Health Impacts of LED Lighting

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Light is at the origins of life
but
Light can also harm life

Gustav Klimt, Death and Life
Risks for the eye

Photochemical effects are dominant

Thermal effects are dominant

Photon energy

Transmission (%)

Wavelength (nm)

Crystalline Focus

Relative Danger

Actinic UV

Blue light
Wavelength effect on cellular apoptosis
1999: Effects observed on rats

**380 nm**

- 0.6 J/cm²
  - No detectable lesions (histology or fundus examination)
  - Lesions visible on the fundus examination
  - ~1% damaged rods
  - Normal appearance of retina

- 0.9 J/cm²
  - 5-15% of rods damaged; increased number of phagosomes (epithelium)
  - Lesions visible on the fundus examination
  - 10-30% damaged rods
  - 30-40% rod losses

**470 nm**

- 500 J/cm²
  - No detectable lesions (histology or fundus examination)
  - Lesions visible on the fundus examination
  - 1% of damaged photoreceptors
  - Swelling of the epithelium
  - Altered distribution of melanosomes
  - Small clear vesicles and dark inclusions
  - Normal appearance of retina
  - Up to 5% of photoreceptors losses

- 900 J/cm²
  - Some damaged mitochondria (epithelium) & increased chromatin concentration of photoreceptors

Luminance (brightness) is the relevant quantity.

The size of the pupil defines the solid angle.
Blue Light Hazard & brightness

Definition of Effective Luminance

\[ L_B(\vec{x}, \vec{\omega}) = \int_{\lambda} L_\lambda(\vec{x}, \vec{\omega}, \lambda) B(\lambda) \, d\lambda \]

- **Effective Luminance**
- **Position, direction**
- **Wavelength**
- **Spectral luminance**
- **Hazard function**

**Group 0** – No risk: Exposure limit attained \( \geq 10\,000 \text{ s} \)
\( L_B;_{\text{max}}=100 \text{ W.m}^{-2}\cdot\text{sr}^{-1} \)

**Group 1** – Low risk: Exposure limit attained between 100 s and 10 000 s
\( L_B;_{\text{max}}=10^4 \text{ W.m}^{-2}\cdot\text{sr}^{-1} \)

**Group 2** – Moderated risk: Exposure limit attained between 0,25 s and 100 s
\( L_B;_{\text{max}}=4\times10^6 \text{ W.m}^{-2}\cdot\text{sr}^{-1} \)

**Group 3** – High risk: Exposure limit attained \( \leq 0,25 \text{ s} \)
\( L_B;_{\text{min}}=4\times10^6 \text{ W.m}^{-2}\cdot\text{sr}^{-1} \)
Some populations are more vulnerable

Kids are more affected by blue light (the crystalline becomes more yellowish with age)

Pseudophakics because artificial lens can be more transparent at short wavelengths

Aphakic persons

A. Pons et al, J. OSA, A24(6), 2007
Flow chart describing the flow of information from the primary light source (in blue) to the luminaire based on this light source (in amber)
The EN & IEC 62471 is ambiguous regarding the distance of measurement that should be used:

- Distance to an illuminance of 500 lx for « GLS » lamps (General Lighting Services)
- OR
- at 200 mm from the source for other lamps

Case of non-uniform source and/or spots:

The Luminance $L_e$ must be evaluated on the emission surface $A$, corresponding to the effective field of view $\alpha_{\text{eff}}$, as well as in the angular cone defined by the angle aperture angle of the light beam entering the pupil $\theta_L$. 
White light contains blue radiation

All sources of white light have a blue component

spectral variations in natural light

- north sky light > 20,000K
- noon daylight 6500K
- noon sunlight 5500K
- sunset sky + sunlight < 4000K 560nm

Incandescence
- B-Y white LED (cold white)
- Sodium HP

Fluorescent tube CRI 80
Fluorescent tube CRI 90
- Metal Halide

Source: Spectres mesurés par M. Garcia du CSTB
Comparison of various light sources on blue light hazard irradiance @ 500 lux

- Halogen bulb 25W 2.600K 230V
- Fluoros ES burner cover 2620K 230V
- Fluoros ES burner only 2670K 230V
- Incand bulb frosted 60W 2700K 230V
- Halogen capsule 28W 2770K 240V 230V
- LED Reflector MR16 7W 4000K 2750K 230V
- LED bulb 6W 2750K 230V
- LED bulb 12W 2750K 230V
- LED bulb 6W 2800K 230V
- Halogen reflector MR16 45W 240V 230V
- Halogen DE R7s 500W with cover glass 2840K 12V
- Halogen DE R7s 500W w/o cover glass 3000K
- LED Tube T8 18W 840 4000K
- LED Reflector MR16 7W 4000K 230V
- LED Reflector 6100K
- Fluor tube T5 24W 840 4000K
- Fluor tube T5 24W 840 4000K
- Fluor tube T5 24W 840 4000K
- Fluor tube T5 24W 840 4000K
- Daylight 6500K
- Fluor tube T5 24W 15000K

Laplace
Why LEDs are accused?

1. The blue diode used by the power LEDs emits at wavelengths very close to the maximum of $B(\lambda)$.

2. The emitting surface of a LED diode is very low (of the order of mm$^2$) therefore the luminance is very strong (it can reach several $10^6$ cd/m$^2$).

3. The efficiency of pupillary contraction and the speed of aversion depend on the wavelength but very little on the blue.

Leslie Lyons LED Magazine, July 7th, 2011
Some examples
(Warm white LEDs)
Some examples (Cool white LEDs)

Mesures CSTB, Rapport ANSES, 2010
The aging of LEDs could worsen the effects

With aging the colour characteristics of LEDs change because of:
- Alteration of the phosphor or its support (glass, plastic ...)
- Blackening of primary optics (thermal effects, impurities...)
- Flux depreciation

CCT changes

Blue/yellow equilibrium changes

Mesures EU-PremiumLight, 2014
Light quantity and colour change during daytime

- A lot of light
- High colour temperature
- Uniform light

- Less light
- Low colour temperature
- Non-uniform distribution

The concentration of melatonin and cortisol depend on the variation of light
Glare & stray light

- Discomfort
- Visual fatigue
- Temporal visual acuity losses
- Lower visual performance

- Temporal disturbances of sleep
- Circadian disruption
- Hormonal perturbations
Recognized Flickering negative effects (typical frequency from 3 Hz to 70 Hz)
- Neurological problems, including epileptic seizure
- Headaches, nausea, fatigue, blurred vision, eye strain
- Apparent slowing or stopping of motion
- Reduced visual task performance
- Distraction
- Autistic vision problem

Invisible Flickering may have also some effects (not really known)
- Ambient flicker at imperceptibly high frequencies can penetrate to the neural site for flicker adaptation, which is presumed to be in primary visual cortex

Fast movement causes flicker to become more obvious - The stroboscopic effect, Phantom arrays, Ghost images...

Women more sensitive to flicker than men, younger people more than older.

Two of the most important parameters influencing indirect perception of stroboscopic effects are frequency and amount of modulation

Possible positive effects of flickering
- Remediation of Intermittent Central Suppression
- 10 Hz flicker could improve recognition memory in older people
- Flicker may induce Brightness Enhancement
Risks related to blue light
- Children
- Both aphakics and pseudophakics persons
- Populations which are already light-sensitive (eye & skin)
- Populations particularly exposed to LEDs (workers)

Risk related to glare

Other risks related to LED’s light exposure
- Disruption of circadian rhythms
- Stroboscopic effects

ANSES’s public health mission involves ensuring environmental, occupational and food safety as well as assessing the potential health risks they may entail.

It provides the competent authorities with the necessary information concerning these risks as well as the requisite expertise and technical support for drafting legislative and statutory provisions and implementing risk management strategies.
Published: 19 March 2012
All artificial light sources are concerned

Risks related to Light exposure (UV to IR)
• Assessment of effects on the healthy eye
• Adverse health effects in persons with pathological conditions
  o photosensitive skin diseases
  o Photosensitive eye conditions

Risks related to Circadian rhythms, circadian rhythm disruptions, sleep and mood

Other risks related to LED’s light exposure
• Flicker & Stroboscopic effects

This Committee deals with questions related to emerging or newly identified health and environmental risks and on broad, complex or multidisciplinary issues requiring a comprehensive assessment of risks to consumer safety or public health and related issues not covered by other Community risk assessment bodies.
## Risk Assessment vs Risk Management

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<th><strong>ANSES</strong></th>
<th><strong>SCENIHR</strong></th>
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<td><strong>Risk management</strong> is the identification, assessment, and prioritization of risks (defined in ISO 31000 as the effect of uncertainty on objectives, whether positive or negative) followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities.</td>
<td><strong>Risk assessment</strong> is a step in a risk management procedure. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat (also called hazard).</td>
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<td>Makes recommendations to the government &amp; drafts legislative and statutory provisions, implementing risk management strategies</td>
<td>Draws the EU-Commission’s attention to the new or emerging problems which may pose an actual or potential threat.</td>
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<td>Recommendations are always based on “worst case scenario”</td>
<td>The opinion is based on a scientific rationale which has taken into account the relevant scientific literature and other accessible and reliable information</td>
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Le mécanisme de dégradation

La lumière bleue peut endommager à la fois les photorécepteurs et les cellules RPE des primates. L’exposition cumulée à la lumière dans la région de 380 nm à 500 nm peut activer la ATR (all-trans-retinal) accumulée dans les segments externes des photorécepteurs. Cette photoactivation peut induire la production d’espèces réactives d’oxygène (ROS), comme l’oxygène singulet, le peroxyde d’hydrogène et d’autres radicaux libres, dans les segments externes des photorécepteurs.

Les ROS attaquent de nombreuses molécules, y compris les acides gras polyinsaturés, une composante majeure des membranes cellulaires. La grande concentration de membranes cellulaires dans la rétine la rend très sensible au stress oxydatif. En particulier, cette contrainte peut perturber les structures membranaires des segments externes des photorécepteurs, provoquant une phagocytose incomplète et une digestion des segments externes oxydés dans l’épithélium. La conséquence est une accumulation du produit résiduaire lipofuscine dans des granules de cellules RPE.

Dans l’œil, la lipofuscine, est également connue sous le nom de "pigment du vieillissement".