Aalto University
School of Electrical
Engineering

Lighting research at Aalto University – Lighting for health and wellbeing

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Lighting Unit

Department of Electrical Engineering and Automation

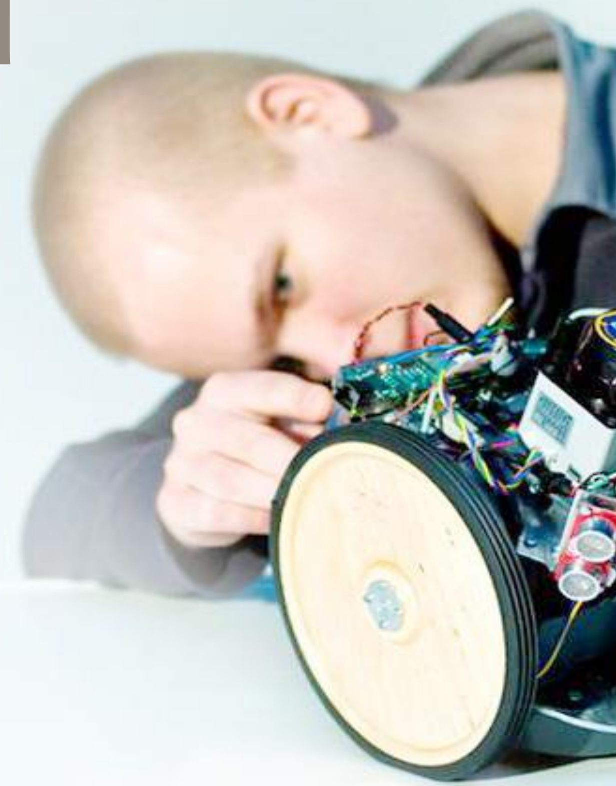
Aalto University, Finland

Outline

- Aalto University and Lighting Unit Intro
- Research Activities/projects
- Service to industry
- EU-project SSL-erate and Lighting for health and well being

Three Finnish higher education institutes, leaders in their field, formed Aalto University on 1st January 2010

Where *science* and *art* meet *technology* and *business*



A community of: 20,000 students and 4,700 faculty & staff, with 340 professors.

School of Engineering	School of Business	School of Chemical Technology	School of Science	School of Electrical Engineering	School of Art, Design and Architecture

School of *Electrical Engineering*

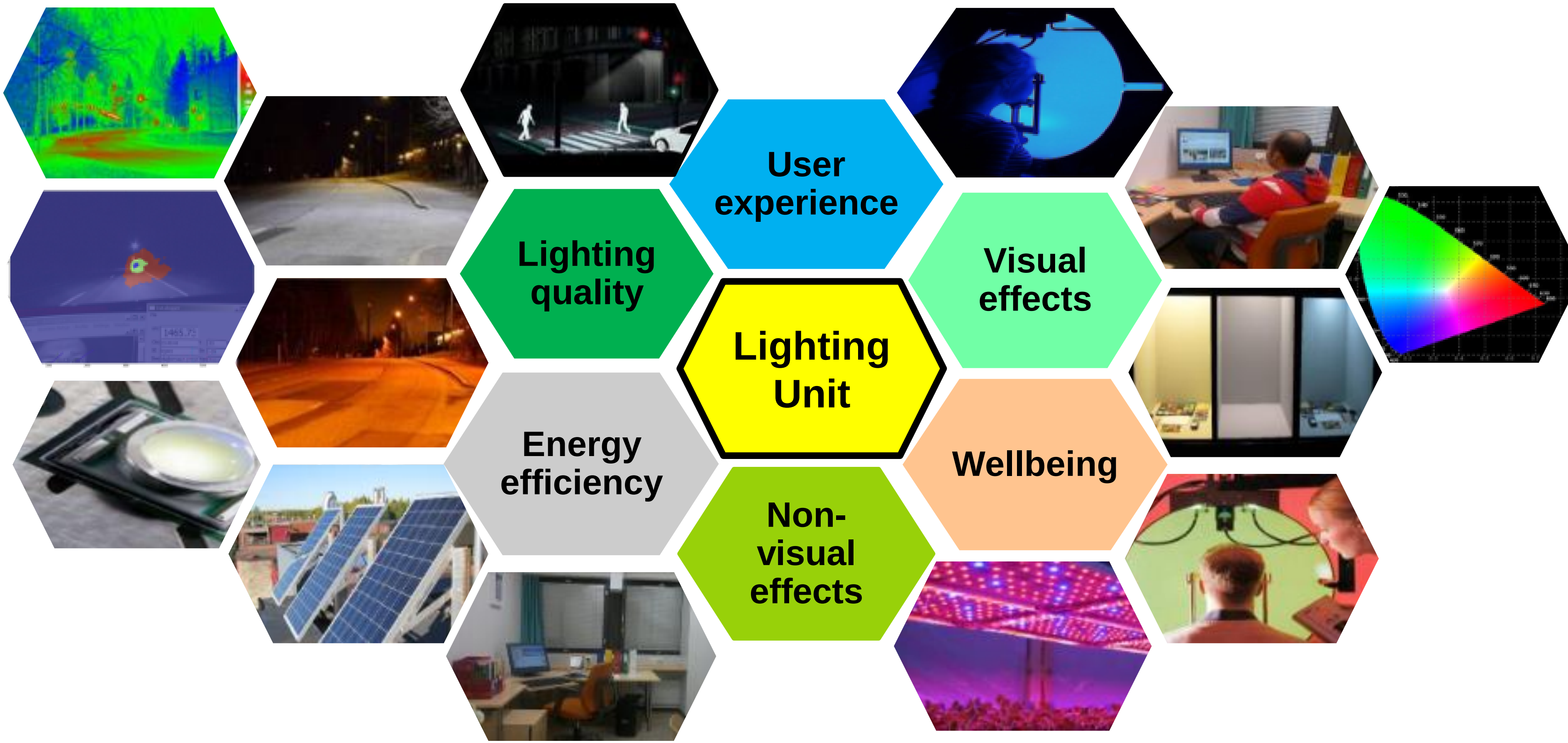
Staff 660
Professors 50
Degree students 3 432

Basic research, latest technologies and high quality engineering

Areas covered:
Micro- and nanosciences
Radio science and engineering
Signal processing and acoustics
Electrical engineering and automation
Communications and networking

Research infrastructures:
Metsähovi Radio Observatory
Aalto Nanofab

Lighting Unit – about 10 people



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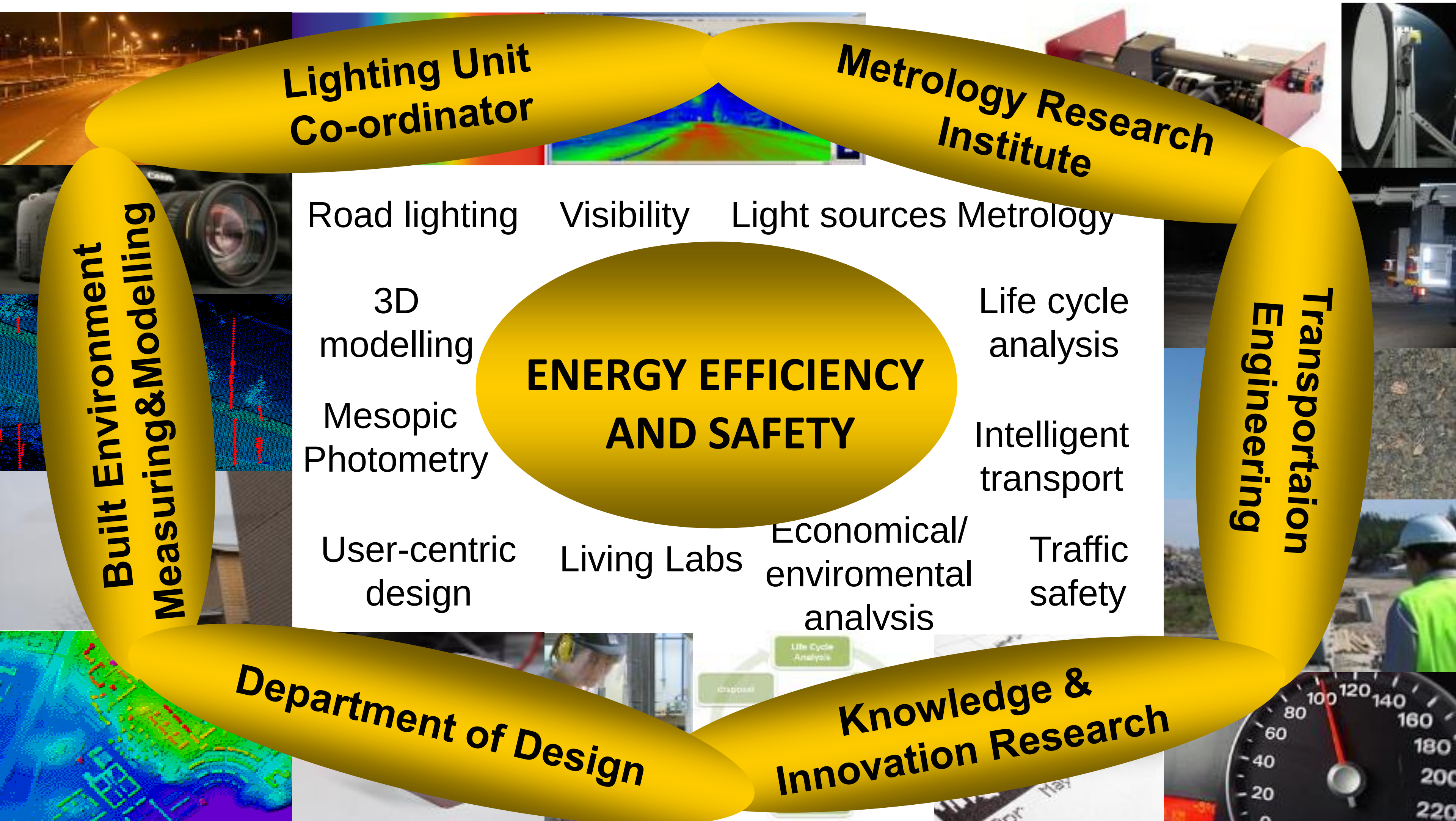
Finland

Lighting Unit - Doctoral Thesis Works 2005-2015

Marjukka Eloholma: Visual performace based mesopic photometry (2005)
Pasi Orreveteläinen: Contrast sensitivity and reaction time at mesopic light levels (2005)
Jaakko Ketomäki: Contrast threhold in the mesopic and photopic luminance ranges (2006)
Henri Juslén: Benefits of lighting for industry - case studies (2007)
Meri Liesiö: Visual performance at low light levels (2007)
Liping Guo: Lighting control in street lighting (2008)
Paolo Pinho: LEDs for plant applications (2008)
Pramod Bhusal: Energy-efficiency of lighting in developed and developing countries (2009)
Aleksandr Ekrias: Development and enhancement of road lighting principles (2010)

Ater Amogpai: LED lighting compined with solar panel in developing countries (2011)
Emilia Rautkylä: Biological effects of light (2011)
Anne Ylinen: Development and analysis of road lighting energy efficiency (2011)
Leena Tähkämö: Life cycle assessments of light sources (2013)
Heli Nikunen: Perceived restorativeness, preference and fear in outdoor spaces 2013)
Wei Luo: Visual adaptation and mesopic photometry in pedestrian way lighting 2014
Mikko Hyvärinen: Methodological questions in lighting acceptance and preference studies (2015)
Janne Viitanen: Energy efficient lighting systems in buildings with integrated photovoltaics (2015)
Mohammad Islam: User acceptance studies for LED office lighting (2015)
Rajendra Dangol: Subjective preferences for light colour and LED lighting (2015)
Can Cengiz: Visual Performance in mesopic conditions: Towards determination of adaptation luminance (2015)
Mikko Maksimainen: Spatial phenomena of human vision in continuously transforming visual field (*expected 201*
Rupak Baniya: LED colour characteristics in office lighting (*expected 2016*)

Aalto Energy Efficiency - Light Energy (2012-2016 + 3 y)
Efficient and safe Traffic Environments



CIE Mesopic Photometry

- Describes mesopic spectral sensitivity in the luminance region of 0.005 – 5 cd/m^2
- Provides common metric for dimensioning and measuring lighting at low light levels (street, outdoor areas, pedestrian ways etc.)

$$V_{mes}(\lambda) = m\, V(\lambda) + (1\text{-}m)\, V'(\lambda)$$

ISBN 978 3 901906 88 6

CIE

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

RECOMMENDED SYSTEM FOR MESOPIC PHOTOMETRY BASED ON VISUAL PERFORMANCE

CIE 191:2010

UDC: 612.843.362.3

Descriptor: Mesopic vision, Photometry, Night value curve

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Why do we need different photometry for low light levels (0.005 - 5 cd/cm^2)?

PHOTOPIC CONDITIONS
DAYLIGHT

CONES

$V(\lambda)$ (est.1924)

MESOPIC CONDITIONS

RODS AND CONES

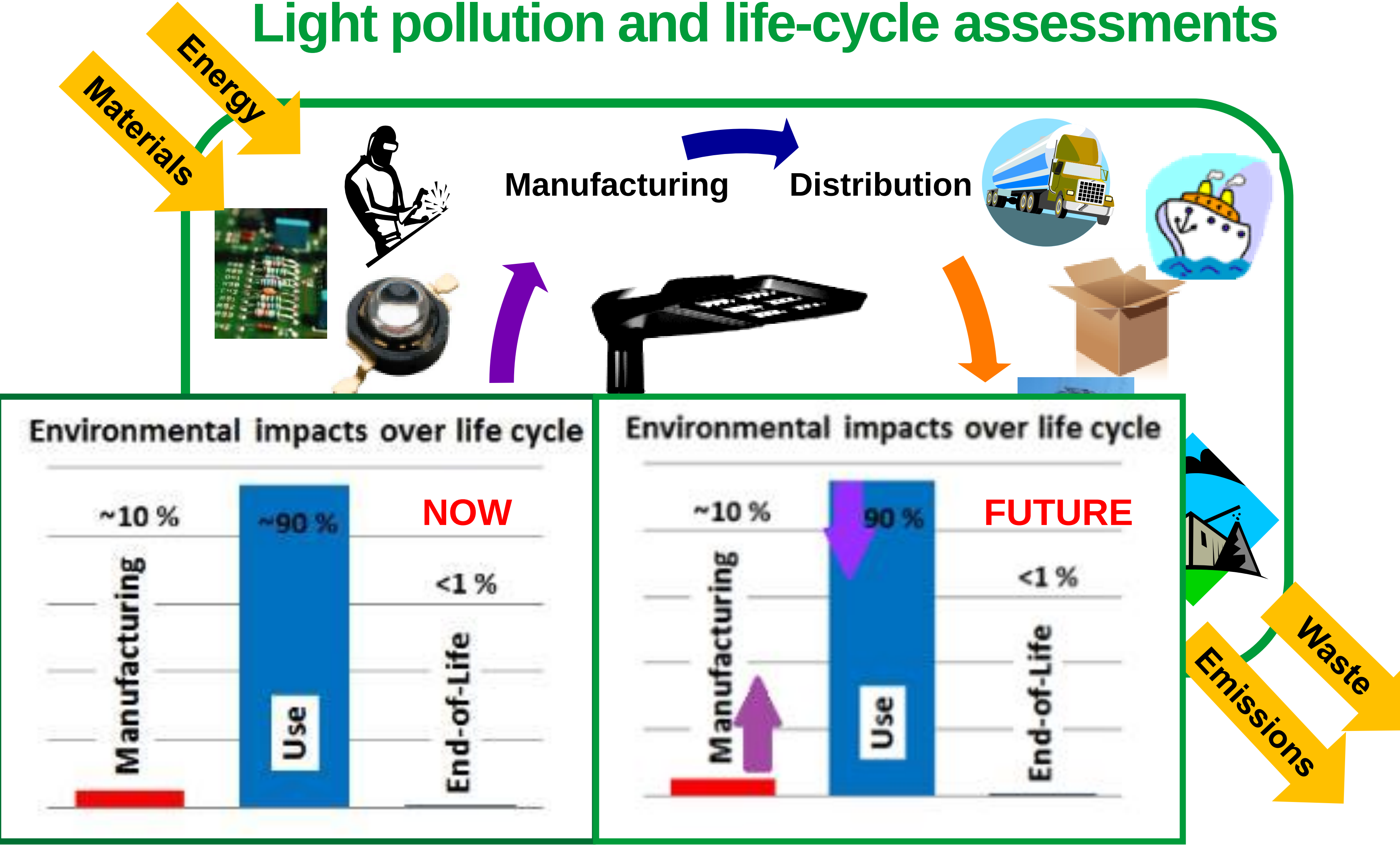
$V_{mes}(\lambda)$ (est. 2010)

SCOTOPIC CONDITIONS
MOONLIGHT

RODS

$V'(\lambda)$ (est. 1951)

Academy of Finland – Environmental impact of lighting: Light pollution and life-cycle assessments

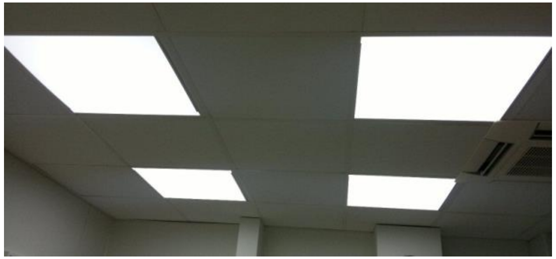


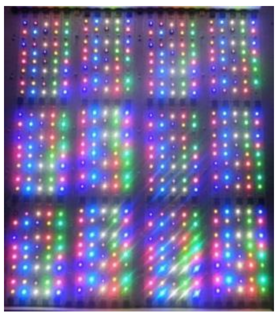
COST Action ES1204
Loss of the Night Network (LoNNe)

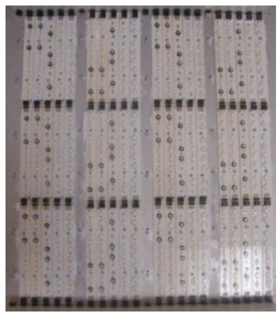
Horticultural LED Lighting

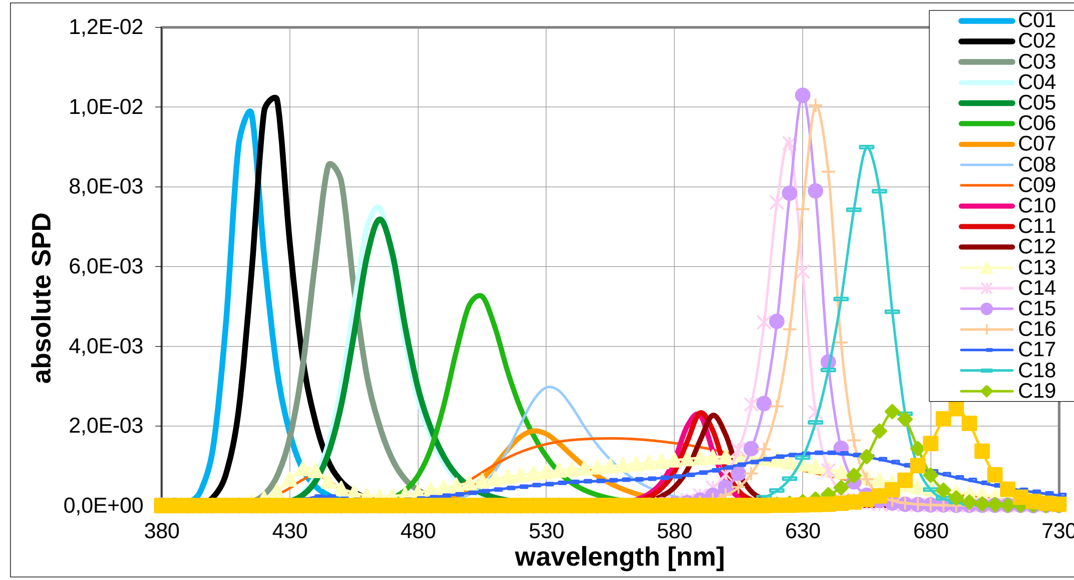
- Main goals
  - Efficient use of energy
  - Growth control and optimization (e.g. morphogenesis, germination, flowering and nutritional value)
  - Increase crop productivity
  - Implement versatile lighting tailored for specific crops

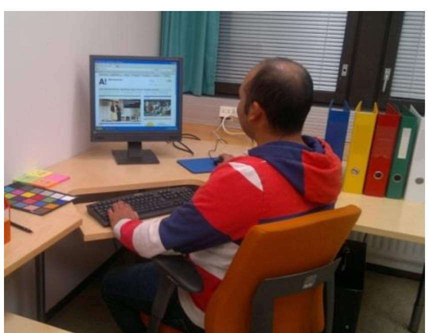
Color fidality and color preference studies

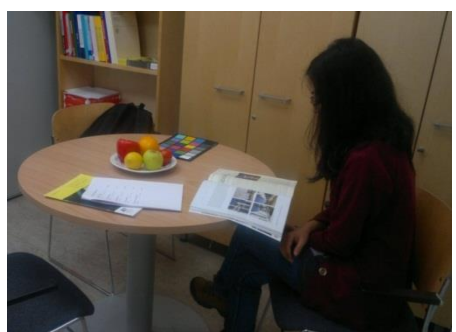




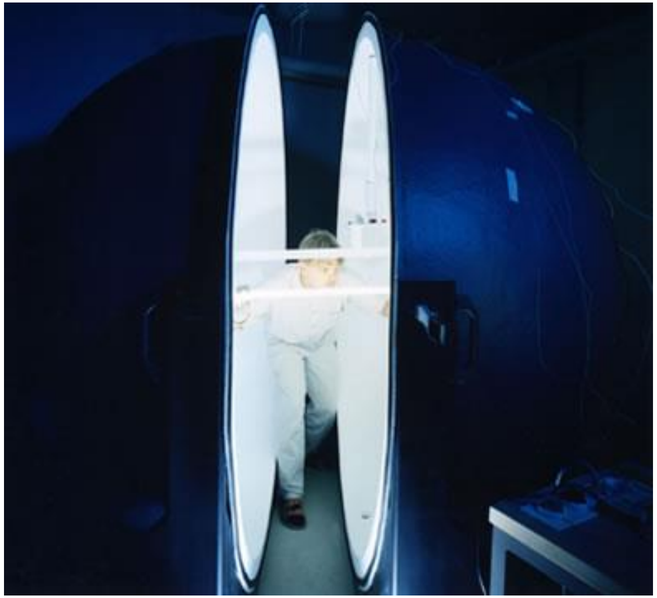


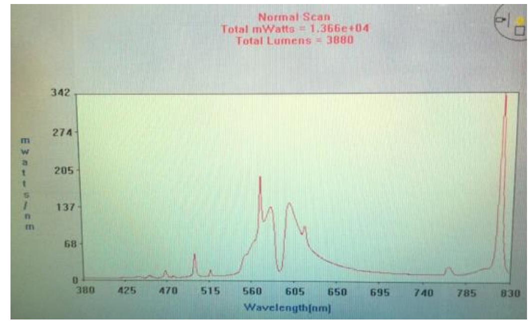


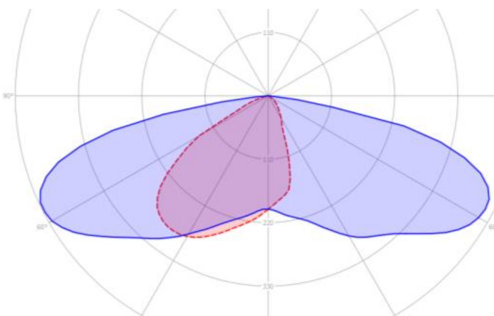




Lighting Unit – Services to Industry







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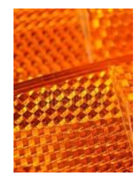
Lighting Unit – Services to Industry



Education Development and Capacity Building Projects in Asia , Africa..

- PROMILL - Promoting Illuminating Engineering Studies and Research in **China** (EC funded) ***2003 - 2006***
- ENLIGHTEN - Educational and research networking between Europe and ***Nepal*** (EC funded) ***2005-2008***
- ELMCA - Curricula Development for Universities in **Thailand, Vietnam, Philippines** (EC funded) ***2007-2009***
- Networking and capacity building project in **Nepal**, **Vietnam** (Foreign Ministry funded) ***2011-2013***
- Networking on Environmental Safety & Sustainability (EC funded) – **Japan, Korea, Australia, New Zealand** ***2012 - 2016***
- Energy efficient lighting curricula development in **Ethiopia**, **Nepal** (Foreign Ministry funded) ***2013-2015***
- Networking and capacity building project in **Nepal**, **Ethiopia** (Foreign Ministry funded) ***2014-2015***

European Commission project SSL-erate: Accelerate SSL Innovation for Europe

24 partners / 13 countries

Light for life: are we using the right light?

.....too little light in daytime

.....too much light by night

consequences

- circadian misentrainment
  problems with body clock, similar to jet-lag
- problems with sleep & alertness
- compromised mood, functioning, well-being and health….

HUMAN CENTRIC LIGHTING:
designed to benefit human health & wellbeing

the right light, at the right time & place

Health and wellbeing (SSL-erate WP3)
non-visual effects of light

- Identify non-visual effects for five application domains (education, healthcare, workplaces, homes, cities)
- Create dose-response curves (scientific studies): which non-visual effects occur in what light intensity ranges
- Give guidance on which light metrics to use in practice

Accelerate uptake Solid State Lighting technology

Lighting in education

scientific insights, new functions & use cases

- vary brightness and blue content
  - helps to get ready for the day
  - supports alertness and concentration during lessons
  - better sleep (duration & timing) and thus learning

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- vary brightness and blue content
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  - supports alertness and concentration during lessons
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- innovation opportunities
  - Dynamic regulation & presets (intensity, spectrum) to support activities (concentration, relaxation,…)
  - Context adaptation & personalization

Workplace Lighting
scientific insights, new functions & use cases

- varying brightness and spectrum influences
  - alertness, vitality, cognitive performance, attention
  - environmental appraisal
  - subsequent sleep (duration & timing)

- From (well-controlled) lab to real-life
  - Balance acute effects & circadian effects



Workplace Lighting

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- varying brightness and spectrum influences
  - alertness, vitality, cognitive performance, attention
  - environmental appraisal
  - subsequent sleep (duration & timing)

- From (well-controlled) lab to real-life
  - Balance acute effects & circadian effects

- innovation opportunities
  - Adapt light settings to user and context
  - Dynamic regulation (intensity, spectrum,)
  - Promote alertness @ start work/shift & post-lunch
  - Flexible regulation (time of year, task, personalization,…)

Healthcare Lighting
scientific insights, new functions & use cases

- Treating depression on a hospital ward
  - Intense daytime light exposure
  - Dawn-simulation

- Elderly:
  - intense daytime light enhances adaptation of circadian rhythms to the natural day-night cycle
  - Dementia: limited evidence better neuropsychiatric behaviour



SSL-erate

Healthcare Lighting

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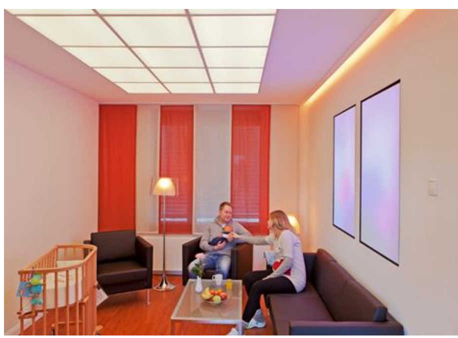
- innovation opportunities
  - User-tunable light (staff/patient/resident): being in control enhances independency, confidence and positive attitude (better mood/healing)
  - 24h light-dark cycle: dawn simulation, cool light that fluctuates with warm light over the course of the day (14h), warm light in the evening, sufficiently dimmed light at night (all rooms & corridors)
  - Use daylight in architecture as much as possible & avoid glare

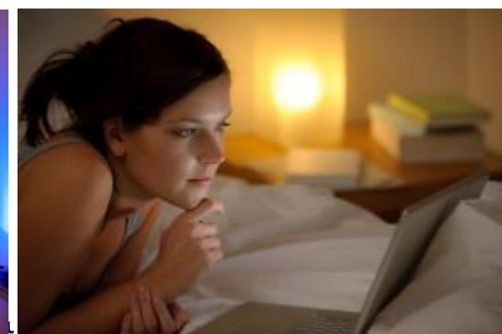
Domestic lighting

scientific insights, new functions & use cases

lightingforpeople
CONNECTING OPPORTUNITIES FOR INNOVATION

- In the evening, blue-enriched light
  - Alerts
  - Compromises sleep: longer sleep-onset, less deep sleep and sleep quality
- In the (early) morning, dawn simulation (bedroom):
  - beneficial effects on sleep inertia & daytime well-being and cognitive performance
- lab results urgently need translation to real-life





SSL-erate

Domestic lighting
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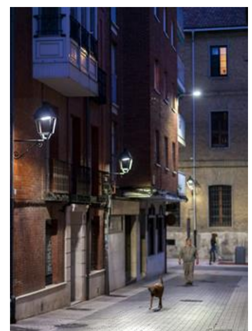
- innovation opportunities
  - Apply light in the early morning and late evening (best sensitivity)
  - During daytime use cooler color temperatures (i.e., blue-rich light) in rooms with little/no natural light entrance
  - Intelligent, dynamic light solutions: simulate dawn and dusk, automated photoperiod of about 12 hours of sufficient brightness and 12 hours of reduced light (relatively dim, blue-deprived light or dark)

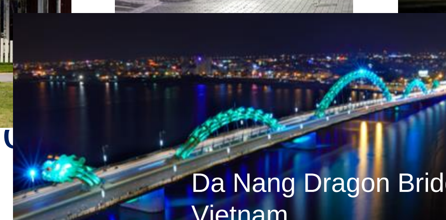
Smart Cities & Lighting

scientific insights, new functions & use cases

- ensuring sufficient visibility, higher perceived safety, reduce criminal activity
- encourage activity/recreation (pedestrian and cyclist), enhance atmosphere, social life & well-being in cities
- light at night must be handled with care, not to disrupt sleep and health



– Address needs



Smart Cities & Lighting

scientific insights, new functions & use cases

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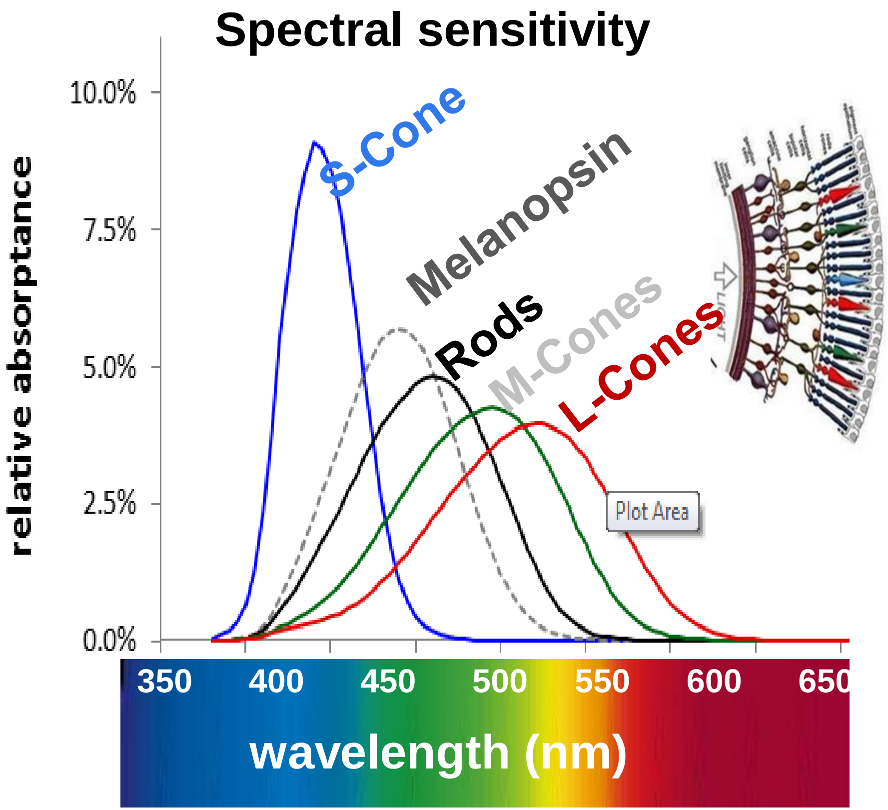
- innovation opportunities
  - carefully choosing the spectra, determining the timing and defining the light intensity range (min and max) of the lighting system
  - Involve car manufacturers in future road lighting
  - Limit blue-content (less circadian active, fewer insects)
  - Address needs of (elderly) pedestrians

Quantify light via five photoreceptor inputs



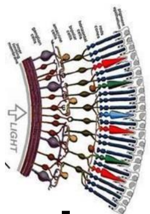
Lucas et al. Trends. Neurosci. 2014

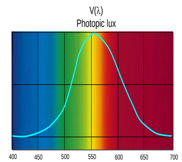
photoreceptors interplay & total spectral sensitivity depends on (non-visual) effect, timing, intensity, adaptation state...

)

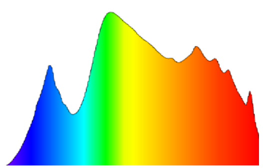
Rethinking light beyond vision and lux…

Visual system





V(λ) - lux
555 nm



spectrum * V(λ)

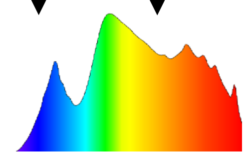
Lux

Non-visual system

rod **G-cone** **R-cone** **B-cone** **Melanopsin**

sensitivities retinal photoreceptors

R	MC	LC	SC	M
496 nm	530 nm	558 nm	419 nm	480 nm



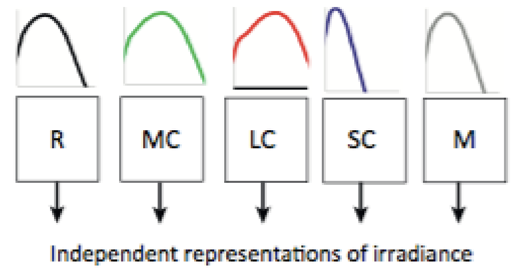
spectrum * sensitivity: (eq.) opic Lux

Lucas et al., TINS 2014

Rhodopic Lux
Chloropic Lux
Erythropic Lux
Cyanopic Lux
Melanopic Lux

new quantities for HCL

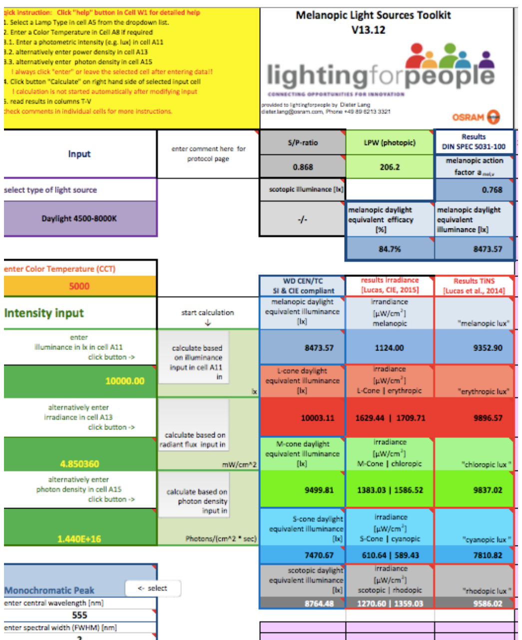
Measuring light

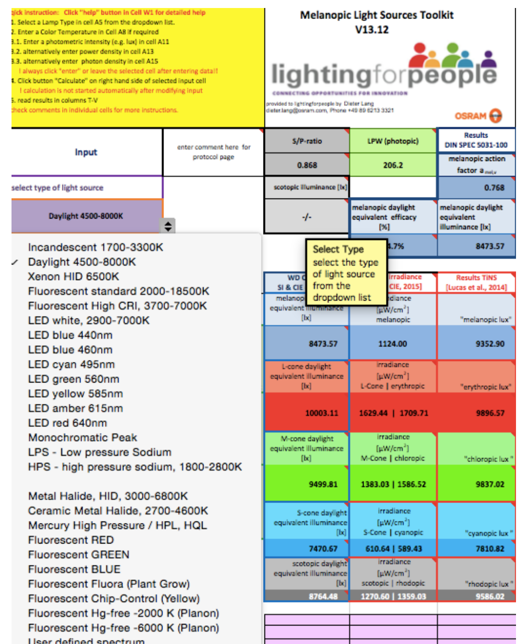


- Lucas et al (2014) created a tool to quan

photoreceptor weighted irradiances

- Improved by Dieter Lang (α-opic daylight equivalent illuminance; and α-opic action factor)

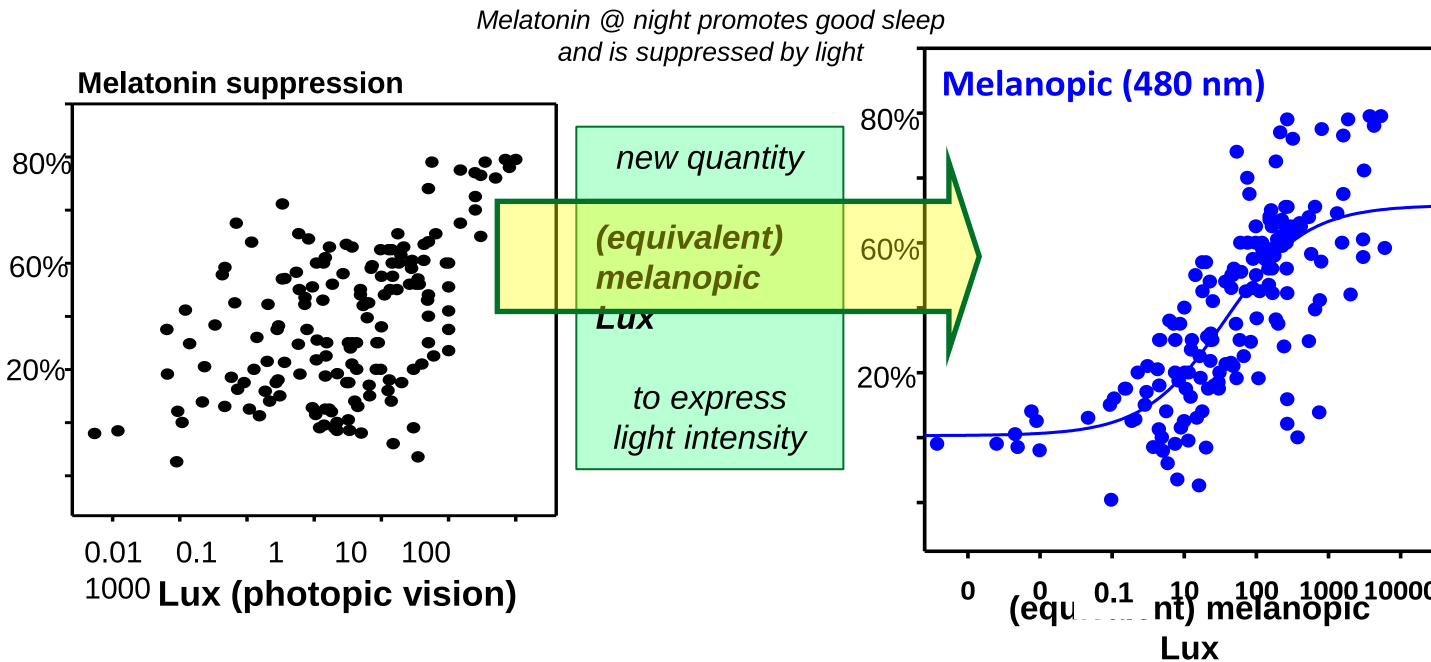




"…allows calculation of melanopic and α-opic data for different light sources at different intensities"

"…primarily intended for

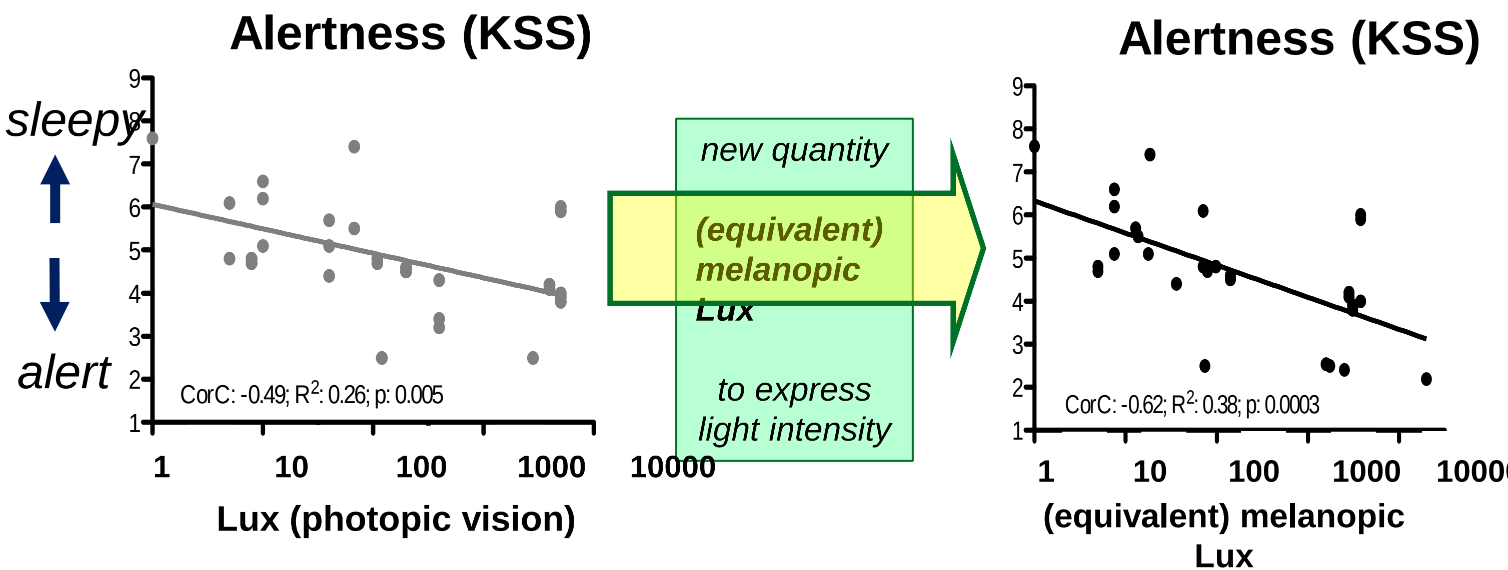
Melatonin suppression and light intensity



Lux does not predict melatonin suppression

"melanopic Lux" predicts melatonin suppression

Alertness and light intensity



Alertness correlates with log(lux)

Alertness correlates more strongly with log("melanopic lux")

Conclusions

- Melatonin suppression: lux (photopic vision) is not predicting the response
- α-opic irradiances are expected to be useful predictors for non-visual effects of light in HCL, especially for narrow spectral bands, mixed colors or special whites
- The lighting practice needs SI compliant metrics:
  - unit “α-opic lux” is not SI-compliant
  - α-opic irradiance & α-opic daylight-equivalent illuminance
  (multiplication factors, definitions & notations pending in CIE)
- Start using α-opic irradiances to design light conditions that achieve, or avoid, certain non-visual effects.
- Application example for dynamic light solutions:
  - offer high melanopic irradiances during daytime
  - and minimize melanopic irradiance during the night

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