The Next Generation of Human-Centric Lighting: "Incandescent LEDs" and Their Hidden Health Power

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Introduction

In the artificial lighting industry, it has long been fashionable to work with high correlated color temperatures (CCT) in an effort to mimic sunlight. Yet reproducing sunlight in all its complexity - intensity, timing, spectrum, modulation, color rendering - is impossible with current technology, requiring choices on which parameters match.

During the fluorescent lamp era, neither high-quality color rendering nor high intensity could be achieved economically. This left CCT as the preferred marketing metric for "sun-like" qualities, largely because cool light sources could easily produce abundant short wavelengths. It was cheaper and more efficient to make fluorescent lamps with CCTs above 3,000 K - often up to 16,000 K. Sunlight's CT at noon is around 5,700 K (a real temperature!), which became the supposed benchmark for a "natural" photonic environment, as long as one accepts the equation CCT = CT.

When LEDs replaced fluorescent lamps in nearly all applications, their first incarnations - cold white, bluish light - were harsh to eyes accustomed to the warm glow of incandescent lamps. Compared to these early LEDs, even most fluorescent lamps seemed gentler. Western LED manufacturers clung to outdated dogmas: flicker wasn't worth avoiding, a CRI of 80 was "good enough", and CCT was synonymized with the real black body emission at real temperature (=CT). Not so in parts of Asia. While some companies followed the old rules, others innovated, eliminating flicker even in retrofit bulbs, achieving daylight-like color rendering, and even pursuing spectra that follow the blackbody radiation curve as closely as possible.

Some visionaries went even further, turning the LED into a "photon synthesizer". Contemporary LEDs can cover spectral ranges from 200 nm into the near-infrared (> 1,000 nm) and beyond. COB (chip-on-board) technology allows multiple LED species to be combined on a single substrate, filling spectral gaps. With specialized phosphors and pigments, the output spectrum can be tuned with remarkable precision - from midday sky to evening glow, or to match the incandescent lamp, which still represents the only electrical light source with a truly natural, continuous thermal spectrum.

Incandescent light - phased out as "energy-wasting" - remains unique: low in high-energy visible light (HEVL), rich in near infrared (NIR; > 700 nm), and still used in thermotherapy and baby care. Both sunlight and fire are thermal light sources whose spectra fall on the Planckian (blackbody) curve, to which life appears optimally adapted: e. g. CRI is 100 for fire, candlelight, unmodified incandescent lamps, and sunlight, regardless of the respective CT.

This article presents 12 + 1 compelling reasons for the health-promoting use of incandescent-like light generated by specialized COB LEDs, referred to here for simplicity as "incandescent LEDs."

#1 Spectrum Endorsed by Evolution

Humans are closely related to non-human primates, particularly Old World monkeys. Many physiological traits, including ocular spectral sensitivity, remain highly conserved. The photopic sensitivity curve (V(λ)) peaks at ~ 555 nm - virtually identical to the maximum transmission of leaf tissue, suggesting adaptation not to unfiltered sunlight but to the filtered light under a forest canopy.

Three archetypal light environments shaped primate evolution:

1. Open landscape – direct sunlight with high spectral power near 480 nm, strongly activating melanopsin pathways, driving sympathetic responses: elevated cortisol, melatonin suppression, and heightened alertness (**Figure 1 left**).
2. Forest canopy – green-dominated spectrum with reduced blue and red; NIR in relation to the visible radiation is several times higher than in open sun (**Figure 1 middle**), fostering parasympathetic, regenerative states.
3. Night – moonlit or dark - very low irradiance and NIR (= darkness), complete absence of melanopsin-relevant blue, supporting restorative processes and sleep.

For humans, the night environment changed in the past ~ 1 million years [1]: the use of fire transformed it into low-illuminance conditions with significant NIR exposure (**Figure 1 right**).

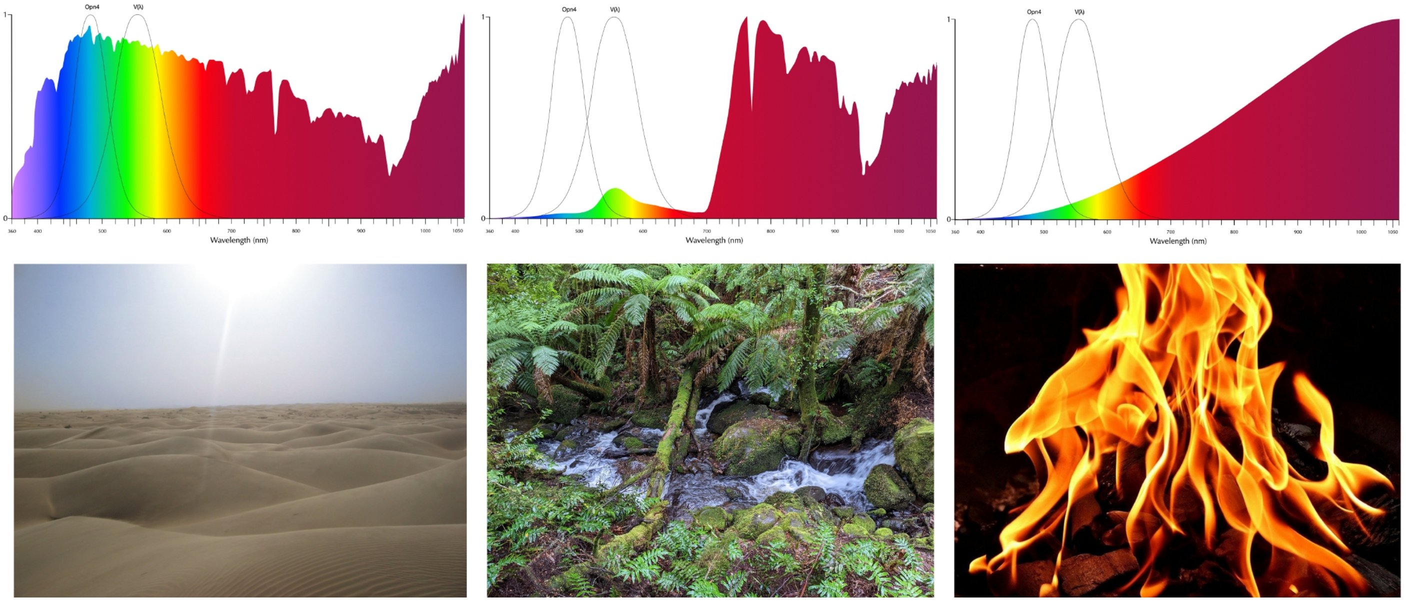

Figure 1: Archetypal light environments shaping primate evolution. **Left:** open landscape with direct sunlight, rich in blue wavelengths, activating sympathetic pathways. **Middle:** forest canopy spectrum, reduced blue and red but high near infrared, fostering regenerative states. **Right:** night/firelight with low illuminance, minimal blue and strong near infrared, supporting restorative processes.

Due to near-hairless skin, phototoxic vulnerability is increased: Humans had to develop distinct protective mechanisms for open-landscape exposure **[2]**. Transitioning from night or canopy to open terrain situation activates light-driven endocrine defense pathways: adrenaline-induced vasoconstriction limits erythemal skin blood flow, cortisol dampens inflammation, catecholamines stabilize cardiovascular function, and mineralocorticoids regulate fluid balance. These responses operate at both systemic and local levels, "from brain to skin" **[3,45]**.

Given this background, modern artificial lighting should be re-evaluated. Options include replicating the "steppe/desert" profile - high blue, strong sympathetic activation; the "oasis under the canopy" profile - low blue, high daytime NIR, neutral vegetative tone; or the pre-electric "night" profile, characterized by the natural blackbody spectrum of fire, rich in NIR, free of HEVL and with minimal blue to allow uninterrupted melatonin secretion. Chronobiologically, the latter two modalities align more closely with today´s (motorically reduced) indoor tasks and offer long-term health benefits by avoiding maladaptive systemic stress reactions.

#2 Low HEVL Content

High-energy visible light (HEVL, ~ 400–460 nm, sometimes up to 470 nm) carries the highest photon energy in the visible spectrum (~ 3.1 eV at 400 nm) and is strongly linked to photo-oxidative stress in eye and skin.

Ocular effects – In the retina, HEVL is absorbed by lipofuscin and other chromophores in the retinal pigment epithelium (RPE). Blue-light-induced damage, not sufficiently described by the Blue Light Hazard (BLH) function, is cumulative and accelerates age-related macular degeneration (AMD). Children and aphakic/pseudophakic eyes filter less short-wavelength light, increasing hazard compared to the standard BLH curve.

Skin effects – HEVL penetrates deeper than UVB, reaching the upper dermis where it promotes reactive oxygen species (ROS) formation. This accelerates collagen breakdown, hyperpigmentation, and photoaging. Damage is primarily oxidative rather than direct DNA injury, making it cumulative and harder to detect.

Indoor overexposure – In sunlight, HEVL is balanced by red/NIR wavelengths that help modulate oxidative stress **[6–10]**. Standard white LEDs, especially with CCT > 4,000 K, often have intense HEVL nm peaks without compensatory NIR, exposing indoor workers to significant cumulative oxidative loads. Reducing 400–460 nm output lessens ocular and dermal oxidative stress **[11]**, especially for:

- Children (clear lenses, large pupils)
- Post-cataract patients (implant lenses have higher short-wavelength transmission)
- Elderly with AMD risk
- Photosensitive skin conditions

Incandescent LEDs produce a smooth spectrum with minimal HEVL and no sharp 450 nm spike (**Figure 2**), closely resembling the natural firelight spectrum shaped by evolution. This lowers cumulative photo-oxidative risk while maintaining full visual performance.

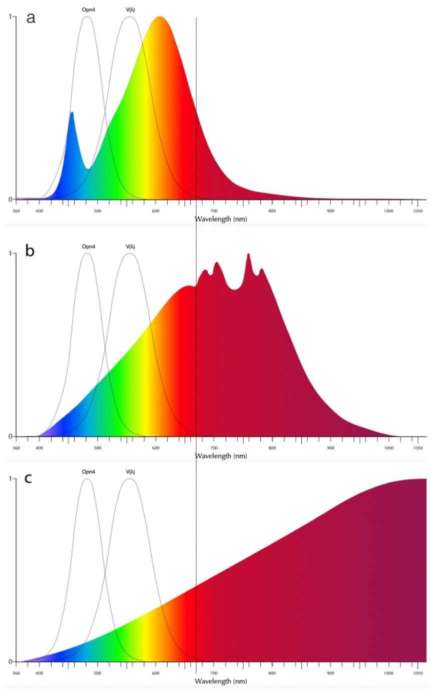

Figure 2: Spectral comparison of standard LED **(a)**, NIR-enriched incandescent LED **(b)** and classic incandescent lamp **(c)**. The spectral curves of the incandescent lamp and LED in the visible part are almost identical regarding continuity and blackbody.

In contrast to HEVL, blue light, particularly near 480 nm, is vital for circadian entrainment, therefore short wavelengths should not generally be eliminated indoors but applied reasonably balanced and timed:

sufficient to sustain non-visual functions without chronically overstimulating the melanopic pathway or causing excessive oxidative stress. For long-term circadian adaptation support, higher CCT (> 4,000 K) exposure with spectral emphasis around 480 nm and reduced HEVL can be applied intermittently, tailored to the individual, and paired with plenty of protective NIR.

#3 Restoring Near Infrared

In sunlight and fire, near infrared (NIR; > 700 nm) makes up at least 40% of total radiant energy [9]. Though invisible, it penetrates deeply into tissue [12], interacting with water, hemoglobin, and mitochondria, and plays a key role in cellular physiology.

Physiological relevance – NIR is absorbed by mitochondrial chromophores, especially cytochrome c oxidase, boosting ATP production, improving microcirculation, and enhancing antioxidant defenses [6]. This photobiomodulation (PBM) supports tissue repair [13], modulates inflammation, and in the retina can counter oxidative stress from high-energy visible light (HEVL) [14]. Low intensity exposure (8 mW/cm^2) to deep red/NIR (~ 670 nm) has been shown to improve retinal sensitivity and mitochondrial efficiency in aging eyes [15].

Modern artificial light, especially phosphor-converted LEDs, cuts off above ~ 630–700 nm due to v(λ)-driven efficiency design, creating a chronic NIR deficit for those mostly sitting indoors behind "climate-friendly" windows filtering NIR for energy efficiency's sake.

Incandescent LEDs can provide significant NIR, with output extending up to ~ 1,000 nm - enough for PBM effects but without the intense heat of wavelengths > 1,500 nm (**Figure 2**). The NIR level can be tailored for the intended application at the expense of nominal energy efficiency.

Biological implications – NIR can mitigate HEVL damage by "preconditioning" tissue (e.g., 630–850 nm), improving resilience in skin and eye. Including NIR in daily lighting reintroduces a natural spectral element largely absent in modern interiors.

#4 Improved Photobiological Safety

Conventional white LEDs emit a pronounced high-energy visible light (HEVL) peak (~ 400–460 nm), generating reactive oxygen species (ROS) in the eye and skin. In ocular tissues, this contributes to cumulative oxidative stress in the retinal pigment epithelium (RPE), photoreceptors, and lens. The negative impact of conventional LEDs on ocular health has been underestimated from the beginning, and growing evidence [16–18] has been systematically ignored by regulatory bodies and standards [19,20].

Incandescent LEDs have minimal HEVL and are rich in near infrared, producing a more balanced spectrum. NIR is non-phototoxic at normal levels and activates mitochondrial cytochrome c oxidase, enhancing metabolism, antioxidant defenses, and tissue repair. By combining low HEVL with ample NIR, incandescent LEDs reduce phototoxic stress while enabling intrinsic repair, aligning artificial lighting with evolutionary photobiological safety.

#5 Hormone Neutrality

Light is both a visual and endocrine signal. Short-wavelength content strongly influences hormonal balance via intrinsically photosensitive retinal ganglion cells (ipRGCs), which peak near 480 nm. These cells project to the suprachiasmatic nucleus (SCN), regulating pineal melatonin and triggering broader neuroendocrine responses [3,21,22].

Melanopic stimulation suppresses melatonin but also engages the hypothalamic–pituitary–adrenal (HPA) axis, raising cortisol, adrenaline, and noradrenaline. Excess blue-rich light at inappropriate times can cause chronic sympathetic activation, contributing to cardiovascular strain, metabolic disruption, and immune suppression [4,23,24].

In the 1970s, Fritz Hollwich showed that altered artificial spectra produced by fluorescent lamps elevated catecholamine breakdown products, indicating heightened sympathetic tone - later confirmed by mapping the ipRGC–SCN pathway [25–27]. Until the full description of the neuronal pathways in 2001 [28], the lighting industry denied these vegetative effects, and after 2001 the effects were reframed as "melatonin suppression," downplaying pituitary axis and stress hormone involvement.

Hormone-neutral lighting meets visual needs while keeping melanopic and non-visual stimulation within physiological limits - especially outside peak daylight hours. Incandescent-type spectra, including modern incandescent LEDs, have low melanopic/photopic ratios and minimal HEVL, reducing melatonin suppression and HPA activation, thus supporting endocrine individuality.

This is especially important for:

- Children/adolescents with developing endocrine systems
- Cardiovascular patients, where extra sympathetic drive is risky
- Those with sleep, mood, depression or anxiety disorders [29,30]

#6 Individual Hormonal Compatibility

Light's endocrine effects vary greatly with age, sex, genetics, chronotype, ocular status, health, and medication use. This makes "one size fits all" lighting inherently suboptimal - and sometimes harmful - for certain groups.

Variability factors:

- Chronotype: Evening types are more sensitive to evening short-wavelength light, which delays circadian phase.
- Age: Children's clearer lenses transmit more blue/HEVL, increasing melanopic stimulation and lifetime increase in SW dose [11].
- Lens status: Post-cataract patients with clear or blue-transmitting IOLs (intraocular lens implants) receive more short-wavelength retinal irradiance; risk for AMD increases [31,32].
- Sex hormones are affected by light, depending on brightness and timing [33,34].
- Medications: Pharmaceuticals such as beta blockers, corticosteroids, antidepressants, and others can alter physiological light responses by impacting the stress hormone axis or affecting melatonin production.

Risks of blue-enriched light – Morning exposure may boost mood in healthy adults but could raise sympathetic tone, blood pressure, or delay sleep in those with cardiovascular, anxiety, or immune disorders. Effects depend on both the melanopic/photopic ratio and the individual's baseline hormonal state.

Clinical implications – A light spectrum that stimulates hormones in one person may harm another. Most general lighting lacks such tailoring, meaning some occupants will be exposed to spectra that disrupt rather than support their hormonal balance.

Incandescent LEDs, with low impact on cellular and endocrine-vegetative integrity, are suited for kindergartens, schools, hospitals, elder care, dementia care and diverse workplaces.

#7 Compatible with All Ages

Photobiological safety standards are based on healthy (male?) adults, overlooking spectral and anatomical differences in children, elderly individuals, and post-cataract patients [35].

Children – Their crystalline lens is highly transparent to short wavelengths, including violet and near-UV light. Aphakic people (without a natural lens or clear IOL) suffer from this transparency in adulthood. For these groups, the aphakic blue light hazard (BLH) function - showing higher HEVL/near-UV retinal exposure - is more accurate than the standard BLH curve.

Age-related transmission – Differences decline above ∼ 500 nm, where elderly, young, and aphakic eyes transmit light similarly [47]. The common recommendation to increase light for the elderly "fourfold" is mostly relevant for short wavelengths; above 500 nm, only about a twofold increase would be needed.

Implications:

1. Energy efficiency: Warm, low-HEVL spectra can meet elderly brightness needs with less than half the extra energy compared to the "4× rule."
2. Spectral safety: Reduced-HEVL light especially protects children and post-cataract patients from retinal phototoxicity.

A warm, low-HEVL spectrum is thus safest and most efficient across all ages, delivering good vision while minimizing avoidable risk.

#8 Sharper Vision

Visual acuity is limited by optical quality and chromatic aberration - the wavelength-dependent focus error caused by refractive index changes in ocular media. Longitudinal chromatic aberration (LCA) is ∼ 2 diopters between 400 nm and 700 nm, with short wavelengths (violet/blue) focusing in front of the retina (**Figure 3 a**).

Approximate LCA vs. 555 nm

- 400–450 nm: +1.0 to +1.5 D → strong defocus, fringes, glare, contrast loss
- 450–500 nm: +0.5 to +1.0 D → moderate defocus, blur
- 500–600 nm: minimal LCA → sharpest focus
- 600–700 nm: −0.3 to −0.5 D → slight defocus

Short-wavelength defocus scatters light on the retina, lowering contrast - most noticeable under high blue content (cold LEDs, snow, water reflections). In precision tasks (aviation, sailing, skiing, marksmanship), yellow/amber filters cutting < 500 nm improve contrast and edge definition (**Figure 3 b**). Warm, low-HEVL sources like incandescent LEDs reduce chromatic blur naturally, enhancing visual comfort and acuity without filters.

#9 Excellent Color Rendering

Color rendering depends on how faithfully a light source reveals colors compared to a natural reference. Humans evolved under continuous thermal spectra (sunlight, fire), all lying on the Planckian locus and scoring a perfect CRI of almost 100. These spectra stimulate all three cone types (S, M, L) in balanced proportions, ensuring natural color perception and minimal metameric mismatch.

Limits of modern metrics – CRI (Ra) can misrepresent narrow-band or "spiky" spectra like fluorescent and standard LEDs. Alternatives (IES TM-30's Rf/Rg, CIE methods) capture more nuance but still favor smooth spectra.

Spectral engineering pitfalls – Non-thermal light sources can be tuned to achieve high CRI scores on standardized test samples yet still perform poorly with real-world colors, particularly saturated reds (R9) and deep blues - crucial in medicine, food presentation, and art. The pursuit of maximum color fidelity often conflicts with spectral optimization for biological safety; reducing HEVL or boosting red and NIR content can lower nominal CRI, though values above 90 and even 95 remain achievable.

Following the blackbody curve, incandescent LEDs reproduce full-spectrum reds and deep reds (> 600 nm) without simulated peaks. This delivers accurate skin tones, consistent object colors, and reduces cognitive load from spectral correction, improving visual comfort during prolonged tasks.

#10 Flicker-Free Operation

Incandescent lamps on mains AC exhibit a small 100/120 Hz modulation (∼ 3–5%) from filament heating and cooling. LEDs, however, can produce anything from harsh, almost stroboscopic flicker across multiple frequencies to virtually zero flicker, depending on driver design - an engineering choice. Light flicker, whether visible or sub-perceptual, can trigger headaches, eyestrain, reduced visual performance,

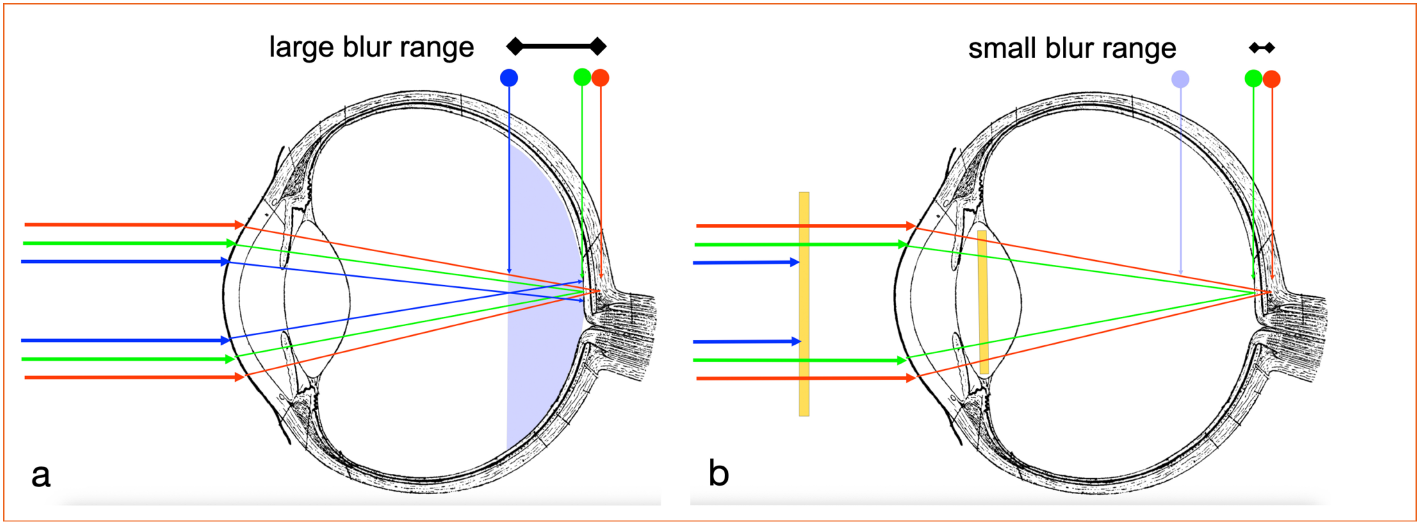

Figure 3: Longitudinal chromatic aberration and resulting defocus for blue-rich **(a)** and blue-filtered **(b)** conditions.

and exacerbate migraine, photosensitive epilepsy, or mood disorders [36–39]. Even beyond conscious detection thresholds, it can elicit cortical responses and disrupt eye movement stability [38,40].

Since LEDs operate on low-voltage DC, electronic circuitry is unavoidable, but it can be designed for modulation-free operation. This is both technically feasible and inexpensive, effectively eliminating this biological stressor.

#11 Psycho-Emotional Benefits

Light shapes emotional state, social perception, and self-image. Warm-spectrum light, like that from incandescent LEDs, feels inviting, flatters skin tones, and fosters relaxation and positive interaction.

Blue-enriched light (~ 470–490 nm) increases amygdala activation, heightening vigilance and, with chronic exposure - especially at night - potentially increasing anxiety [41,42]. Aesthetically, it reduces warm skin reflection, accentuates superficial blood vessels, and can give a pallid or cold appearance. Warm spectra enhance subdermal scattering, mask vessels, and produce a healthier look.
Such psycho-emotional and aesthetic effects influence mood, communication, and productivity. Choosing spectra that support both physiology and psychology is as important as meeting visual task needs.

An important publication demonstrated that malillumination is associated with increased prevalence of certain psychological disorders [30]. To translate these findings into everyday lighting practice, it is essential to have hormonally neutral light sources like the incandescent LED available - particularly those with low color temperatures - to minimize melanopic stimulation and its potential impact on neuroendocrine balance.

#12 True Cost Efficiency

Energy efficiency metrics rarely include the health costs of chronic exposure to biologically unbalanced light, which may raise risks for cardiovascular disease (CVD), age-related macular degeneration (AMD), cancers , metabolic disorders, and mood conditions [43–46]. These costs can vastly exceed the small electricity savings from the most efficient - but physiologically suboptimal - light sources.

Example 1 – AMD Treatment vs. Lamp Energy

Treating one wet AMD patient in Germany costs ~ €30,000/year. A 100 W incandescent lamp run 24/7 uses 876 kWh/year, costing ~ €263 at €0.30/kWh. For the price of one year of AMD treatment, ~ 114 such lamps could run 24/7 for a year - or one personal lamp for one and a half human lifetimes.

Example 2 – Cardiovascular Diseases Costs vs. National Lighting Savings

CVD costs Germany ~ €80 billion/year. Comparing the incandescent LED to a slightly more efficient but biologically inferior LED might save €5/year per luminaire. Across 100 million luminaires, that's €0.5 billion/year - less than 0.7% of CVD costs. Even a small rise in CVD burden would erase any savings many times over.
Conclusion – Marginal gains in luminous efficacy cannot justify spectra that harm health. Incandescent LEDs - with low HEVL, high NIR, excellent CRI, and evolutionary compatibility - are more cost-effective long term when health care costs are included.

#12+ One Last Thing – Regulatory Perspective

Under both European and international frameworks, a medical device is defined as any instrument, apparatus, or other article intended by the manufacturer to be used for human beings for a medical purpose, such as diagnosis, prevention, monitoring, treatment, or alleviation of disease. In the EU, the Medical Device Regulation (MDR 2017/745) explicitly includes products that exert their principal intended action by physical means - such as light - if that light is meant to achieve a physiological effect for health purposes.
This definition creates a regulatory grey zone for modern "biologically active" lighting technologies. If a light source is marketed or designed to deliberately influence physiological parameters - such as melatonin secretion, alertness, and circadian phase shift - it may, in principle, fall under medical device regulation. This would trigger requirements for:

- Clinical evidence of safety and efficacy.
- Quality management systems for production.
- CE marking under the MDR, with possible classification above Class I.
- Ongoing post market surveillance.

The Human Centric Lighting Paradox

So called "human centric" or dynamic lighting systems are explicitly intended to influence nonvisual physiological functions - often marketed with claims about boosting mood, performance, or circadian alignment. In a strict legal interpretation, such intended use could place them in the medical device category, especially if any therapeutic or preventive health claims are made. However, enforcement is inconsistent, and most such products currently enter the market without MDR conformity assessment.

Why the Incandescent LED Is Different

The incandescent LED provides a spectrum closely resembling traditional incandescent lamps. Its primary function is general illumination, and it can be specified and sold without any intended medical purpose. As such, it does not trigger medical device classification. Physiological compatibility is achieved as a byproduct of its neutral spectral qualities, not through targeted photobiological intervention.

From a regulatory risk perspective, this is significant:

- No additional conformity burden: It remains a standard lighting product under low voltage and EMC directives (and possibly eco design rules), not MDR.
- Lowest physiological interference: Because it avoids extreme spectral manipulations, its negative impact on hormonal, retinal, and vascular parameters is minimal.
- Avoids claim based reclassification: By not marketing it as a therapeutic or preventive tool, the manufacturer avoids crossing into regulated medical territory.

The Strategic Advantage

For specifiers and facility managers - especially in hospitals, care homes, schools, and workplaces - the incandescent LED offers a safe regulatory position combined with a biologically favorable spectrum. It sidesteps the compliance uncertainties that could emerge for biologically active lighting in future legal reviews, while still delivering the health aligned qualities many facilities want.

Conclusion

COB technology enables the incandescent LED - more efficient than tungsten yet providing all key advantages: high CRI, natural blackbody spectrum, NIR enrichment, and low HEVL. As a hormonally neutral, health-supportive light source enabling optimal vision for all ages, it merits a central role in future healthcare, lighting design, and computer display technology. ■

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Dr. Alexander Wunsch, MD, PhD

Dr. Alexander Wunsch, MD, PhD, is a physician, light therapist, independent researcher, and scientific consultant. From 2008 to 2019, he served as a lecturer in the Master of Arts program in Architectural Lighting Design at Wismar University of Applied Sciences. His research is focused on the physiological and pathological effects of light on humans, and he has been a vocal critic of the ban on incandescent lamps. His work advocates for a paradigm shift in the field of photobiology and calls for a health-centered redefinition of lighting standards. Dr. Wunsch emphasizes the necessity of shifting from the utilization of energy efficiency as the predominant criterion for indoor lighting, promoting instead the adoption of salutogenic lighting concepts grounded in human biology. This approach prioritizes the beneficial impact on health over considerations of technical or economic feasibility.

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