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Milan in Italy replaced sodium street lighting with blue-rich white LED sources. City-centre illumination now looks brighter and bluer than in the suburbs.

Make lighting healthier

Artificial illumination can stop us sleeping and make us ill. We need fresh strategies and technologies, argues **Karolina M. Zielinska-Dabkowska**.

Life on Earth evolved in day-and-night cycles. Plants and animals, including insects such as the fruit fly, have a biological clock that controls their circadian rhythms — as the 2017 winners of the Nobel Prize in Physiology or Medicine showed. Now, humans' increasing reliance on artificial lighting is changing those rhythms[1].

For more than a century, incandescent light sources served us well. These bulbs were cheap to produce and dispose of, and easy to dim. Their spectrum is continuous and includes most of the colours of the rainbow, much like a sunset (see 'Light-source spectra'). They had their problems. In the 1990s, some researchers blamed electric illumination for changing our sleeping patterns from the natural rhythm of two four-hour phases broken by an hour of wakefulness, to a single eight-hour phase each night. Incandescent lamps are energy hungry and policymakers worried about their contribution to global warming. In 2005, lighting consumed around one-fifth of the world's energy.

In 2009, the European Commission began to withdraw incandescent lamps from the European market. Other countries followed, from Switzerland and Australia to Russia, the United States and China. Low-energy lamps — at first mainly compact fluorescent lamps (CFLs) and later light-emitting diodes (LEDs) — have been promoted as replacements. The health risks this policy poses to humans, animals and plants have yet to be thoroughly assessed.

As a lighting researcher and designer, I am convinced that the costs of this transition far outweigh the benefits for human health and the environment. Because the world's urban population spends more time indoors under artificial lighting than in daylight, the health impacts are already evident. Around one billion people globally lack vitamin D or do not have enough[2]. Seasonal affective disorder, a type of depression that can occur in winter when there is less natural daylight, is on the rise. Shift workers face increased risks of cancer[3], obesity[4] and sleep problems[5].

Biologically benign forms of energy-efficient lighting are needed. I call on physicists, engineers, medical experts, biologists and designers to develop them. Policymakers, planners and regulators should rethink standards, encourage the use of natural light and minimize the negative impacts of artificial lighting at night, indoors and out.

SPIKY SPECTRA

In my view, there is now enough evidence to conclude that the first wave of low-energy light sources is harmful. CFLs are most hazardous. They contain mercury, a neurotoxin. There are no protocols for recycling or disposing of them — 80% are thrown into landfill. Ultraviolet light can escape from defective tube coatings to burn skin or

damage the retina at close range; the US Food and Drug Administration recommends coming no nearer than 30 centimetres to a CFL for more than an hour a day.

CFLs have 'spiky' rather than smooth spectra: they emit only certain blue, green and orange-red frequencies (see 'Light-source spectra'). Their flickering at 100–120 hertz can cause headaches and eye fatigue[6]. The energy savings may be overestimated — CFLs take minutes to warm up, so are likely to be left on for longer. When switched on and off many times, they fail more quickly.

Solid-state lighting in the form of LEDs is more promising. LEDs do not contain mercury and produce only a small amount of UV (compared to CFLs or even incandescent lamps). They are more energy efficient, brighter and more long-lived than CFLs. Unlike CFLs, they can be dimmed or tuned and render colours well. But LEDs have downsides[7]. Some contain heavy metals such as nickel, lead and copper, and poisons such as arsenic. Again, there are no special programmes for recycling or disposing of them. Poor-quality LEDs can also flicker and produce stroboscopic effects, such as trails of lights that can confuse pedestrians, cyclists or car drivers.

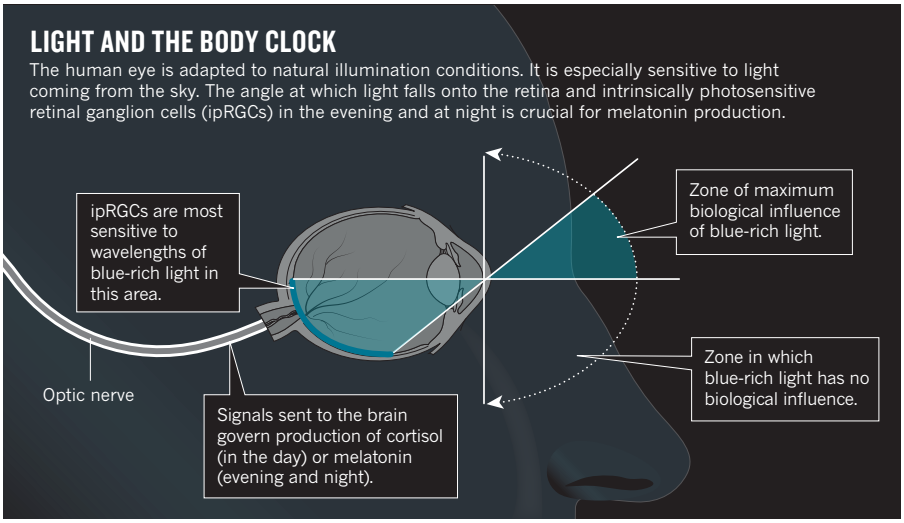
The lighting industry is beginning to address the lack of daylight in indoor spaces. In recent years, it has promoted artificial, biologically effective lighting in office and home environments, known as human-centric or circadian lighting. This promises to adjust people's daily rhythms in indoor spaces, using LED colour-changing lights that mimic daylight according to the time of the day. The German Commission for Occupational Health and Safety and Standardization (KAN) has issued concerns regarding these practices. The risks of adverse effects remain, because there is still too little understanding of the link between light stimuli and non-visual responses. Research is needed to find out more and to firm up standards accordingly.

BLUE PROBLEM

In the meantime, artificial lighting is in my view becoming a public-health hazard. CFLs and LEDs emit more blue light of short wavelengths than a sunset or an incandescent lamp does (see 'Light-source spectra'). Most white LED lamps are made by coating blue or sometimes violet LEDs with yellow pigment, usually phosphor.

The human circadian system is exquisitely sensitive to the spectrum of light visible to the eye, especially blue wavelengths, and its amount and intensity (see 'Light and the body clock'). As well as rod and cone receptors used for vision, the eye contains cells called intrinsically photosensitive retinal ganglion cells (ipRGCs). These send signals to the brain that trigger the body to produce or inhibit neurotransmitters and hormones

CLAIRE WELSH/*NATURE*



throughout the day[8]. The spectral sensitivity of melanopsin, the photopigment of ipRGCs, reaches maximum absorbance at approximately 480 nanometres, matching the colour of a clear blue sky at noon.

In the morning, waking is helped by blue wavelengths of daylight triggering releases of the neurotransmitters serotonin and dopamine and the hormone cortisol. In the evening, as natural levels of blue light drop and are replaced by dim red light, melatonin hormone is produced and helps us to fall asleep. Complete darkness is needed at night to initiate processes of cell renewal.

> ***"Healthy lighting design is becoming an important ethical issue that cannot be ignored."***

When people are subjected to artificial blue-rich white light at night, from screens and electronic devices as well as artificial illumination, the photosensitive ganglion cells in the retina signal the brain to stop producing melatonin. Such disturbances can have wide effects: on sleep and waking cycles, eating patterns, metabolism, reproduction, mental alertness, blood pressure and heart rate, hormone production, temperature, mood patterns and the immune system.

Artificial light at night impacts other species, too. Pollinators such as moths, flies and beetles are attracted to lights instead of focusing on feeding, mating or breeding[9]. Bats alter their feeding behaviour; birds, fish and turtles change their migratory routes; and the growth of trees and plants is affected.

CITY LIMITS

The scale of our exposure to artificial lighting is increasing as cities switch sodium street lamps to LEDs. In the United States, 10% of all street lighting has been converted. New York City is changing all 250,000 of its street lights. Milan in Italy was the first city in Europe to do so on such a scale — and the result can be seen from space. By 2015, the city centre's illuminations were brighter and bluer than those of the suburbs.

Good lighting design can mitigate some problems. 'Light trespass' into living areas, including bedrooms, can be reduced by designing outdoor luminaires that shine downwards or use shields to block stray rays. Street lights can be dimmed using intelligent control systems and wireless networks of motion sensors. The Van Gogh village in the municipality of Nuenen in the Netherlands, for example, lowers its street lights by 80% when there is no activity and turns them up when a pedestrian, cyclist or car approaches, surrounding them with a safe circle of light as they proceed. Intelligent lighting is expensive to install, but the investment pays back quickly: the Nuenen system reduced energy and maintenance costs by 62%.

New problems requiring regulation are emerging as LEDs become widespread. For example, electromagnetic radiation from wireless lighting controls, outdoor LED signs and digital billboards can interfere with mobile phones, aviation towers and medical equipment such as hearing aids or implantable cardiovascular devices[10].

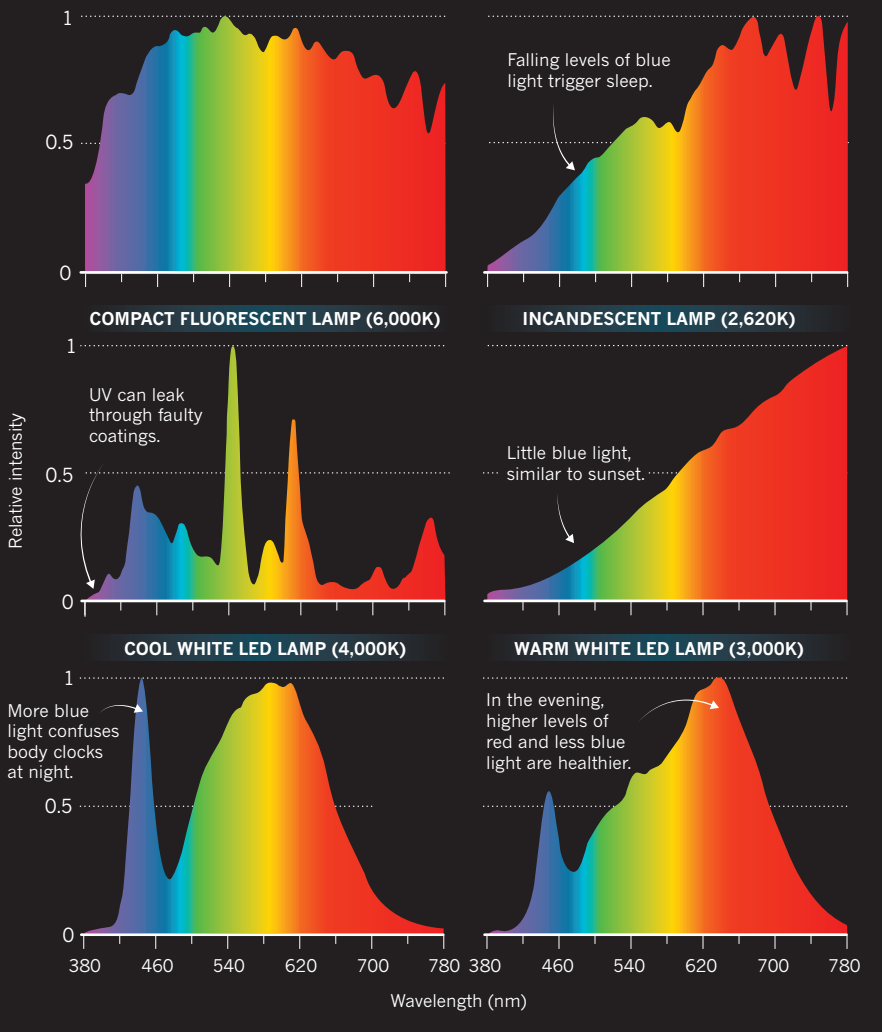
TIGHTER STANDARDS

Until healthier lighting options become available, the following steps need to be taken to reduce potential negative impacts on the circadian clock. In my opinion, CFLs should be withdrawn from sale because of the scarcity of disposal and recycling protocols. LED sources should be regulated more tightly. Indoors, I recommend using warm white LEDs in the early evening (with colour temperatures below 3,000 kelvin and with as little blue light in the spectrum as possible) and there should be no exposure to light at night, or only to light with a spectrum greater than 600 nm (amber, red colour). Lighting should be indirect, flicker-free and dimmable.

Independent research — beyond the

LIGHT-SOURCE SPECTRA

Modern light sources differ from constantly changing daylight in the range of light wavelengths that they emit, measured in nanometres. (The lighting industry uses correlated colour temperatures in kelvin, which are an approximate measure.)



SOURCE: K. M. ZIELINSKA-DABKOWSKA/ASENSETEK LIGHTING PASSPORT PRO STANDARD SPECTROMETER

lighting industry — is needed into the health and environmental impacts of LED sources, including those with adjustable spectral characteristics, intensity, timing and duration based on the time of the day, evening or night. Emissions outside the visible range must be considered, such as near-infrared radiation (750–950 nm) that is present in daylight and incandescent lamps but not LEDs. Research shows that there needs to be a balance — the use of these light frequencies can repair damaged retinal cells[11] and are necessary. The use of heavy metals in LEDs must be reduced and a process for waste management established. The impacts of control technology in outdoor and indoor spaces must be explored.

Governmental and medical bodies need to draw up stricter regulations and standards for the use of short wavelengths of light at night. In June 2016, the American Medical Association issued a policy statement (Guidance to Reduce Harm from High Intensity Street Lights) to help communities select from the different LED lighting options. Recommendations for light intensity thresholds, timing and duration for indoor and outdoor environments at night are also necessary. It is likewise essential to define the exact spectral characteristics of recommended light sources in nanometres rather than only correlated colour temperatures (CCT) in kelvin. The latter is an approximate measure and cannot accurately describe the light spectrum.

Policymakers should encourage better use of natural light indoors during the day. Artificial light should be used only when there is not enough daylight available, especially in factories, hospitals, nursing homes and offices where people spend a lot of time. Building regulations should reward practices and technologies that harness natural light.

Municipalities should incorporate sustainable night-time illumination polices and guidelines into their urban lighting master plans. Street and security lighting should be directed downwards and shielded. Light levels for walking, cycling and driving should be the minimum acceptable. Passive technologies should be explored. For example, glow-in-the-dark surfaces that absorb energy from the Sun during the day and release it at night could be used on roads and cycle ways (from this low angle, the light would fall on the retinal zone in which blue light has no biological influence). Lights in parks and near forests should be switched off or dimmed late in the evening.

Electromagnetic field emissions from LED outdoor advertisements must be controlled. Digital displays on facades should be no brighter than illuminations on nearby streets, buildings and squares. Installations should be switched off late in the evening to reduce light trespass into residential buildings.

Finally, the public's awareness of lighting issues must be raised. Researchers and lighting practitioners need to communicate the challenges. Healthy lighting design is becoming an important ethical issue that cannot be ignored. An increasing number of communities, such as Monterey in California, are winning lawsuits against municipalities for inappropriate LED city lighting.

For all these reasons, I still use the old incandescent light sources in my home, sleep in complete darkness and spend at least one hour each morning in bright daylight to activate my circadian clock — as do many lighting designers, physicians and chronobiologists. It is imperative that we return to the bright day and dark night cycle that evolution engraved in us. ■ SEE NEWS FEATURE P.268

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1. Gaston, K. J., Visser, M. E., Hölker, F. *Phil. Trans. R. Soc. B* **370,** 20140133 (2015).
2. Naeem, Z. *Int. J. Health Sci. (Qassim)* **4,** 5–6 (2010).
3. James, P. *et al. Environ. Health Perspect.* **125,** 087010 (2017).
4. Rybnikova, N. A., Haim, A. & Portnov, B. A. *Int. J. Obes.* **40,** 815–823 (2016).
5. Cho, J. R., Joo, E. Y., Koo, D. L. & Hong, S. B. *Sleep Med.* **14,** 1422–1425 (2013).
6. Wilkins, A. J., Nimmo-Smith, I., Slater, A. I. & Bedocs, L. *Lighting Res. Technol.* **21,** 11–18 (1989).
7. Behar-Cohen, F. *et al. Progr. Retinal Eye Res.* **30,** 239–257 (2011).
8. Lucas, R. J. *et al. Trends Neurosci.* **37,** 1–9 (2014).
9. Knop, E. *et al. Nature* **548,** 206–209 (2017).
10. de Sousa, M., Klein, G., Korte, T. & Niehaus, M. *Indian Pacing Electrophysiol. J.* **2,** 79–84 (2002).
11. Eells, J. T. *et al. Mitochondrion* **4,** 559–567 (2004).