Humans, animals and plants have complex physiological responses to the daily and seasonal variations in solar radiation under which they evolved.

**Photobiology is the study of these responses to optical radiation in the ultraviolet (UV), visible, and infrared (IR) portions of the electromagnetic spectrum.**

Photobiological responses result from chemical and physical changes produced by the absorption of radiation by specific molecules in the living organism.
While the subject of all of our talks today is “Human Responses to Light”

Let's take a quick look at the natural world around us....
There are lots of examples of lighting effecting nature....

Page 80 LG6;
A4.4 – Birds and Flight
There are lots of examples of lighting effecting nature....
There are lots of examples of lighting effecting nature....

Page 82 LG6;
A4.4 – Amphibians
There are lots of examples of lighting effecting nature....
What effects are there that light can have on humans?
### Effect of optical Radiation – *Causing harm or damage*

<table>
<thead>
<tr>
<th>Locat or Process</th>
<th>Ultraviolet (100nm – 400nm)</th>
<th>Visible and near-IR (380nm – 1400nm)</th>
<th>IR (Over 1400nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>Erythema (delayed)</td>
<td>Burns</td>
<td>Burns</td>
</tr>
<tr>
<td></td>
<td>Carcinogensis</td>
<td>Erythema (Immediate)</td>
<td>Erythema (Immediate)</td>
</tr>
<tr>
<td>Aging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drug Photosensitivity</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Melanogensis</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Melanoma (Postulated)</td>
<td></td>
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</tr>
<tr>
<td>Eye - Cornea</td>
<td>Photoconjunctivitis</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Photokeratitis</td>
<td></td>
<td></td>
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<tr>
<td>Eye - Lens</td>
<td>Cataracts (immediate and delayed)</td>
<td>Near-IR cataracts</td>
<td>IR cataracts</td>
</tr>
<tr>
<td></td>
<td>Coloration</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sclerosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye – Retina</td>
<td>Retinal Changes</td>
<td>Thermal lesion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shock lesion</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>Photochemical lesion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Macular degeneration (postulated)</td>
<td></td>
</tr>
</tbody>
</table>

*IESNA Handbook Version 10*
### Effect of optical Radiation – *Beneficial*

<table>
<thead>
<tr>
<th>Locat or Process</th>
<th>Ultraviolet (100nm – 400nm)</th>
<th>Visible and near-IR (380nm – 1400nm)</th>
<th>IR (Over 1400nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phototherapy</td>
<td>Psoriasis</td>
<td>Retinal detachment</td>
<td></td>
</tr>
<tr>
<td>Herpes simplex</td>
<td>Diabetic retinopathy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dentistry</td>
<td>Hyperbilirubinemia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment of vitiligo, eczyma</td>
<td>Glaucoma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photochemotherapy</td>
<td>Removal of port wine birth marks and tattoos</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surgery</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seasonal Affective Disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jet Lag</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-theraputic</td>
<td>Vitamin D production</td>
<td>Biological rhythms</td>
<td>Radiant heating</td>
</tr>
<tr>
<td></td>
<td>Protective pigmentation</td>
<td>Hormonal activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Circadian rhythm set</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*IESNA Handbook Version 10*
2016 Human Physiological Responses to Light Meeting Report

July 19th, 2016
Washington, D.C.

Prepared For:
U.S. Department of Energy
Solid-State Lighting Program

Tulane University
Thomas Jefferson University
Lighting Research Center
University of California San Diego
Thomas Jefferson University
F.Lux Software LLC
Cree
Brigham and Women’s Hospital
Lighting Science Group
Pacific Northwest National Laboratory
NEMA
Acuity Brands Lighting, Inc.
Philips Lighting Research
Johns Hopkins Bloomberg School of Public Health
University of Connecticut
University of Colorado Boulder
Stanford University School of Medicine
Example Summary

Vitamin D
Transforms Cholesterol-containing body oils into pre-Vitamin D

Absorbed by body transformed into Vitamin-D then moved by blood around the body.

UVB (280nm -315nm)

UV used for the treatment of various skin diseases such as Psoriasis and eczema
Seasonal Affective Disorder
Florida - 2% of population - Latitude 27.7°N

New Hampshire - 10% of population - Latitude 43.2°N
London 51.5°N

Wick Scotland – 58.4°N

The diagram shows the variation in daylight hours throughout the year for two locations: London (51.5°N) and Wick Scotland (58.4°N). The timeline is from January to December, with different equinoxes and solstices marked.

- **Vernal (North) / Autumnal (South) equinox**
- **Summer (North) / Winter (South) solstice**
- **Autumnal (North) / Vernal (South) equinox**
- **Winter (North) / Summer (South) solstice**

Daylight hours range from 12 hours at the equator to a maximum of 24 hours in the middle of the year's longest daylight period. The diagram also highlights the number of hours of daylight at different latitudes and months.
Good effects – Seasonal Affective Disorder

Image from: www.sad-lighthire.co.uk

- 30 mins – 4 hours
- 2,500 lux – 10,000 lux
- Optical nerve
- Shorter Wavelength

Image from: www.sad-lighthire.co.uk
Human response to Visible light
Human response to Visible light

Human pupil....
Contraction and Dilation
Human response to Visible light

- Cd/m²
- 8mm
- ~2mm
Vision Adaptation States

Cd/m²

- 8mm
- ~2mm

An Acuity Brands Company
Human response to Visible light

Scotopic – “Night time Vision” – Mono chromatic – Lacking Detail

Photopic – “Day time Vision” – Lots of colour – Plenty of detail

Mesopic – Transition between the two....
Human response to Visible light

Moonless Clear Night Sky

Car Headlights

Sun at different time of day

Quarter Moon

Overcast skies

Scotopic  Mesopic  Photopic

Cd/m²
How do we perceive light...
Human response to Visible light

Starting in a lit space and dimming, our eye does not perceive the measured lux level....

<table>
<thead>
<tr>
<th>Dim Level</th>
<th>Perceived Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>32%</td>
</tr>
<tr>
<td>5%</td>
<td>22%</td>
</tr>
<tr>
<td>1%</td>
<td>10%</td>
</tr>
<tr>
<td>0.1%</td>
<td>3%</td>
</tr>
</tbody>
</table>
Age of viewer – how much affect?

<table>
<thead>
<tr>
<th>Age Group</th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;25</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>25-65</td>
<td>x2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;65</td>
<td>x4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Interior and EXTERIOR applications

Most outdoor lighting requirements

INTERIOR and EXTERIOR applications

Busy outdoor, indoor social

INTERIOR and exterior applications

Sports, healthcare, general indoor, commerce outdoor

INTERIOR applications

Some health care procedural situations

IESNA handbook 10th edition Page 4.33
Colour of light – Orange or White
Human response to Visible light - Orange

- $\nu\lambda$ (Photopic) efficiency
Human response to Visible light - Orange

Rubbish Colour Rendering...
Astronomers don’t hate it...
Human response to Visible light - Orange

The Sky is Blue...

![Graph showing the relative spectral power of Low Pressure Sodium (SO)]

![Diagram illustrating Earth's atmosphere and the sun's rays in space]

![Image of an office illuminated by yellow light]

![Image of a street illuminated by yellow light]
Human response to Visible light - Orange

The Sky is Blue...

[Image of a graph showing the relative spectral power vs. wavelength for Low Pressure Sodium (SO) light, and a diagram illustrating the interaction of light with the Earth's atmosphere.]
We feel safer, and less crime is committed;

A good lighting system is one designed to distribute an appropriate amount of light evenly with Uniformity Values of between 0.25 and 0.40 using lamps with a rating of at least 60 on the Colour Rendering Index. Good lighting will use energy efficient lamps in suitable luminaries. These luminaries will be positioned to minimise any light pollution so as to provide a high quality system only when and where required.
Human response to Visible light - White

Can use less power;

<table>
<thead>
<tr>
<th>Lighting class</th>
<th>Benchmark (e.g. R&lt;sub&gt;i&lt;/sub&gt; &lt; 60 or when S/P ratio of light source is not known or specified)</th>
<th>S/P ratio = 1.2 and R&lt;sub&gt;i&lt;/sub&gt; ≥ 60 (e.g. some types of warm white lamp such as metal halide)</th>
<th>S/P ratio = 2 and R&lt;sub&gt;i&lt;/sub&gt; ≥ 60 (e.g. some types of cool white compact fluorescent or LED)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F&lt;sub&gt;min&lt;/sub&gt;</td>
<td>F&lt;sub&gt;max&lt;/sub&gt;</td>
<td>ε&lt;sub&gt;min&lt;/sub&gt;</td>
</tr>
<tr>
<td>P1 or S1</td>
<td>15.0</td>
<td>3.0</td>
<td>13.4</td>
</tr>
<tr>
<td>P2 or S2</td>
<td>10.0</td>
<td>2.0</td>
<td>8.6</td>
</tr>
<tr>
<td>P3 or S3</td>
<td>7.5</td>
<td>1.5</td>
<td>6.3</td>
</tr>
<tr>
<td>P4 or S4</td>
<td>5.0</td>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>P5 or S5</td>
<td>3.0</td>
<td>0.6</td>
<td>2.2</td>
</tr>
<tr>
<td>P6 or S6</td>
<td>2.0</td>
<td>0.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

BSI Standards Publication

Code of practice for the design of road lighting
Part 1: Lighting of roads and public amenity areas

BS 5489-1:2013
Protect and improve health and wellbeing, and reduce health inequalities.

PHE is an executive agency, sponsored by the Department of Health

This report concerns Human responses to lighting based on LED lighting solutions and has been produced by Public Health England (PHE) for the Chartered Institution of Building Services Engineers, CIBSE and the specialist professional body for lighting, the society of light and lighting (SLL)
Blue Light hazard

Blue light is known to be phototoxic for the retina.

The International Commission on Nonionizing Radiation Protection (ICNIRP) regularly reviews the biological evidence and publishes exposure guidelines.

www.icnirp.org
Blue Light hazard – why might LED be bad?

The blue LEDs used in street, office and domestic LED lighting generally emit at around 450 nm to 460 nm. For this reason, there are concerns that the guidelines may be exceeded......
Blue Light hazard – why might LED be bad?
Blue Light hazard – why might LED be bad?

Weighted Irradiance
Blue Hazard function applied
Blue Light Hazard – Ocular Safety

Human responses to lighting based on LED lighting solutions

Commissioned by the Chartered Institution of Building Services Engineers and the Society of Light and Lighting
Blue Light Hazard – Ocular Safety

No UV

Negligible Infrared

LED fittings measured; Not bright enough to cause retinal damage in normal use at reasonable distances.
Blue Light Hazard – Ocular Safety

What about at non-reasonable distances?

Human responses to lighting based on LED lighting solutions

Commissioned by the Chartered Institution of Building Services Engineers and the Society of Light and Lighting
Blue Light Hazard – Ocular Safety

What about at non-reasonable distances?

At a distance of 2 m, reaching the exposure limit values for the Blue Light Hazard would require steady fixation for over 2½ hours, based on conservative calculations.
LEDs are associated with tablets and e-readers, but the light exposures from e-readers are not necessarily equivalent in illuminance or spectrum to an LED for general lighting. News articles often appear relating to people’s concerns about these devices and the concerns may spill over to LED lighting with little supporting evidence.

A recent study (Chang *et al.*, 2015) showed that reading from these devices for 4 hours before sleep can suppress and shift the onset of melatonin secretion compared to a print book. The results should be interpreted with care, as a very dim room light condition was used for reading from a print book, rather than a well-directed reading light.

PHE recently looked at potential retinal phototoxicity relating to “blue light” from a range of screens including monitors, laptops, mobile phones, as well as tablets and e-reader similar to those in Chang *et al.* (2015).

In the blue light study (O’Hagan *et al.*, 2016) the light measured from these devices was shown to be well within long-established international guidelines or safety limits (ICNIRP, 2013).
2016 Human Physiological Responses to Light Meeting Report

Existing research has addressed the fear of optical damage from LED light, assuring that short periods of direct LED light exposure would not harm the eye, however, additional work is needed to determine if prolonged exposure to LED light can cause problems.

David Sliney of the Department of Environmental Health Sciences, Johns Hopkins Bloomberg School of Public Health, spoke broadly on retinal phototoxicity, and more directly toward the “blue-light hazard.” He explained that phototoxicity occurs when individual photons alter biologically critical molecules in the retina. Photomaculopathy is blue-light retinal phototoxicity that results from a person staring at an intense light source for a long time. Sliney claims that it is difficult to receive this type of injury from LEDs because the eye has a natural aversion and involuntary eye movement to harsh light. However, more research is needed to determine whether there are issues related to chronic exposure to blue light.
Flicker

2016 Human Physiological Responses to Light Meeting Report

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Flicker comes in numerous forms, some I am going to touch on are:

• Naturally Occurring

• Tunnel lighting – Avoiding Flicker

• Wagon Wheel effect
Flicker – Natural exposure

Naturally occurring flicker
Manual Occurring Flicker
BS5489-2-2003 – Flicker – Tunnel Lighting
BS5489-2-2003 – Flicker – Tunnel Lighting

Y < X
X < Y

OK
R I S K
R I S K

Tunnel Lighting Diagram
BS5489-2-2003 – Flicker – Tunnel Lighting

ANSI/IES RP-22-11

BS5489-2-2003
### BS5489-2-2003 – Flicker – Tunnel Lighting

<table>
<thead>
<tr>
<th>MPH</th>
<th>km/h</th>
<th>m/s</th>
<th>Spacing (m)</th>
<th>Tunnel length after 20s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>6.2</td>
<td>10</td>
<td>2.8</td>
<td>1.39</td>
<td>0.69</td>
</tr>
<tr>
<td>12.4</td>
<td>20</td>
<td>5.6</td>
<td>2.78</td>
<td>1.39</td>
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<tr>
<td>18.6</td>
<td>30</td>
<td>8.3</td>
<td>4.17</td>
<td>2.08</td>
</tr>
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<td>24.9</td>
<td>40</td>
<td>11.1</td>
<td>5.56</td>
<td>2.78</td>
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<td>31.1</td>
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<td>13.9</td>
<td>6.94</td>
<td>3.47</td>
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<td>37.3</td>
<td>60</td>
<td>16.7</td>
<td>8.33</td>
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<td>43.5</td>
<td>70</td>
<td>19.4</td>
<td>9.72</td>
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<td>11.11</td>
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<td>55.9</td>
<td>90</td>
<td>25.0</td>
<td>12.50</td>
<td>6.25</td>
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<tr>
<td>62.1</td>
<td>100</td>
<td>27.8</td>
<td>13.89</td>
<td>6.94</td>
</tr>
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<td>110</td>
<td>30.6</td>
<td>15.28</td>
<td>7.64</td>
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<tr>
<td>74.6</td>
<td>120</td>
<td>33.3</td>
<td>16.67</td>
<td>8.33</td>
</tr>
</tbody>
</table>
Flicker – Wagon Wheel Effect

Most often seen in Western movies. *Recordings of any regularly spoked wheel will show it*.

The effect is a result of temporal aliasing.

It can also commonly be seen when a rotating wheel is illuminated by flickering light.

These forms of the effect are known as stroboscopic effects: the original smooth rotation of the wheel is visible only intermittently.
Flicker – Wagon Wheel Effect

Frame rate of Camera matching blade rotation
Links describing Wagon Wheel effect

http://www.mekanizmalar.com/wagon-wheel-effect.html

https://www.youtube.com/watch?v=SFblINinFsxk

https://www.youtube.com/watch?v=QOwzkND_ooU

https://www.youtube.com/watch?v=at38hbbMn7E

https://www.youtube.com/watch?v=MqLwgisyjjw
Flicker – Wagon Wheel Effect

Stroboscope....
Flicker – Wagon Wheel Effect

All Very nice....
Flicker - Dimming

Methods of Dimming – to 55% examples.....

- PWM
- Constant current
- Combi Dim
FLICKER

Methods of Dimming – to 55% examples.....

**PWM**
- Switching LED on/off in fixed frequency
  - Good dimming regulations at low levels
  - Potential noise generation
  - Potentially undesirable flicker, depending on frequency

**Constant current**
- Varying LED current, LED always on
  - No flicker
  - No noise generation
  - Higher LED efficacy at lower dimming levels

**Combi Dim**
- LED are not switched off (amplitude change)
  - Modulation in *variable* frequency
  - Less current when possible
  - Best dimming regulations at deep dimming levels
  - High duty cycle frequencies
    - No flicker
Protect and improve health and wellbeing, and reduce health inequalities.

PHE is an executive agency, sponsored by the Department of Health

This report concerns Human responses to lighting based on LED lighting solutions and has been produced by Public Health England (PHE) for the Chartered Institution of Building Services Engineers, CIBSE and the specialist professional body for lighting, the society of light and lighting (SLL)
Of the Street light fittings that were tested – flicker was not a major issue. Though it has been in the past
Photo-induced Epilepsy
3-30Hz (can go up to 60 Hz)

Flicker Fusion Frequency
80Hz (assumed Max)

Annoying, Headaches, Eyestrain
Up to about 100Hz – maybe higher

Other Effects (non-specific adverse health effects)
Up to 1 kHz
Percentage Flicker

The most widely quoted measure of the amount of flicker in the light given off from lamps. It should be given along with the flicker frequency.

Example;
- Ten cycles in 0.1s
- Curve Smooth (sinusoidal)
- Max illuminance ~0.95
- Min illuminance ~0.75

0.01s > 1/0.01 = 100 Hz (x2 UK 7& Ireland mains freq)

Percentage flicker =

100% x ((0.95 - 0.75) ÷ (0.95 + 0.75)) = 11.8%
The incandescent, and Tungsten Halogen lamps have Percent Flicker between 9.6% and 12.4%. Use 15% as a rule of thumb figure for new technology. i.e. no worse than old technology.
Flicker Index

Flicker Metrics

Not really aimed at adverse health effects

**Flicker index**

Flicker index is calculated as the difference of the area above divided by the sum of the areas above and below the average relative illuminance.

Example, flicker index = 0.072
<table>
<thead>
<tr>
<th></th>
<th>100Hz</th>
<th>1kHz</th>
<th>Smoothed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Flicker</td>
<td>12.7%</td>
<td>2.6%</td>
<td></td>
</tr>
<tr>
<td>Flicker index</td>
<td>2.1%</td>
<td>0.4%</td>
<td></td>
</tr>
<tr>
<td>Percent Flicker</td>
<td>23.4%</td>
<td>1.2%</td>
<td></td>
</tr>
<tr>
<td>Flicker index</td>
<td>2.0%</td>
<td>0.2%</td>
<td></td>
</tr>
<tr>
<td>Percent Flicker</td>
<td>17.3%</td>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td>Flicker index</td>
<td>5.1%</td>
<td>0.2%</td>
<td></td>
</tr>
<tr>
<td>Percent Flicker</td>
<td>7.8%</td>
<td>0.4%</td>
<td></td>
</tr>
<tr>
<td>Flicker index</td>
<td>2.0%</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>Percent Flicker</td>
<td>10.7%</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>Flicker index</td>
<td>2.7%</td>
<td>0.2%</td>
<td></td>
</tr>
</tbody>
</table>
Flicker – Domestic LEDs
IEEE Std 1789-2015
IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers

Mod\% = 0.08*\(f\)
Mod\% = 0.025*\(f\)

Recommended Operating Area
Summary (information sources)

• Nature – SLL - Lighting Guide 6
• Overview of Light effects – IESNA Handbook
• Direct responses to Light / Perceived Light – IESNA Handbook
• Light Colour - securedbydesign.com – ILP PLG03 – BS5489-1
• Blue Light Hazard – SLL - PHE ‘Human responses to LED’
• Flicker – BS5489-2 – RP-22 - SLL - PHE ‘Human responses to LED’
END
Sky glow

Indirect - Human Response to Light

When ever we put lighting outside, some light is going to go to places we don’t want it to go.

18% of the terrestrial surface of the earth is exposed to night sky brightness that is considered “polluted” by astronomical standards.

Lower angle light
Lower light levels
Maybe less wavelengths of light.