever gone to a meeting or to a site visit without your mobile phone? The chances are that you quickly returned to your office to get it, or felt frustrated and at a loss without it. When the first mobile phones came out, their main service was simply telephony. Now, a mobile phone is a personal computer that we use for a wide range of business and social functions. We all consider wireless communication and connectivity a necessity.

This means we send a lot of data through cellular networks. With an estimated seven billion mobile phones on the planet – more than the world's population – it is estimated that every day, worldwide, we send 500 petabytes of data – that's five with 17 zeros. This ever-increasing demand is a technical challenge for our mobile and wireless communication systems.

Technical challenges

One issue is the sheer amount of energy needed to run mobile phones. Although this is low for a single handset, the combination of billions of phones and the running and maintenance of communication networks and base stations means that the total daily energy requirements are very high.

A major challenge is the limited availability of the radio frequency (RF) spectrum – as shown in the frequency allocation chart, there are virtually no wavelengths (white spaces) available for public use. This has been termed the 'spectrum crunch'. The RF spectrum is cluttered, scarce and expensive.

Ten years ago, I looked at the entire electromagnetic spectrum, which includes light waves, infrared, gamma rays and x-rays, as well as radio waves. I concluded that the visible light spectrum is huge (around 300THz is available: 430-770 THz), unregulated (free), secure and safe. We have developed new electronic systems – microchips and printed circuit boards (PCBs) – and turned off-the-shelf LED sources into high-speed communication devices that will form a new layer of wireless networking, otherwise known as LiFi.

LiFi technology

LiFi is a term first coined in my 2011 TED Talk, when it was demonstrated in public for the first time.

Using light waves instead of RF to deliver data, LiFi provides 10,000 times more bandwidth. It is a bi-directional, networked, mobile, high-speed data communication technology that complements WiFi, and has the key benefits of greater capacity, security and energy efficiency.

With LiFi technology embedded, LEDs are transmitters, and photo detectors – such as in your mobile device – are receivers. These are inexpensive, already in common use and have existing infrastructures, avoiding the need for thousands of base-station masts. If street lighting columns were fitted with LED sources, for example, they could provide the next 5G and 6G networks.

How LiFi works

LEDs are based on electroluminescence, whereby certain materials emit light when electricity is applied. LEDs are illuminated by the movement of electrons in a semiconductor material, such as aluminum-gallium-arsenide (AlGaAs) and gallium nitride (GaN). The light emits from the p-n junction of the diode.

LiFi modulates the changes in the intensity of light to communicate data – mathematical algorithms are used to enable encoding of '0s' and '1s' into subtle changes of the intensity of light of an LED. This is done at very high speeds of more than 100 million times a second. At the receiver, algorithms convert the signal into the same binary data stream.

In the Optima Lab at the LiFi Research and Development Centre, transmission speeds of 3.5Gbit/sec at 2m distance, and real-time video streaming at 1.1Gbit/sec at 10m distance, have been demonstrated. This is almost twice as fast as current WiFi systems.

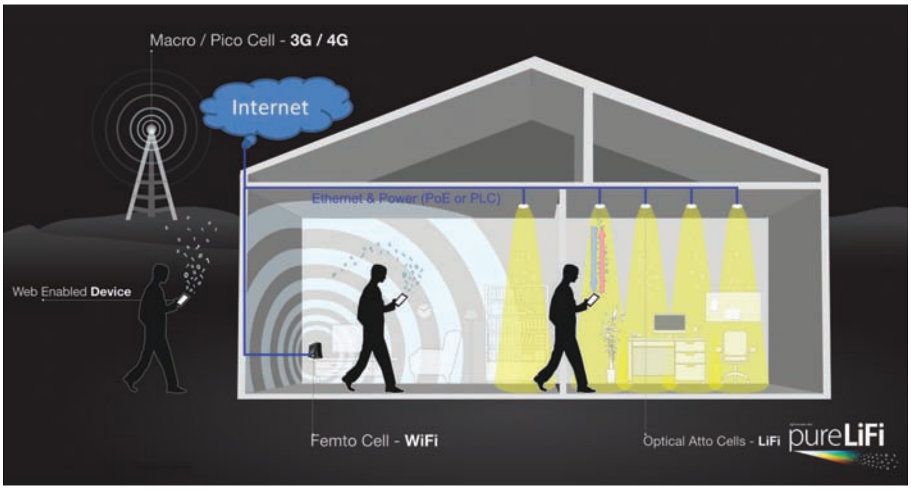
Optical attocell networks – the next step

With a LiFi chip integrated, an LED luminaire in a ceiling becomes a LiFi access point, and

> In the future, luminaires will be replaced because of the new functions and not because they are worn out – rather like smartphone upgrades today

LIFI RESEARCH AND DEVELOPMENT CENTRE

The LiFi Research and Development Centre at the University of Edinburgh undertakes research, promotes knowledge exchange with the global LiFi community, and operates a Flexible Open Collaboration model with partners to develop LiFi products and new spin-out companies.



Users will soon be able to access the internet via LiFi as well as through WiFi hotspots at home and outdoors

all LiFi access points together form an optical attocell network. The optical access points are programmed for multi-user access and signal handover, giving connectivity similar to a 5G base station. In heterogeneous networks, this would enhance the area data rate (the number of bits per second per square metre) by three orders of magnitude compared to what is currently available with RF systems only.

We are currently developing new systems to manage dynamic handover and resource sharing in hybrid LiFi/WiFi networks. This will overcome the problem experienced in airports, shopping centres or museums when you cannot get a signal. In the future, for example, geo-location systems in buildings could use hybrid networks.

Light as a service

Light sources today serve one purpose: lighting. In the next five years, LED sources will become smart-sensing and high-speed communication devices. They will be an integral part of emerging smart buildings and the Internet of Things (IoT), where Light as a Service (LaaS) will be a dominating theme. LiFi will be 'pulled' into the lighting industry by new business models. In the future, luminaires will be replaced because of the new functions and not because they are worn out – rather like smartphone upgrades today.

Applications

LiFi is particularly appropriate for environments where WiFi is unsuitable or where it does not provide enough capacity to meet increasing demands. Examples of these initial markets include:

- Places where secure data exchange is of paramount importance, such as in hospitals, company headquarters, and homeland security agencies
- Modern factories where the operation of tools and machines requires constant and reliable connection to central computer servers (an example of IoT in operational buildings)
- Intrinsically safe environments such as refineries, oil platforms or petrol stations where electromagnetic radiation from the antennae of RF communication systems could spark explosions

The connected solar panel

In my TEDGlobal 2015 talk, we showed that off-the-shelf, 30cm x 30cm solar cells can be used to receive data speeds of up to 15 Mbps. This new technology means that solar panels on buildings can be adapted to be used for mobile wireless communication, thereby greatly improving the energy sustainability of buildings. This will also give the many millions of people and rural communities throughout the world – who don't have infrastructures for electric power or for the internet – to have sustainable access to information for the first time.

Emerging industry

LiFi could have a huge impact on our everyday lives, and independent market research has forecast that it will be a $6bn industry by 2018. The lighting sector is redefining itself as a result of LEDs, which have a 20 times longer lifespan than incandescent lamps. Old business models are ceasing to exist, creating a huge opportunity for LiFi.

- To view Harald Haas's original 2011 Ted Talk visit **http://bit.ly/tedvlc**

ABOUT THE AUTHOR

Harald Haas, chair of mobile communications at the University of Edinburgh, holds 26 patents and 20 pending patent applications. His book, *Principles of LED Light Communications: Towards Networked LiFi*, was published by Cambridge University Press in 2015. In 2014, he was selected by the Engineering and Physical Sciences Research Council as one of 10 RISE (Recognising Inspirational Scientists and Engineers) Leaders. LiFi was listed as one of the 50 best inventions in *Time* magazine in 2011.

Paris showcase for first fully industrialised LiFi luminaire

One University of Edinburgh spin-out company is pureLiFi, which was set up in 2012 and launched its first product – Li-1st – in 2013, and Li-Flame in 2015. It designs, develops and delivers LiFi solutions for original equipment manufacturer (OEM) companies, and has international partnerships with organisations such as Cisco, Rolls-Royce and Independence Blue Cross.

It has now linked up with French LED lighting company Lucibel to produce the first fully industrialised LiFi luminaire. This off-the-shelf product integrates the pureLiFi access point into a single Lucibel luminaire, cutting installation costs for lighting and communications. The first installation will be at the Paris headquarters of property developer Sogeprom, a subsidiary of Societe General.

Li-1st is the first commercially available, high-speed, bi-directional LiFi system, offering 5Mbps download and upload speeds. Rather than being a mass-market product, its aim is to create future partnerships

First demonstrated at the Mobile World Congress in Barcelona, in 2015, Li-Flame is the first fully networked LiFi system, capable of transmitting to multiple users at the same time, and is in the process of being miniaturised.

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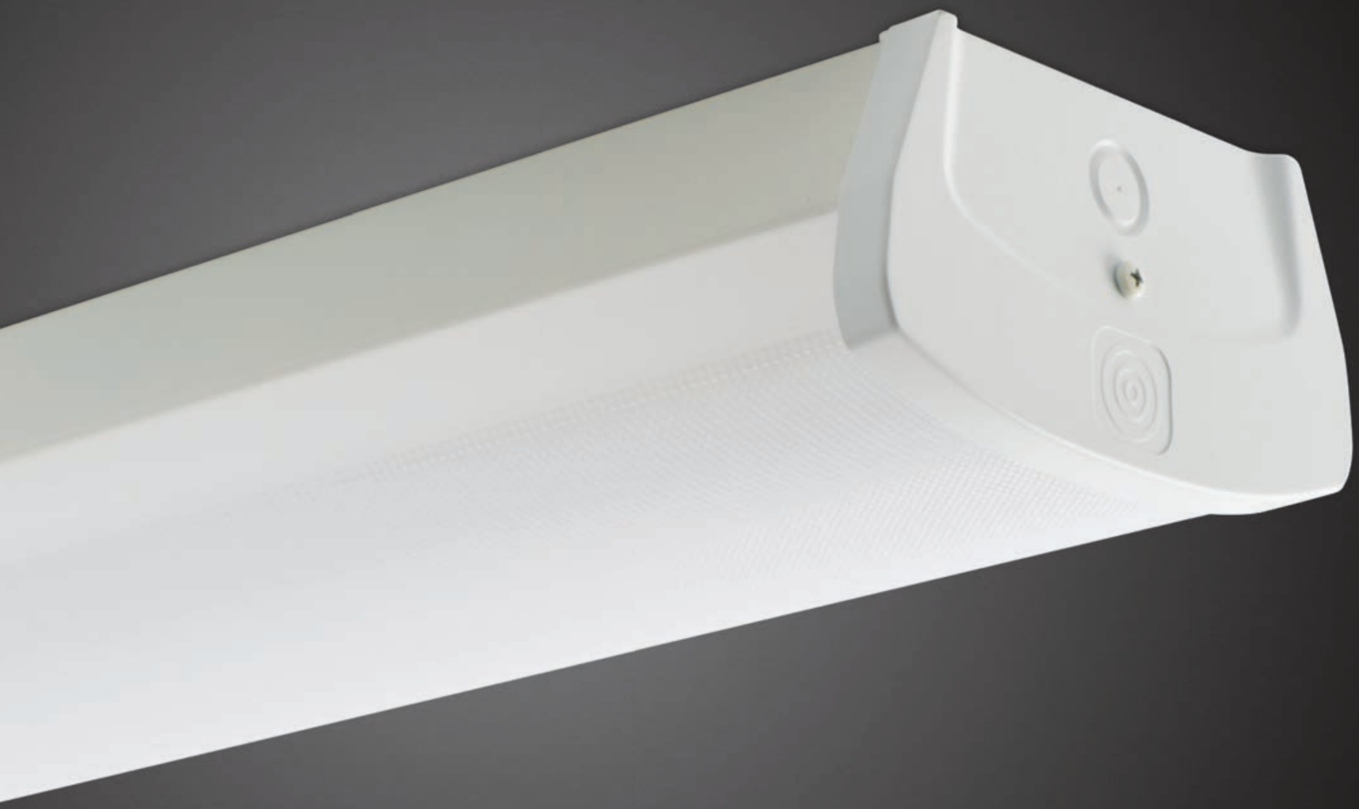

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The radical difference that various light sources can have on the colours of objects and materials

CREDIT: ANDREJ ŽÚREK, SLE SMART LIGHTING ENGINEERING

Another new metric has been mooted as a replacement for the flawed colour rendering index. **Peter Raynham** explains how TM-30 works and gives an initial verdict

GETTING THE MEASURE OF COLOUR

The Illuminating Engineering Society (IES) in the US has published a new Technical Memorandum, *TM-30 Method for Evaluating Light Source Color Rendition*. The colour properties of light sources and how they can best be measured – especially with regards to solid-state technology – is the subject of ongoing research, analysis and discussion at the International Commission on Illumination (CIE), the body responsible for sanctioning lighting metrics.

The consensus is that the current CIE metric – the Colour Rendering Index (CRI), which has been around for some decades – does not measure up, especially where LEDs are concerned.

'The CRI is generally not applicable to predict the colour rendering rank order of a set of light sources when white LED light sources are involved in this set,' said a 2007 CIE technical report, *Colour Rendering of White LED Light Sources*. The question is, what will replace it?

A promising new metric, the Colour Quality Scale (CQS) – devised by researchers Wendy Davis and Yoshi Ohno, at the National Institute of Standards and Technology in the US – emerged some years ago, but was given the thumbs down by the CIE.

So the current discussion in the lighting world is about whether TM-30 will catch on, or suffer the same fate as the CQS. To answer this question fully, we are probably going to have to wait a few years. In the meantime, what is this new metric and what differentiates it from other proposals?

TM-30 sets out two basic metrics of colour quality for light sources. One is a potential replacement for the existing CRI metric and the other gives an indication of the change in colour gamut associated with a particular light source. These metrics are referred to as Rf and Rg – the 'f' stands for colour fidelity and the 'g' for colour gamut.

The calculations involved are, in many ways, similar to those used for the CRI system and, in general, the main changes increase the complexity. The basic principle is to evaluate the colour of a series of colour samples when illuminated first by a test source and then by a reference source, assess the colour differences, and then use the values to evaluate a quality metric.

The first change is the selection of reference source. With CRI, if the correlated colour temperature (CCT) of the test source is less then 5,000K then the reference source is a Planckian radiator; if the CCT is higher, it's a constructed phase of daylight – a CIE Daylight (D) series illuminant. TM-30 uses a sliding changeover between Planckian and daylight between 4,500K and 5,500K, which means the proportions of the two references that inform the calculation vary over this range.

What is colour rendering?

According to *CIE 17.4, International Lighting Vocabulary*, colour rendering is defined as the 'effect of an illuminant on the colour appearance of objects by conscious or unconscious comparison with their colour appearance under a reference illuminant'. In other words, the Colour Rendering Index (CRI) is a measure of how well – that is, how realistically or naturally – light sources render the colours of objects, materials and skin tones. This is measured in Ra values. With a scale maximum of Ra100 (incandescent/halogen), Ra80 is regarded as the minimum for good quality lighting.

The next big difference between the two systems is in the colour sensitivity functions associated with colorimetric observers. The CRI formula uses the two-degree observer to define the standard 1931 chromaticity. However, TM-30 uses the CIE 10-degree observer.

The next stage compares the appearance of the series of colour samples when illuminated by both the test and reference sources. There are two differences in this part of the process compared with the existing calculation of CRI.

First, the system uses 99 colour samples – as opposed to the eight pastel shades with CRI – and, second, the colour difference formulae are different and rely on the CIECAM02 colour space as defined by *CIE 159: 2004 A Colour Appearance Model for Colour Management Systems*. The colour difference is then averaged, scaled and subtracted from 100 to give the Rf, which is a number between 0 and 100 that represents the colour fidelity of the source, just like the Ra value of the CRI system.

The gamut area of the test colours under the reference source is then compared to the area of the colours under the test source. This process would normally involve the calculation of the area of a 99-sided polygon. So for a slight 'simplification', colour samples are grouped into 16 clusters according to their hue angle and then averaged, so it is only necessary to calculate the area of a 16-sided polygon.

It is also possible to show this process diagrammatically. Figure 1 shows the gamut calculation for a high-pressure sodium (HPS) lamp. The white line joins the average colour points for the samples illuminated with the reference lamp (full radiator with temperature of 1,841K). The black line joins the averages of the point illuminated by the HPS lamp and the arrows indicate the degree of colour shift. In this example, the HPS lamp has an Rf value of 27 and an Rg value of 57. This is quite a good score for a lamp that has an Ra of 12.

So TM-30 has defined two new colour metrics and the maths to calculate them, but is this a real step forward in the quest for a better set of metrics in this area? The sliding crossover between full radiator and daylight for the reference source has removed an anomaly in the current system, and the introduction of a colour gamut metric is a good idea. The use of CIECAM02 to calculate colour difference is also an improvement.

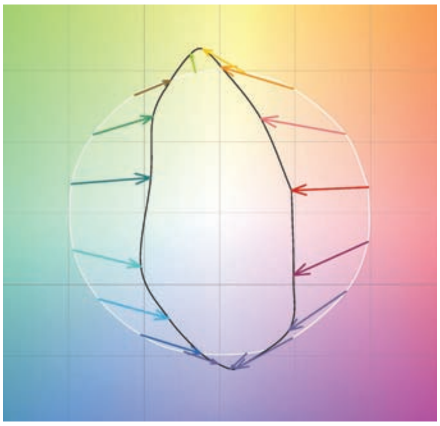

Figure 1: Gamut calculation for a HPS lamp

However, CIECAM02 was designed for use with colour functions derived with the two-degree observer functions and not 10-degree functions, so there is some uncertainty in the results. What's more, it is not clear what was gained by the use of the 10-degree observer. The value of using 99 colour samples also has to be questioned. Why 99, and why group them into 16 bins for the gamut calculation?

The final question is whether the numbers generated are more meaningful than the conventional Ra system? Table 1 gives CCT, Ra, Rf and Rg values of a few common lamp types.

Two CIE technical committees – one looking at colour fidelity metrics, the other at colour preference metrics – are currently studying this area, and TM-30 will form part of their remit. They are scheduled to report in 2016. However, the CIE has emphasised that the replacement for CRI, whatever it is, must gain formal international agreement.

> The consensus is that the Colour Rendering Index does not measure up, especially where LEDs are concerned

'New metrics introduced at the regional level could cause confusion in the global lighting market,' it says in its October response to the proposed metric.

● Visit this article at **www.cibsejournal.com** to see the CIE Position Statement on CRI and Colour Quality Metrics (October 2015)

Colour rendering values for different units in common lamps

Lamp type	CCT [K]	Ra	Rf	Rg
SON	1,837	13	27	57
White SON	2,419	82	79	105
Cosmo	2,716	60	64	87
TL 84	4,155	78	76	97
High spec LED	2,981	97	97	100

Table 1: CCT, Ra, Rf and Rg values of common lamp types

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Hybrid lighting, sustainability and wellbeing

This module explores the evolution of lighting systems and the impact of hybrid systems on the built environment and energy costs

Hybrid lighting systems enable the use of available natural daylight, supplementing it with artificial light to meet the required level of room illumination. The intensity, quality and availability of light have been shown in numerous studies[1] to have pervasive impacts on health and wellbeing of people, flora and fauna, so is intrinsically linked to the 'sustainability' of the human environment. As well as the financial prerogative to use more effective lighting, there is a growing responsibility to design increasingly sustainable lit environments. This article will consider the evolution of lighting systems and how hybrid lighting may create opportunities to meet the natural requirements of humans, improving the productivity and effectiveness of the built environment while reducing energy costs.

Environmental and financial imperatives have driven the need to improve the underlying technology and methods that provide lighting to the built environment. Concerns about environmental quality and waste disposal have led to increasing interest in efficiency and quality. It is often reported[2,3,4] that people are now spending more time indoors, both at home and at work. Increased information-based economic activity has been one factor driving this trend, and this requires improved illumination that not only enables effective working, but also contributes to wellbeing – particularly in the absence of accessible windows and daylight.

The evolution of general-purpose lighting for the internal built environment

The sun, of course, provides the prime source of light that supports almost all life on Earth, via photosynthesis, while driving the planet's climate and weather. As a free light source, it is not only guaranteed, but also provides psychological and physiological benefits.[5] Based on CIBSE's SLL LG10[6], benefits of daylight may be summarised as:

- Exposure to light during daylight hours provides essential regulation of the circadian system (or 'body clock')
- Natural light helps facilitate healthy sleep duration and quality, as well as improving task performance during the waking hours
- The connection to the outside world it provides is beneficial to building occupants
- Exposure to natural sunlight can moderate some psychological illnesses, such as seasonal affective disorder (SAD)
- Sunlight enables the human body to synthesise vitamin D.

However, exposure to the sun's light can also have deleterious effects, both in health terms (principally due to the ultra-violet (UV) component) and in 'ageing' materials. Overall, though, daylight is undoubtedly beneficial. Unfortunately, it is only available for limited periods and, in the core of buildings, sometimes never available.

Modern lighting emerged in 1802, when Humphry Davy created the first **incandescent light**, but it was not until 1879 that Thomas Edison developed the first commercially practical incandescent lamp. Incandescent lamps consist of a sealed glass enclosure (the 'bulb') containing inert gas, with a filament of tungsten wire inside the bulb. Until very recently, this general lighting service (GLS) 'bulb' has been the basis for many people's perception of illuminated colour and, indeed, it has a colour rendering index (Ra) of 100 – the maximum value. Ra provides a quantitative measure of the ability of a light source to reveal the colours of various objects faithfully in comparison with an ideal, – or natural – light source. The incandescent lamp is not very efficient, as it produces a significant amount of heat, and only a very small fraction of the electrical energy is converted to light.[7] A typical luminous efficacy would be between 3 and 20 lm/W. Incandescent lamps emit UV light that can be partly reduced by the glass enclosure, and typically have a working life of around 1,000 hours.

The **halogen lamp** is an evolution of the incandescent lamp, with a tungsten filament sealed in with an inert gas 'doped' with a halogen. The earliest commercial lamps, called quartz iodine lamps, were launched by General Electric in 1959. Modern versions of these type of lamps have an efficacy of 10-25lm/W, and give light at a higher temperature, compared with a non-halogen incandescent lamp, operating at very high temperature. These relatively cheap lamps potentially emit high amounts of UV and have a lifetime of around 2,000 hours.

The **compact fluorescent lamp** (CFL) was invented by Ed Hammer, an engineer with General Electric, in response to the 1973 oil crisis. Today's CFLs are cheap to purchase and energy efficient, at 45-75 lm/W, but typically have poor colour rendering. There are also increasing environmental concerns about their mercury content. Their lifetime is typically between 4,000 and 8,000 hours, and they produce significant amounts of UV light.

The first light-emitting diodes (**LEDs**) were made in 1971 by Jacques Pankove (inventor of the gallium nitride LED) at RCA Laboratories. Dramatic improvements in efficiency and form have been made in the past couple of years so LED lamps that appear almost identical to traditional GLS 'bulbs' are available with a colour rendering index of more than 80. Practical lifetimes are in the order of 15,000 hours, with a lamp efficacy of 75 lm/W – which, theoretically, could rise much higher. They emit little heat and have no UV output and, unlike CFLs, contain no mercury. Many LED-based products now available can be controlled to alter their colour and output.

Natural daylighting

Natural daylighting systems (as in Figure 1) collect, channel and distribute natural daylight from the external space to indoor environments that cannot directly use daylight from windows. The routes for the sunlight can be fabricated as part of the building construction, using surfaces with light colours or reflective materials to reflect and channel the otherwise inaccessible sunlight into the occupied space.

Often, 'off the shelf' systems providing greater amounts of daylight – typically known as 'lightpipes' or 'Sunpipes' (a proprietary name) – are used. These are tubes with a highly reflective inner surface that allows effective transmission of diffuse daylight to the internal space.

Figure 1: The dome allowing light to enter the lightpipe (Source: Monodraught)

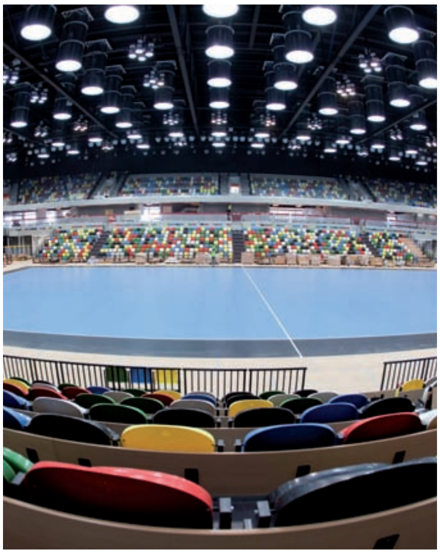


Figure 2: Olympic handball arena in London featuring lightpipes in the roof (Source: Monodraught)

Figure 3: Falconry Centre in Dubai (Source: Monodraught)

These have been applied in many installations – for example, residential spaces, schools, supermarkets, hospitals, warehouses, airports, Olympic arenas (such as that shown in Figure 2) and huge specialised falconry centres in the Middle East (Figure 3). There have been many research projects in the education sector that have linked daylighting with increased achievement rates, health and attendance. Many classrooms are predominantly lit using large vertical windows at the back of the room. By applying natural daylighting systems, a classroom can be supplied with 300% more daylight[8], while also reducing the lighting energy cost significantly.

In healthcare applications, natural daylighting systems can offer a payback period of five to six years[8], while also reducing the likelihood of SAD. In retail stores, various studies[9,10] have indicated that natural daylight is positively and significantly correlated to higher sales. With the addition of natural daylighting, an average non-daylit, retail, monitored[10] chain store recorded 40% higher sales.

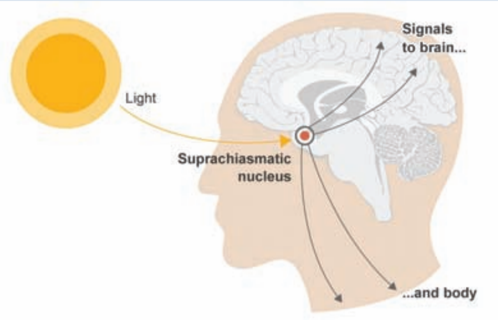
Productivity in offices served by natural daylighting systems has also been shown to increase, with a 20% rise in output from employees – along with reduced absenteeism because of sickness.[11] It is thought that natural daylighting systems may reduce the incidence of sick building syndrome (SBS).

Natural daylighting systems are often added as part of a refurbishment scheme to improve lighting quality and reduce energy costs. They have a lifetime that is likely to exceed 25 years, provide UV-free healthy natural daylight and – particularly if they are sealed (with lenses/lighting diffusers) – require little maintenance or control. They will, however, only supply light in daylight hours.

Circadian lighting

Circadian lighting is a strategy that considers the circadian rhythm (see boxout). Circadian lighting systems are designed to be able to control the colour and intensity of the light at particular times, with feedback from the illuminated space. For example, blue wavelengths are beneficial during daylight hours because they boost attention, reaction times and mood, but appear to be disruptive at night[13]. So as part of a control regime, the 'blue light' could be controlled throughout the day to transition from a stimulating 'biological light'(with maximum blue content) to a restful 'biological darkness' (with little or no blue content).

Circadian rhythm



(Source: PhotonStar – www.photonstarlighting.co.uk)

The biological processes that regulate the sleep-wake cycle make up the human circadian system. Nearly every cell of the body has a daily rhythm and 'clock' controlling it. The suprachiasmatic nucleus – or pair of nuclei – (SCN) in the brain acts as the master clock, synchronising the body's functions. It roughly follows a 24-hour pattern, and light is fundamental to driving the cycle. Cells in the eye respond to light and keep the SCN in tune with external environments. It also stops the sleep hormone melatonin being made during the day.[12]

The discovery of a novel retinal photoreceptor in the human eye and the photo pigment melanopsin has renewed the attention paid to circadian research, and has drawn substantial interest from the lighting community. The phase of the circadian rhythm can be advanced or delayed by exposure to bright light at specific times. Failure to entrain the circadian pacemaker results in sleep disorders, fatigue, performance problems, hormone and metabolic disorders.

But the circadian system is only the most well-explored of the non-visual effects of light on human physiology and, hence, on human performance. There are known to be other effects of light exposure, such as increased vitality during the day, but the mechanisms through which these effects occur are unknown.[12]

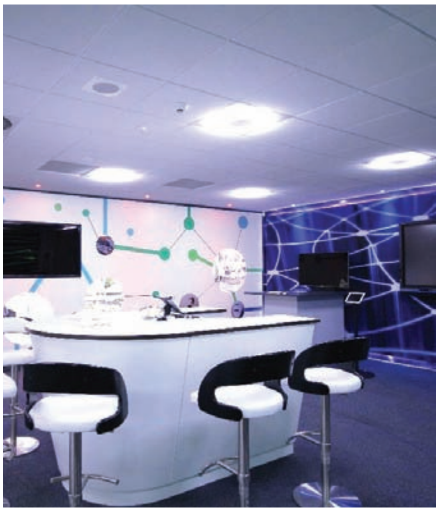


Figure 4: IBM Innovation Centre Laboratory that employs circadian lighting solutions together with a wireless control system (Source: PhotonStar – www.photonstarlighting.co.uk)

Hybrid lighting systems

Hybrid lighting systems combine natural daylighting systems with energy efficient and 'intelligent' LED lighting solutions. It is thought that hybrid lighting systems designed for circadian lighting in industrial and commercial working environments can reduce daytime artificial light by 50%. By combining natural light and artificial sources currently available – potentially applying centralised, high-efficiency light sources – energy costs for lighting could be reduced significantly. Well-designed hybrid lighting may be optimised for humans, providing effective floor, wall and ceiling illumination to reduce the 'cave effect' (where lighting systems focus light, resulting in some dark surfaces). They can readily meet both LG7 and UGR19 recommended guidelines for offices – the unified glare rating (UGR) expresses the chance of direct glare by a luminaire; the higher the figure, the greater the chance of glare, with UGR19 the appropriate level for an office.

So, for the example shown in Figure 4, during daylight hours a lightpipe collects sunlight through a clear dome, directing it through a mirror-finished aluminium tube and distributing it evenly through a ceiling diffuser. This is coupled with a wirelessly controlled, colour-adaptive LED lighting system, using an 'intelligent' monitoring system. The complete lighting solution can be applied to practically any location to meet required lighting performance, with the adaptive LED lamps ensuring that lighting levels, colour and quality are maintained. The system may adjust the lighting to suit circadian needs – or, indeed, any particular demands for activities (or flora and fauna) within the space. This type of hybrid system can substantially increase the real product life of the active light systems and reduce energy consumption. Compared with a totally active lighting system, there will, of course, be additional builders' work and installation costs. A life-cycle cost analysis should be undertaken taking proper account of potential productivity gains from increased daylight, as well as the likely maintenance costs, which are likely to be lower with hybrid systems.

Figure 5: A hybrid lighting system

Hybrid lighting systems have been developed to take account of real-world applications and take 'smart lighting' to the next level by adding circadian controls to the more traditional on-off and dimmable controls. However, when considering such applications, the designer has to ensure that they are able to satisfy the demands of circadian rhythms properly – by being able to predict the integration of active lighting and daylight – while properly assessing the life-cycle costs.

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Turn over page to complete module

Module 88
December 2015

1. When considering the attributes of daylight, which of these statements is least likely to be true?

☐ A It can moderate some psychological illnesses
☐ B It enables the human body to synthesise vitamin D
☐ C It generally improves task performance
☐ D It has low UV content, unlike LED lamps
☐ E It acts to regulate the circadian system

2. Which of these efficacies is likely to apply to currently available LED 'GLS' lamps, as discussed in the article?

☐ A 25lm/W
☐ B 50lm/W
☐ C 75lm/W
☐ D 100lm/W
☐ E 125lm/W

3. When applying natural daylighting systems in buildings, which of these is likely to increase?

☐ A The likelihood of SAD
☐ B Lighting energy cost
☐ C Productivity
☐ D Absenteeism
☐ E Maintenance requirements

4. What potential reduction in daytime artificial light in commercial buildings is thought to be achievable when using systems designed on circadian principles?

☐ A 10%
☐ B 30%
☐ C 50%
☐ D 70%
☐ E 90%

5. Which predominant colour should be moderated to improve night-time wellbeing in resting humans?

☐ A Red
☐ B Orange
☐ C Yellow
☐ D Green
☐ E Blue

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Advanced glass optic is heart of Venture's new LED retrofit street lighting

Venture Lighting Europe has created a new, advanced retrofit LED solution for street lighting, with benefits for local authorities. The company has created the VLED Westminster module, incorporating its latest lighting technology – Suprax glass optic – as a retrofit solution for street lighting luminaires.

The innovation, which offers councils the ability to extend the life of their street lighting to 100,000 hours, can be retrofitted to almost any existing luminaire. With improved energy consumption, Venture's module will also significantly reduce energy costs across the whole lighting scheme.

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Tamlite's highly skilled and knowledgeable team provides solutions across a range of industries. Regardless of the application or its complexity, there is a 100 per cent commitment to meet the exacting requirements of a particular sector or type of organisation. As the 'eyes and ears' of the company across the UK, the team's everyday dialogue and interaction with clients is vital and helps to shape Tamlite's research and product development activities. This keeps the company at the forefront of new designs and the latest industry guidelines.

As well as its own in-house testing laboratory, Tamlite offers the full design service that you would expect from one of the UK's largest lighting manufacturers. Despite its large size, the company has also established itself as an expert in bespoke solutions, providing an industry-leading response time from initial concept to delivery.

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