Lucerne University of
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Technik & Architektur
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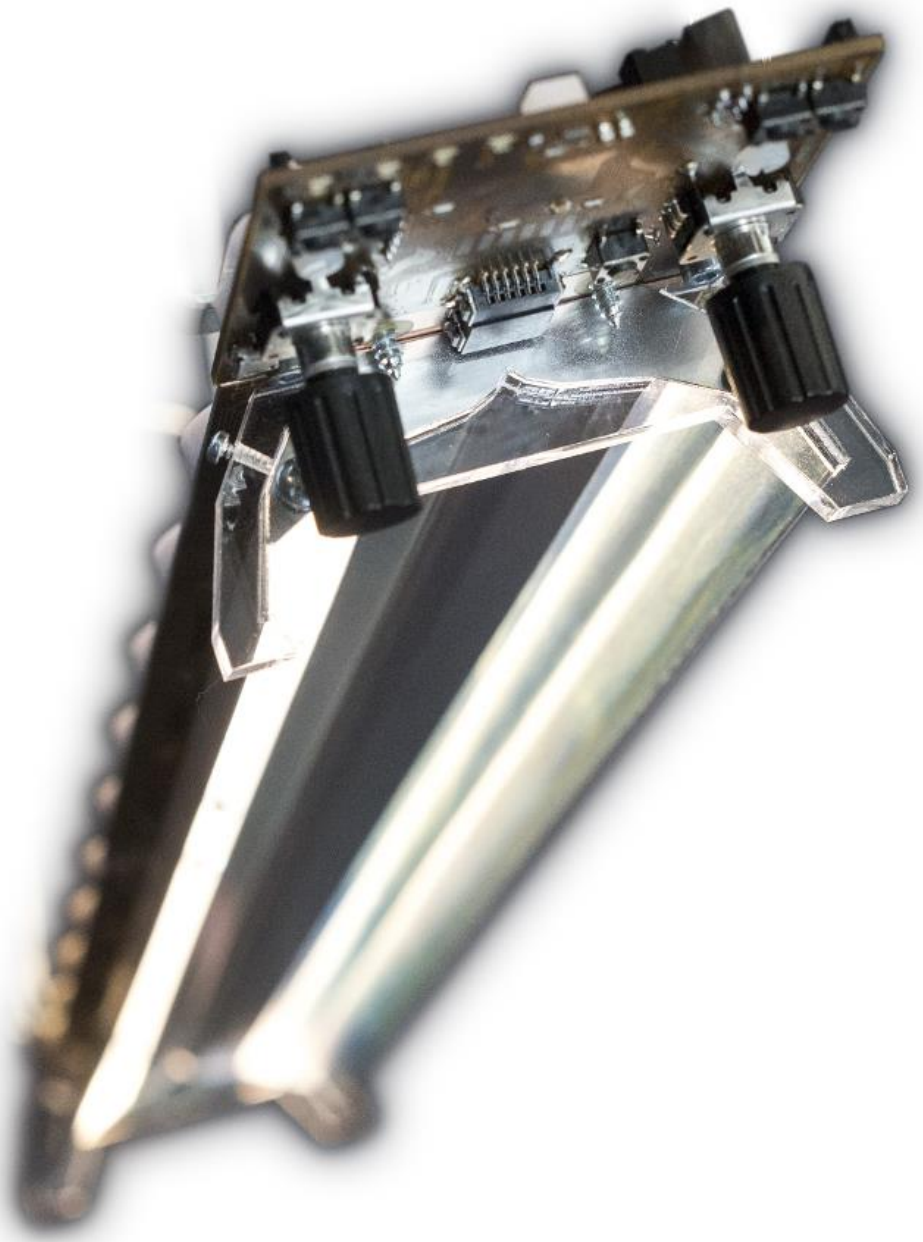
Smart Lighting
Technology Demonstrator Luminaires



Swissphotonics Smart Lighting Workshop
EPFL Lausanne Rolex Centre
30. October 2015

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Human centric Smart Lighting Luminaires Demonstrators

Contents

Pendant Luminaire

Table Luminaire

Extended table Luminaire

Why technology demonstrator?

- Demonstrator show the technology and are kept purely functional
- It has deliberately avoided a "shell" or "body“

Why?

HSLU (Lucerne University of Applied Sciences and Arts) helps enabling

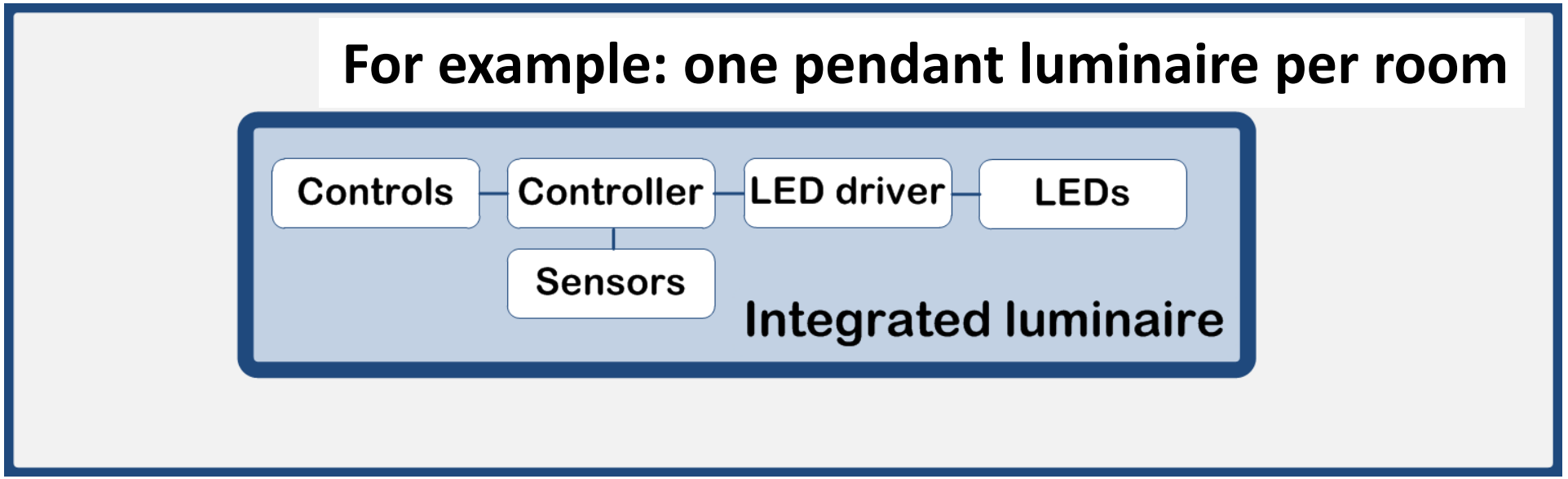
smart lighting technology for small and middle size companies

How?

- Demonstrator is independently developed by HSLU
- HSLU enables the technology through support and know-how transfer
- Product and design is developed by industrial partner

Our vision
Human centric lighting for everybody at home

Our objective
- Easy to use
- Good light quality
- Biological effective
- Energy efficient
- Long life



Targets for Demonstrator
- State of the art luminaire for residential use
- Plug & Play: No user programming or configuration required

Requirements: Classical and human centric quality features

Good lighting Classic quality features

- Standard series 5035 (partly)
- DIN SN/EN 12464-1

- **Visual comfort**
- **Visual ambience**
- **Visual performance**

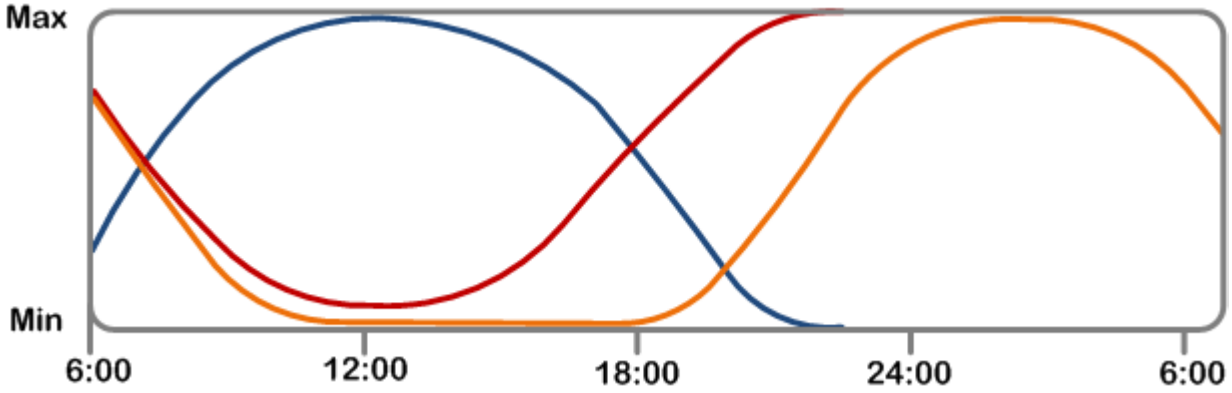
Further criteria for the lighting design

- Daylight Integration
- Change of the lighting situation
- Energy efficiency
- Custom settings

Chronobiological relevant lighting (new features)

Circadian performance requirements for lighting

- Planning recommendation DIN SPEC 67600
- Notes on melanopic effect factor DIN SPEC 5031-100



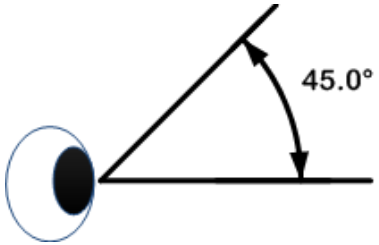
- Curve of the hormone levels of melatonin
- Importance to have light with low melanopic effect (warm white)
- Artificial lighting similar to daylight with high biological effectiveness (cold white, more blue portion)

Specification for human centric lighting

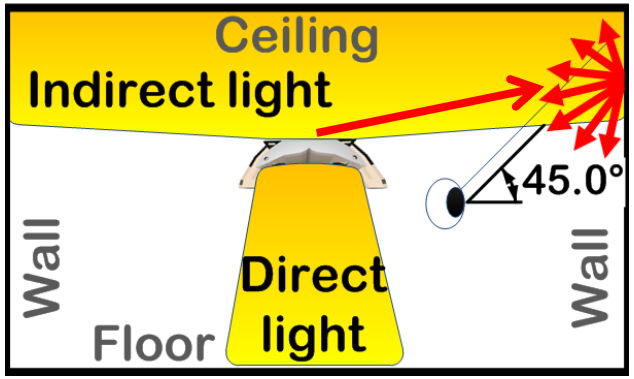
- We considered the values of the planning recommendation
  - Illuminance level from 500lx to 2000lx
  - Color temperature <3000K to >5300K

- Compared to conventional lighting a biological effective lighting has to provide higher illuminance an color temperature range

- Light angle and intensity at eye
  - 250 lx vertical measured
  - Entry angle 0° to 45°
  - Glare free



Ideal light entry angle due to position of light receptors in the eye for circadian synchronization



Conclusion

- Indirect light required for floodlighting the ceiling and walls

What LED color temperature for low melanopic effect?

Suggested is <3000K but how much less?

Dining table at 3100K

Dining table at 2100K

Dining table at 1750K

- According to a newer publication 2100K is recommend for night-light.
- It has a good user acceptance and causes a low melatonin delay.
- Our LED Selection: 2200K LEDs

Quelle: Licht 2016/4 Gesunde Nachtbeleuchtung

Approach for smart lighting luminaire (pendant luminaire)

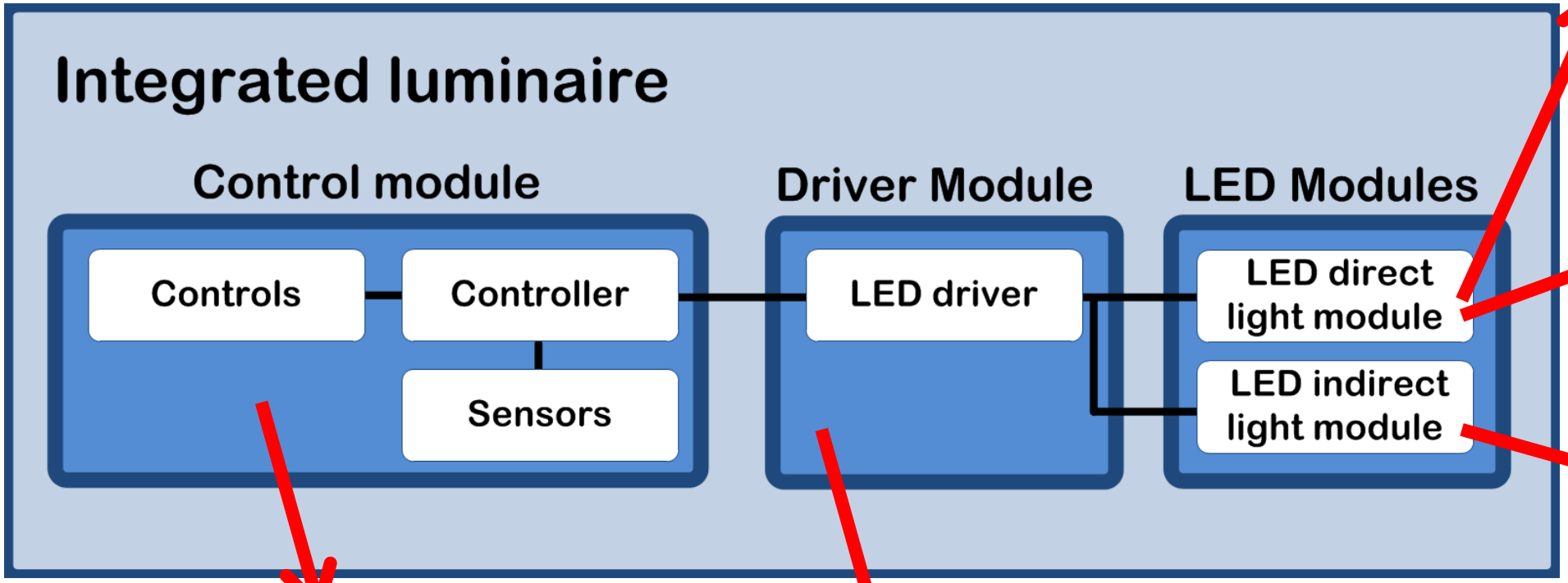
- Direct light
  - 38 mid power LED
    warm white 2200K, CRI80, total 1250 lm
  - 38 mid power LED
    cool white 5700K, CRI80, total 1370 lm

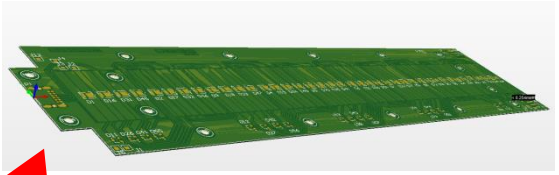
- Indirect light
  - 18 mid power LED
    warm white 2700K, CRI80, total 970 lm
  - 18 mid power LED
    cool white 5000K, CRI80, total 1110 lm

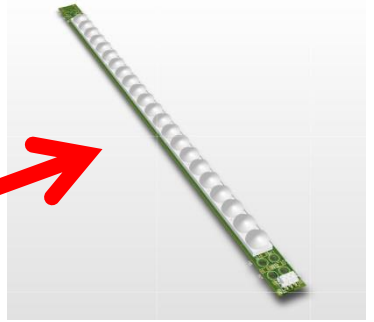
- Integration of a classical embedded system into a luminaire
  - Microcontroller
  - Integrated time base (real time clock)
  - Sensors
  - LED drivers

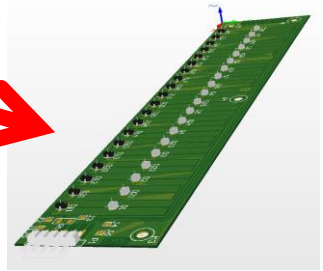
for
- Independent control of illuminance and color temperature
- dependent on time and ambient light

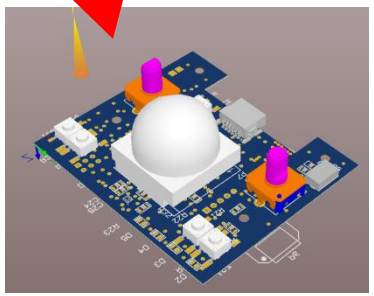
Reducing complexity with a modular concept

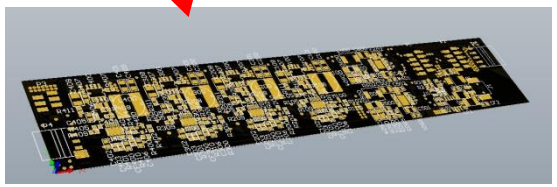










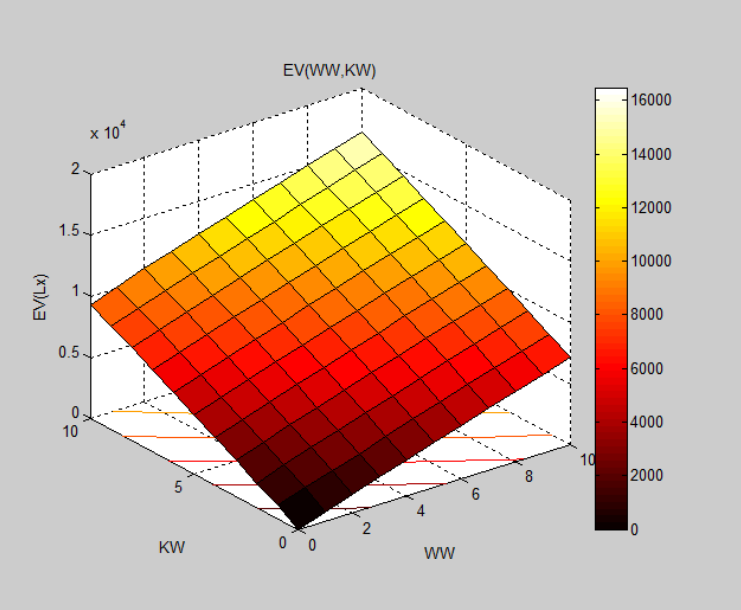


Advantages

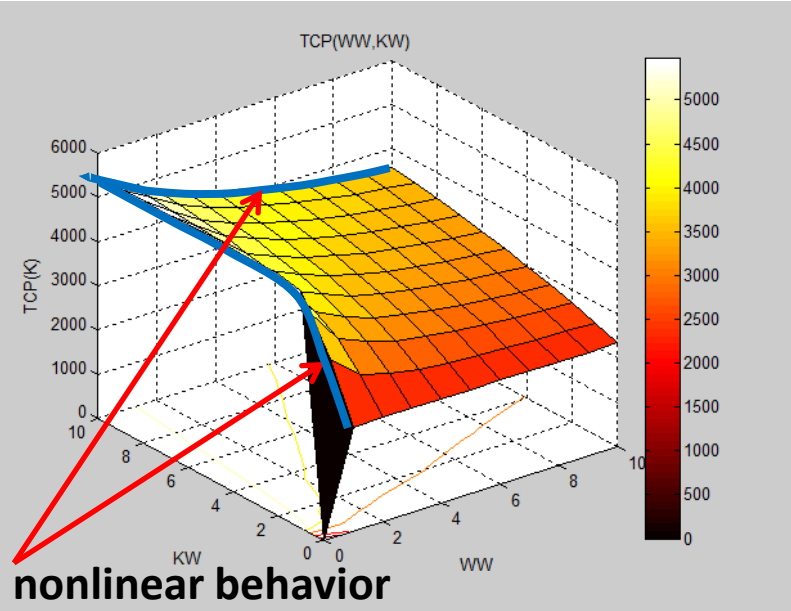
- Reusable in different products
- Easily adaptable to better LEDs
- Replaceable in case of failure

Challenges in producing light with variable color temperature

Illuminance depending on the PWM control value



Color temperature as a function of the PWM control value



Findings

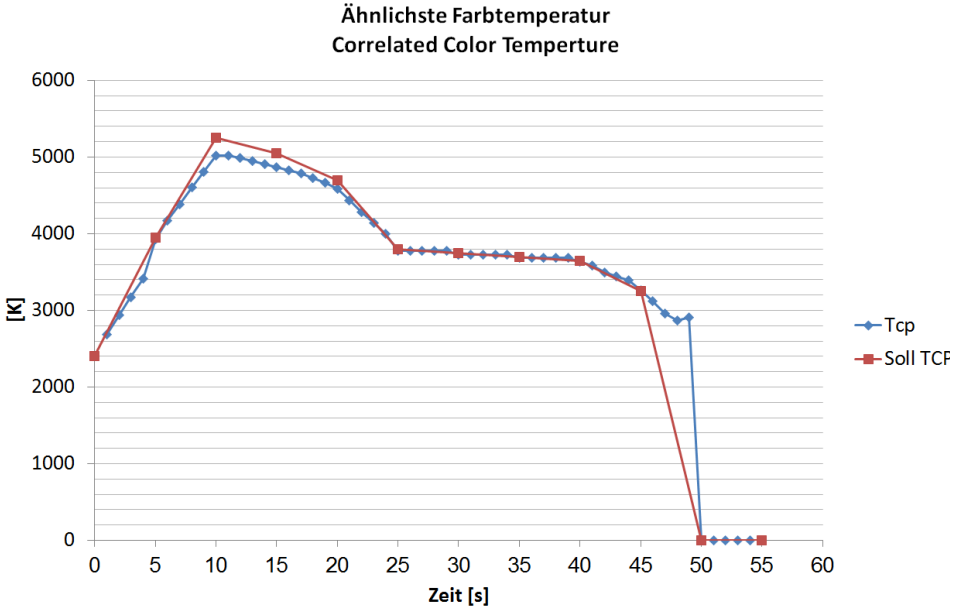
- The dependency of the resulting color temperature from the control value (PWM) is nonlinear
- It depends not only on the control value but also on the efficiency of the LED
  - Different behavior between warm and cold-white LEDs (same type)
  - Reason: They are not equally efficient (due to different phosphor)

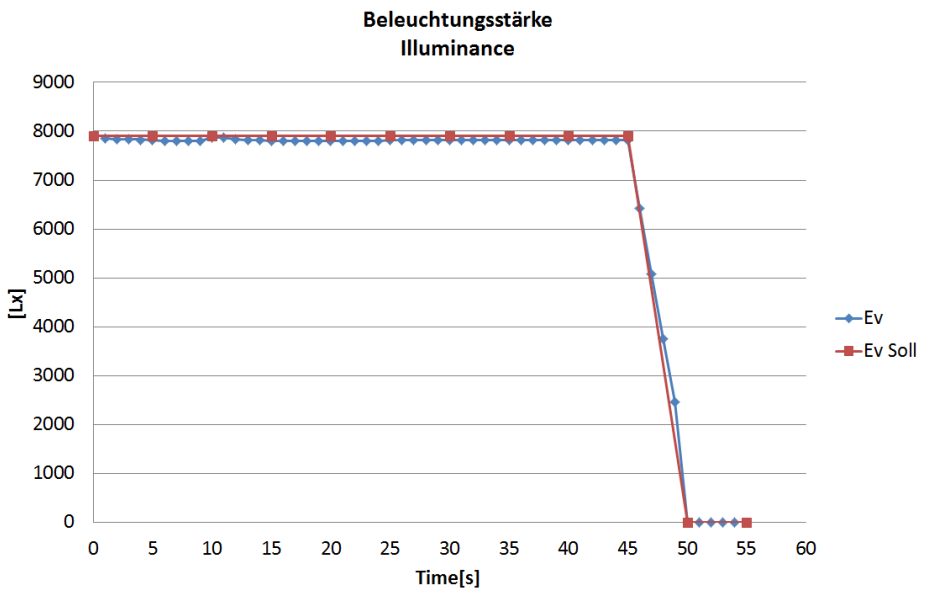
Causes - The LED efficiency is depending on the LED current (temperature)
- LED temperature is also dependent on mechanical design (heat dissipation: housing, PCB, heat sink)

Conclusion - For good control, due to the manufacturing tolerances for LED flux and color, **individual calibration of each luminaire is suggested**

Precisely controlling of color temperature and illuminance

- A look-up table based control software is implemented in the control module
- Shown is the result of the performance test of the luminaire (control-, driver- and led module)
- The aim of the tests: Constant illuminance at a given color temperature variation





Conclusion

- precise control of illuminance and color temperature is achievable with an calibration procedure integrated in the production

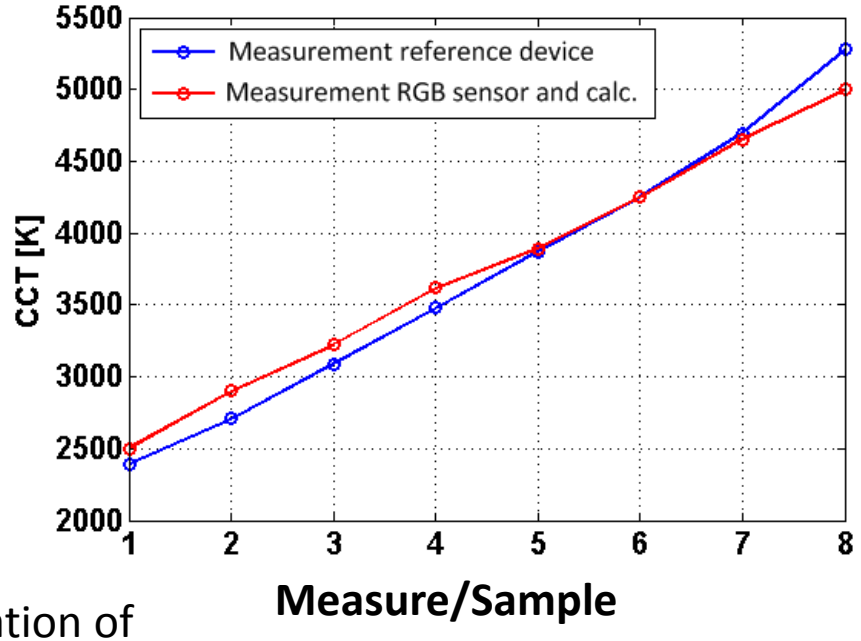
Use of 1.50$ RGB Sensor for color temperature measurement

Target
- Measuring intensity and color temperature

Implementation
- Use of a cheap digital RGB Sensor
- Deriving color temperature from RGB values
- Calculations with microcontroller
  - Data conversion (CCT from RGB)
  - Error compensation (Calibration needed)
- Two sensors integrated
  - One looks in direction ceiling
  - One looks in direction floor

Sensor cost: 1.50$ 3.5k Units (Digi-Key)

Result of accuracy of color temperature measurement
- The maximal error is 5.2%

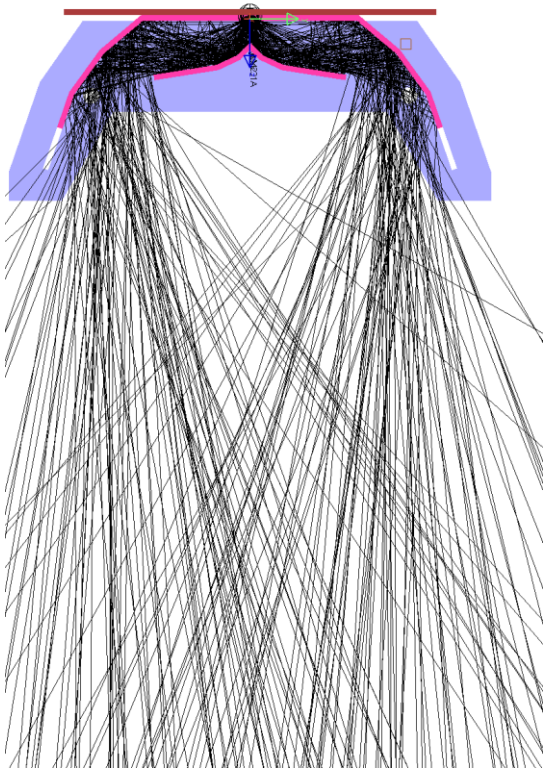


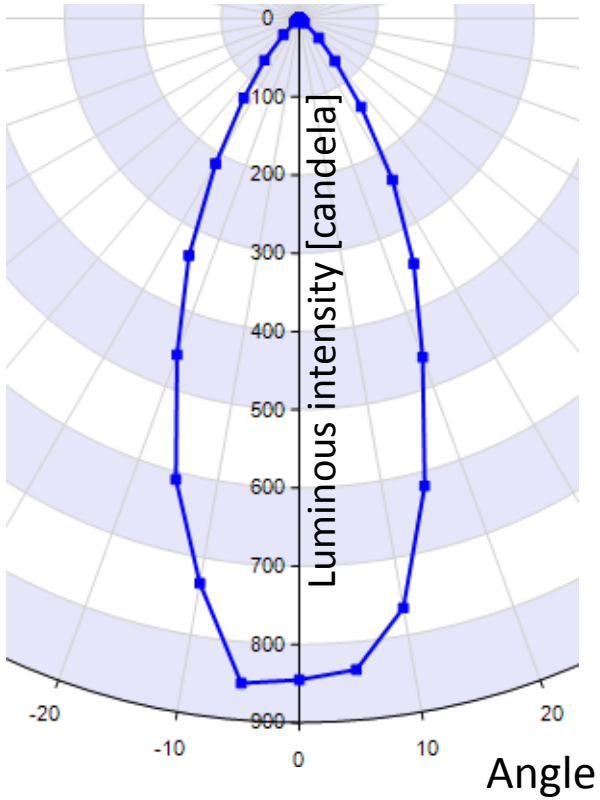
Enables: Compensation of
- change of daylight intensity and color temperature
- LED aging effects (intensity and color drift)

Approach: Integrated close loop control for light intensity and color temperature

Approach for direct light shaping: Reflector design

- The choice of reflector material is important
- The angle-dependent reflectivity of the used reflector sheet metal is between 93% and 97%
- Optical simulation based on measured BRDF data of reflector sheet metal





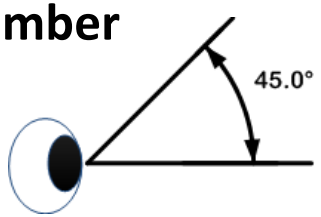
Simulated Light distribution curve of direct light of the pendant luminaire

Results

- Good light shaping
- No glaring
- No multiple shadows
- Simulated optical efficiency of the reflector 85%
- Failure of one LED is not noticed (longer lifetime)

Solution for high efficient indirect light generation

Remember

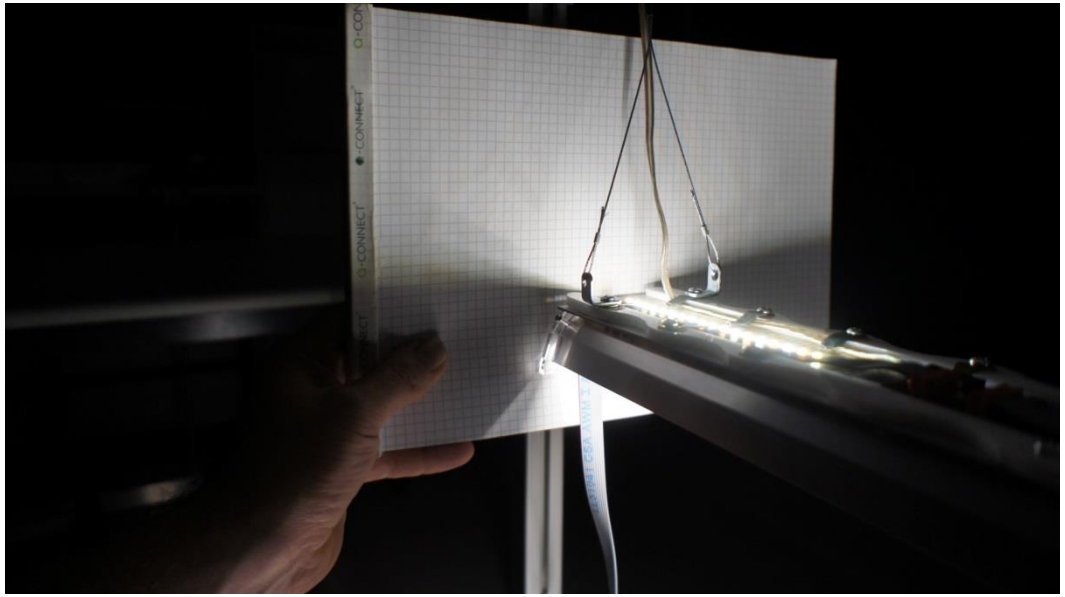


Highest melanopic effect if light enters eye from top and front

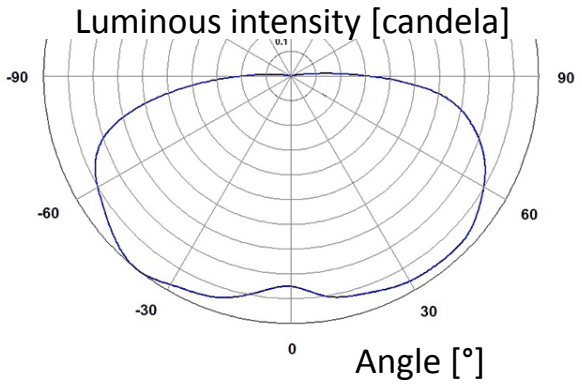
Target

Flat floodlighting the ceiling, diffuse reflected light enters with required angle range

LED selection



Emission characteristics of the LED with very wide beam angle of 170°

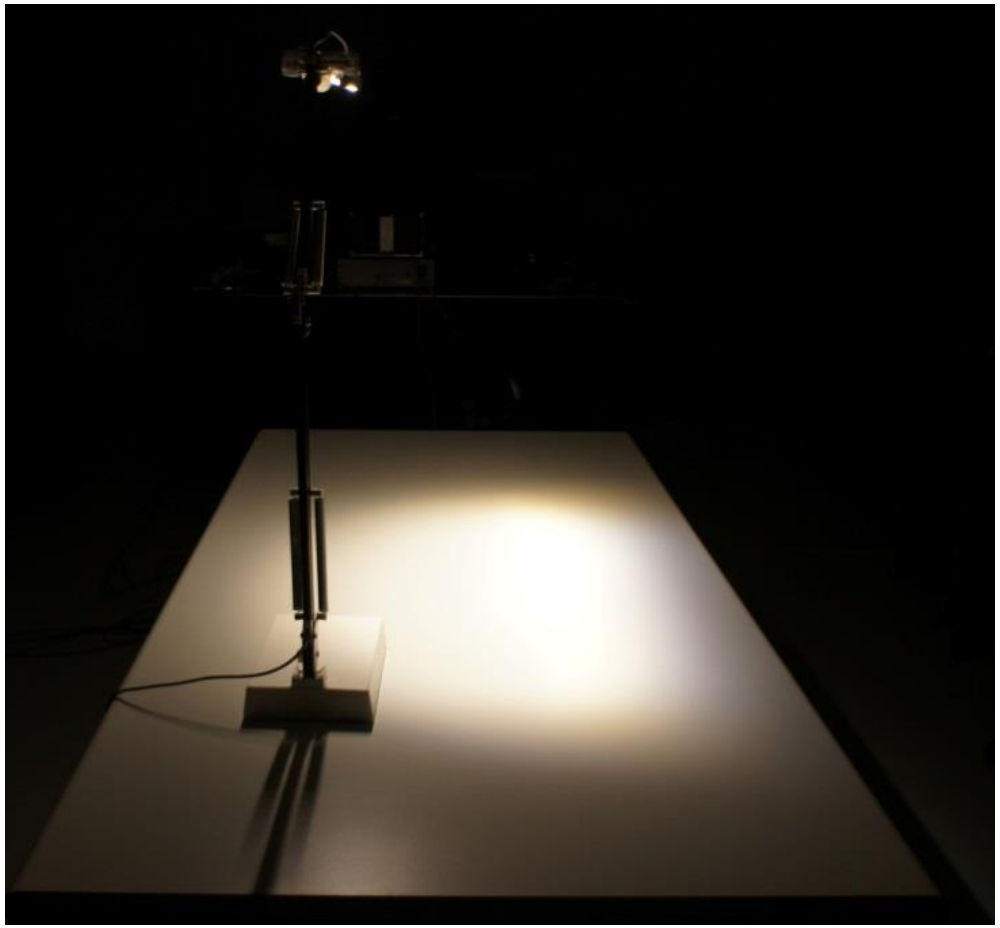


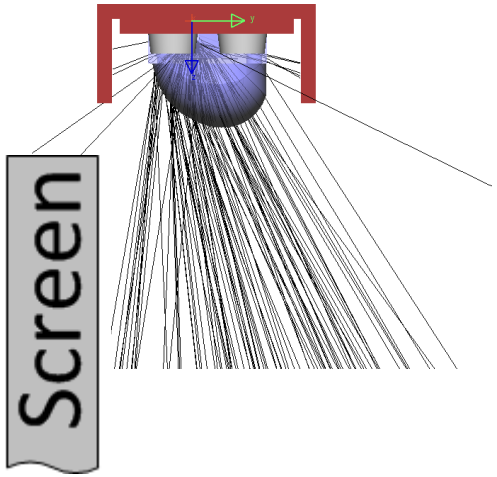
Result

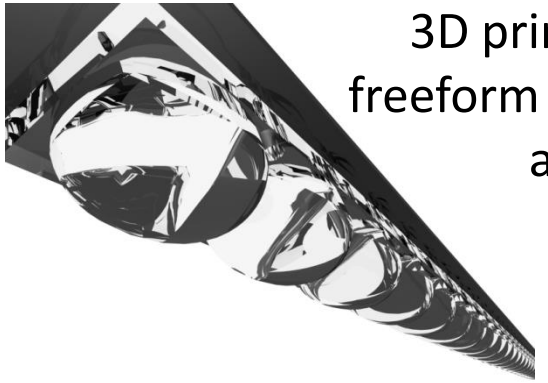
+ no secondary optics for light shaping required
+ excellent optical efficiency for indirect light
- LED (wide angle type) not yet available with >5000K, <2700K

Table luminaire with asymmetric light shaping

Target

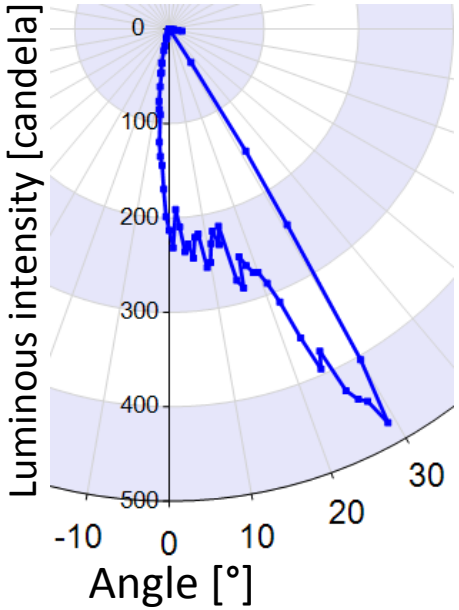






3D printed freeform lens array

Result



Light distribution curve of asymmetric freeform lens array

+ glare free light
+ Good light shaping
+ Optical efficiency 77%
- Multiple shadow

Your development partner: Competence Center Electronics of Hochschule Luzern Technik & Architektur

- The luminaires of the future are smart integral solutions based on the fusion of electronics, sensors, embedded controller & SW and optics

- We would like to assist you in the development of such luminaires

Thank you for your attention ☺

Contact

Licht@hslu
Wirkung - Energie - Funktion
Interdisziplinäre Betrachtung von Licht

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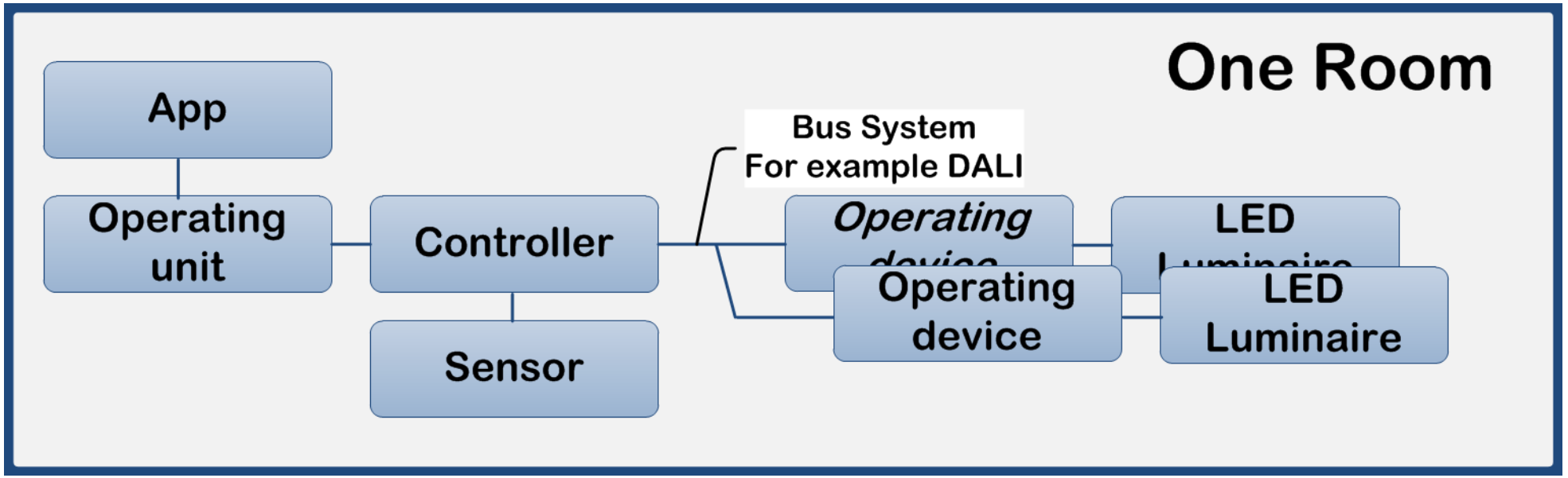
Appendix

State of the art human centric lighting solutions

- Circadian lighting system for professional applications
- Functions are divided into separate units

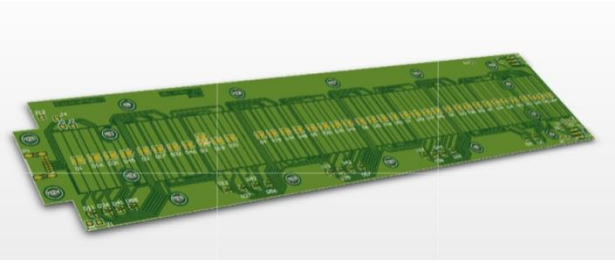
An circadian illumination system for larger rooms



Market considerations

- Gap: No practical solution for at home (residential) available
- Today's solutions are to complicated and to expensive

LED module design
Defensive LED forward current and good cooling

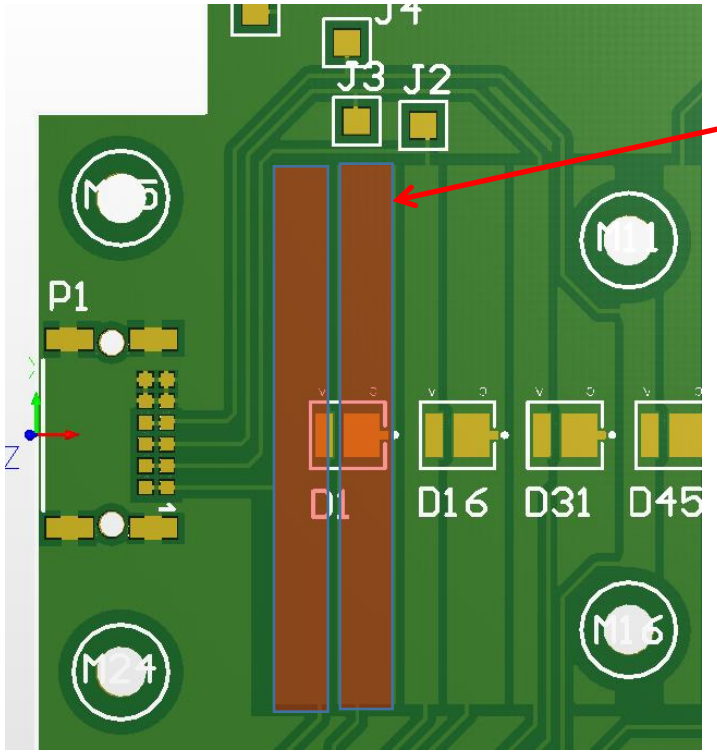


Objective

The cooler the LEDs the higher the efficiency and the longer the service life

Solution

- More LEDs with less current
- Direct light LED with constant current 100mA
- Indirect light LED with constant current 65mA
- Aluminum core PCB and conductor tracks form a heat sink for optimum cooling of the LEDs



- Good heat distribution, thanks to large-area solder pads of copper
- PCB design optimized as a heatsink

Licht@hslu
Finding a meaningful and efficient use of light

Lucerne University of Applied Science and Arts

Department
Lucerne School of Engineering and Architecture

Sections
- Interior architecture
- Building construction
- Building Technology
- Computer science
- Electrical Engineering
- Mechanical Engineering
- Industrial Engineering Innovation

One entry point for subject light

Licht@hslu

Interdisciplinary work at the junction of design and technology

www.hslu.ch/licht

Summary: Checklist requirement for biological relevant light

Higher illuminance:	Mid power LED array for higher luminous flux as required according classical luminaires		
Meloanopic effective light:	high effective light > 5300K		Indirect light LEDs only 5000K and 2700K
	low effective light < 2200K		
Area light sources:	Direct light: light shaping transforms LED point source array to emitting surface source Indirect light : wide angle emission LEDs for efficient floodlighting ceilings and walls		
Time-varying dynamic light at the right time:	Through integrated embedded system and sensors for time synchronized control of light		

Summary: Checklist conventional requirements

Visual comfort

Color rendering:	CRI> 80
harmonic brightness allocation:	Integrated Optics

Visual ambience

Modelling:	Directional direct light and indirect light
Light color:	2200K to 5700K from
Variable Light direction:	Good glare-free direct light and indirect light

Visual performance

Lighting level:	high luminous flux
Glare limitation:	Integrated optics

Additional criteria

Daylight Integration:	Adaptive adjustment of intensity and color temperature
Energy efficiency:	- Optimized optical, electronic and thermal design - Optimal LED selection
Changes in Light situation:	- Dynamic lighting - Different lighting scenarios available
Custom settings:	Intuitively adjustable
Lifetime:	Optimized design for long life
Maintainability:	Excellent servicing due to modular concept

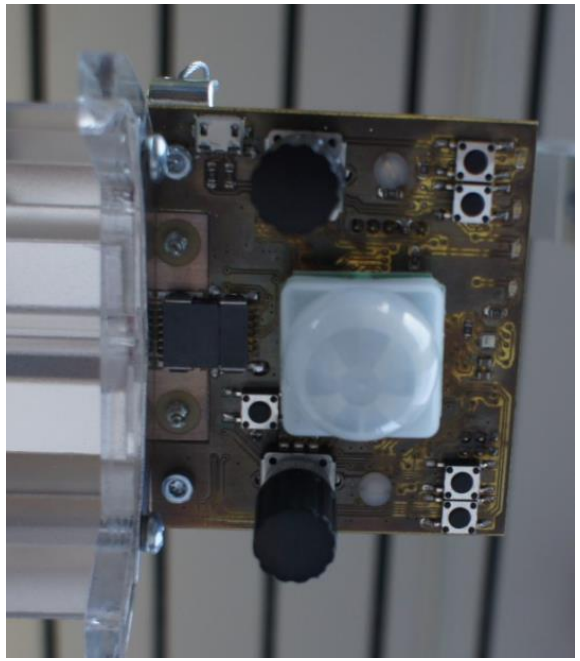
Neue Erkenntnisse aus der Wissenschaft nutzen

Human Centric

- Blendfreies Licht
- Dynamische Farbtemperatur analog dem natürlichen Sonnenlicht
- Gesunde Nachtbeleuchtung
- Direkt- und Indirekt Licht für gutes Raumklima
- Sehr benutzerfreundlich

Intelligenz durch integrierten Mikrocontroller und Sensoren

Smart



Leuchte passt Farbtemperatur und Intensität automatisch und dynamisch dem Umgebungslicht an

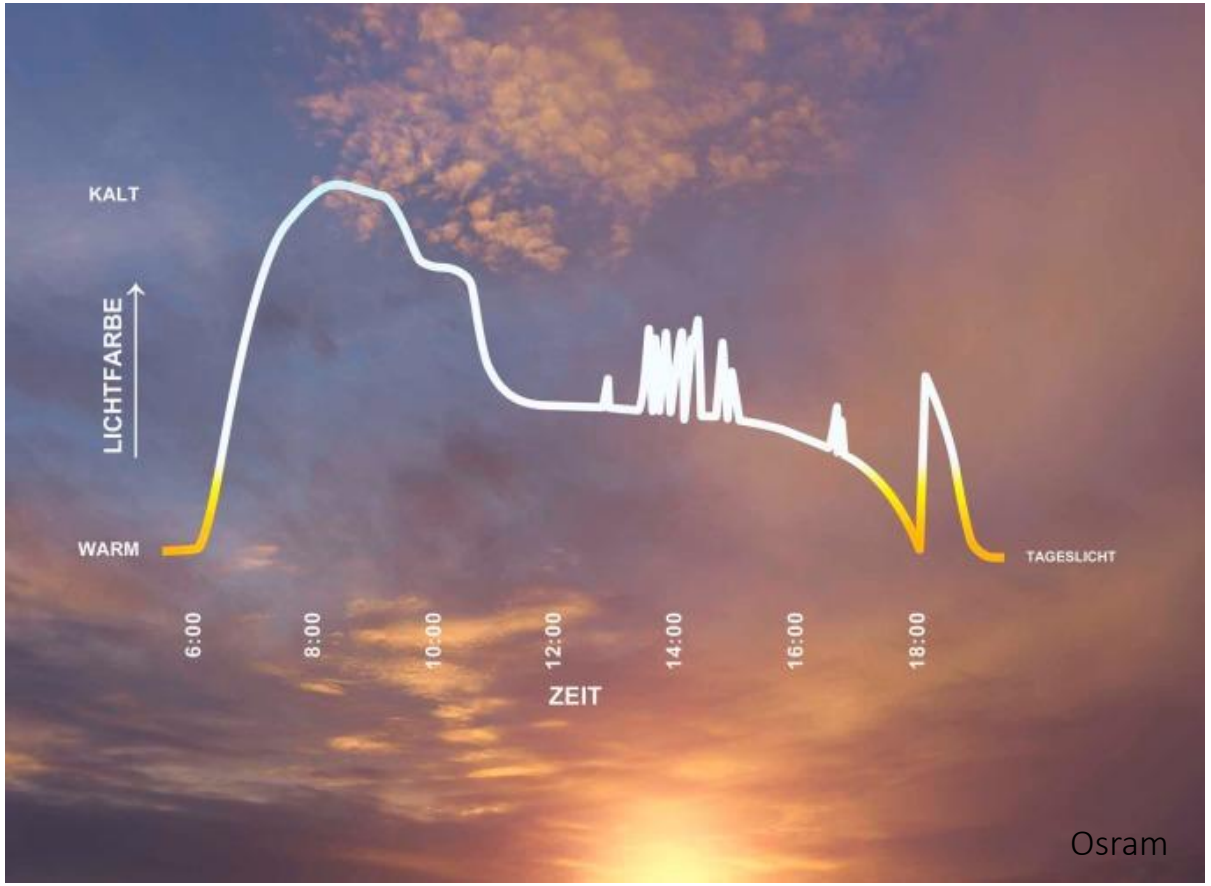
- Integrierte Lichtsensoren für Intensitätsmessung und Farbtemperatur Messung
- Bewegungssensor für Präsenzdetektion und Gestensteuerung
- Microcontroller für Leuchten Steuerung
- Integrierte Echtzeit-Uhr mit Batterie Backup
- Bedienelemente für manuelle Einstellung

Dynamisches Licht

- Die Lichtfarbe und -Intensität prägt massgeblich die Tag-Nacht Synchronisation beim Menschen
- Eine geeignete Beleuchtung kann den natürlichen Rhythmus unterstützen

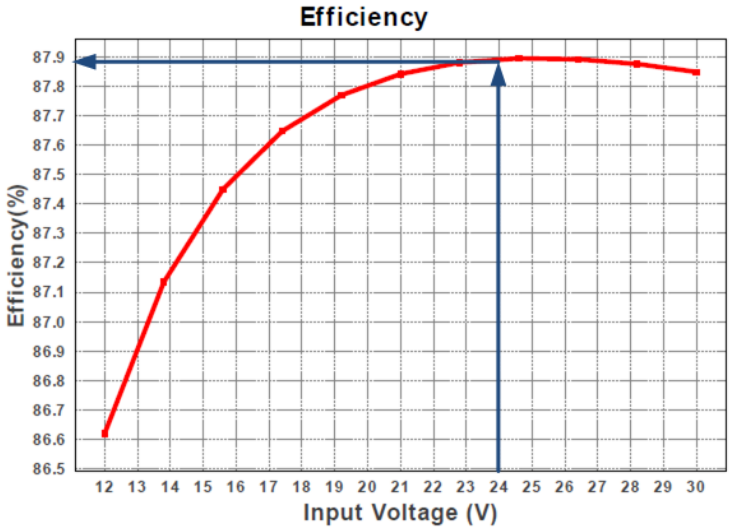
Verschiedene Szenarien sind machbar z.B.:

- *Dynamische Farbtemperatur analog dem natürlichen Sonnenlicht*
- *Stimulation am Morgen und nach Mittagessen*
- *Adaptiv dem Umgebungslicht folgen*

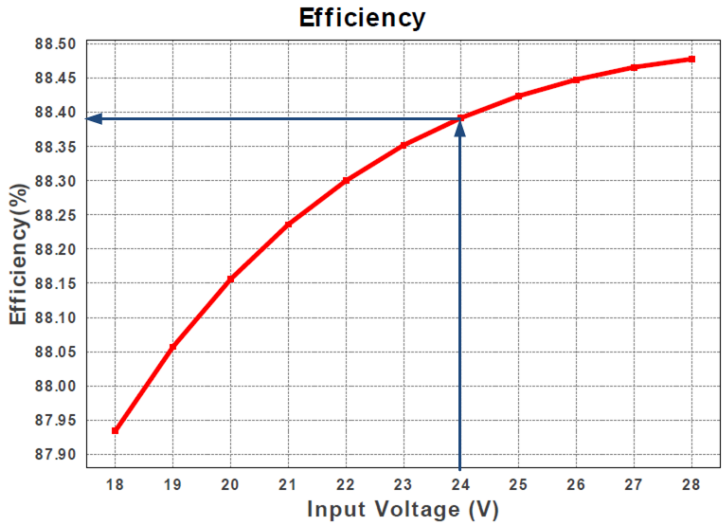


Typischer Verlauf der Farbtemperatur über einen Tag

Integrated LED drivers with high efficiency



Efficiency driver for direct lighting



Efficiency driver for indirect light

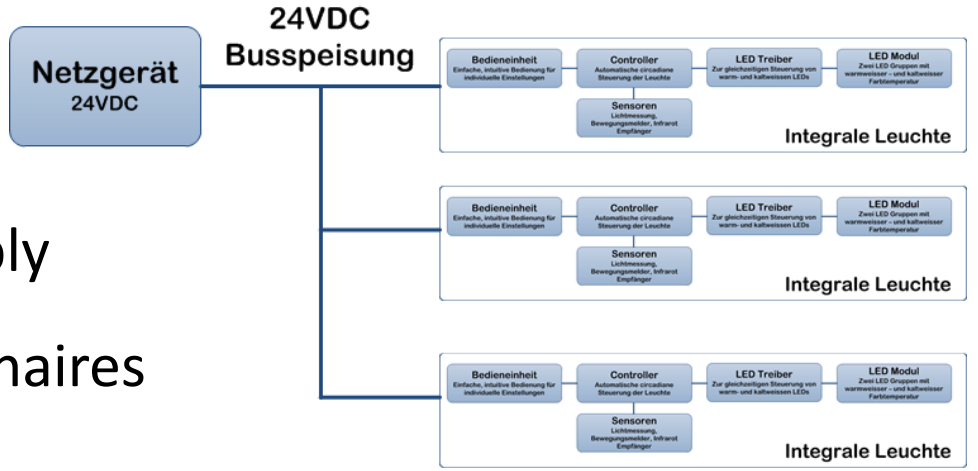
Result

Simulated efficiency for drivers: 88%

24V DC bus power supply for effective AC/DC conversion

One power supply

For several luminaires



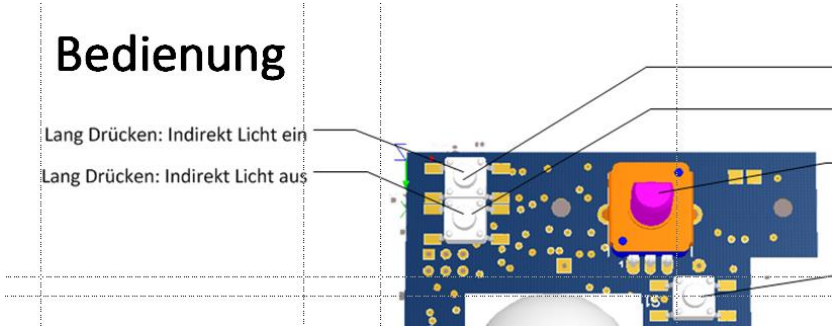
Vorbild ist das Tageslicht

Vorbild ist das Tageslicht
Das Tageslicht gibt die Faktoren einer biologisch wirksamen Beleuchtung vor:
- Beleuchtungsstarke,
- Flachigkeit,
- Lichtrichtung,
- Farbtemperatur und
- die Dynamik des Lichts im Tages- und Jahreszeitenverlauf.

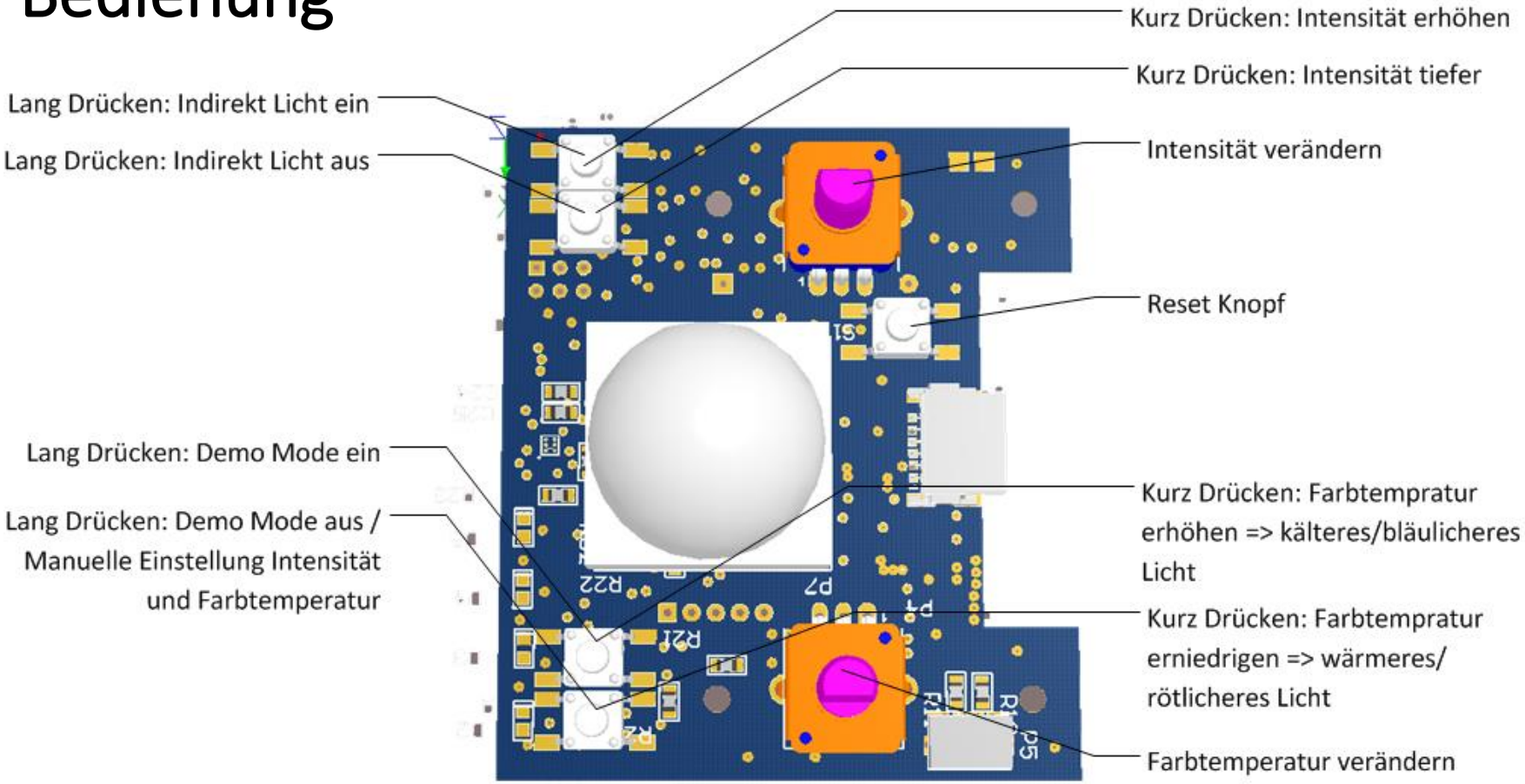
Dabei hangt die Helligkeit des Tageslichts stark von der geografischen Lage, Wetter, Jahres- und Tageszeit ab. In Mitteleuropa konnten die meisten Raume zwar von etwa 8 bis 17 Uhr mit naturlichem Licht beleuchtet werden. Doch meist reicht das durch die Fenster einfallende Tageslicht in der Raumtiefe nicht aus.

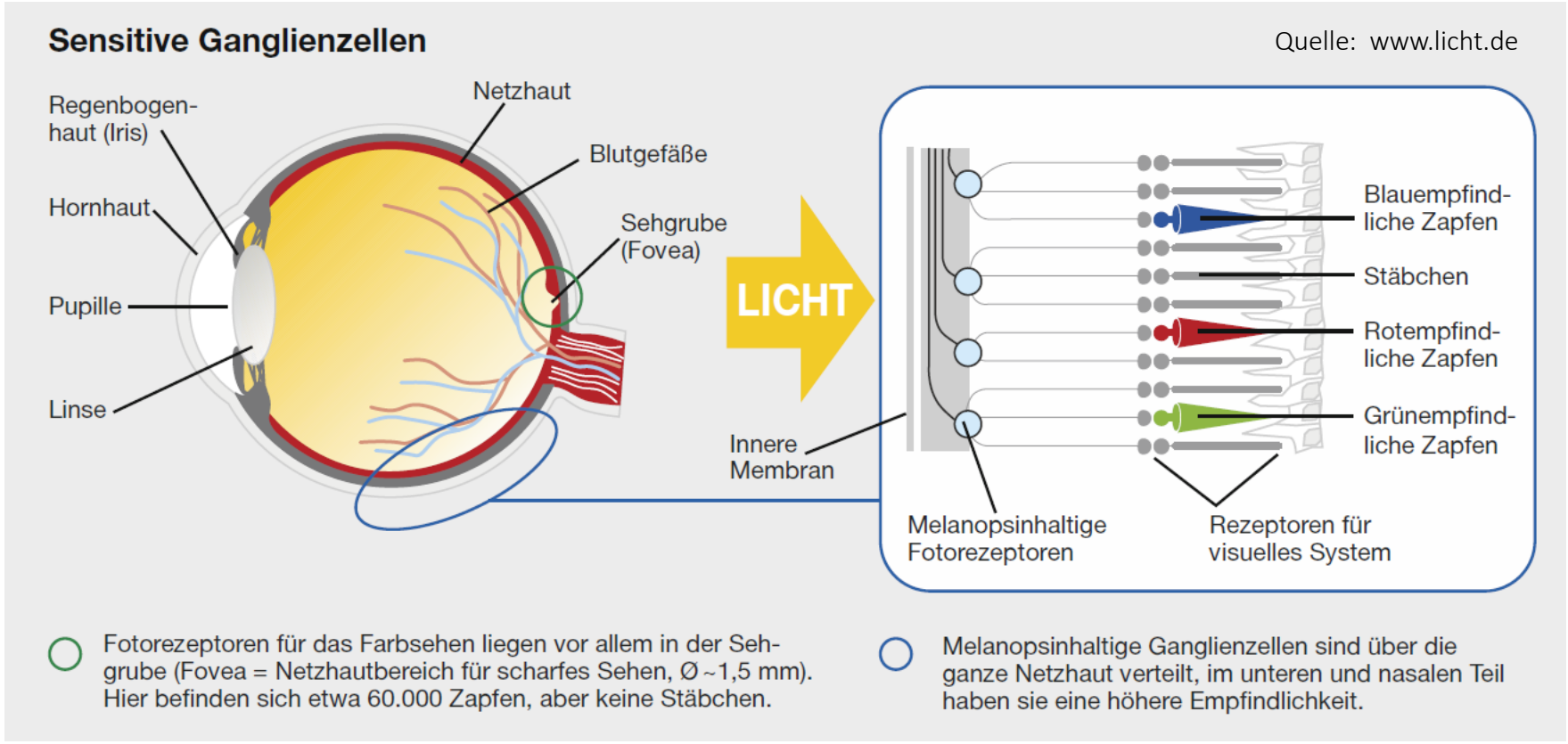
Aufstart der Leuchte

1. Speisungskabel einstecken
   - Pendelleuchte Leuchte startet im Demo Mode (Farbtemperatur Zyklus im 1 Min. Rhythmus
   - Tischleuchte startet im manuellen Einstellmodus
2. Pendelleuchte Indirekt LEDs einschalten (Siehe Info Bedienung)



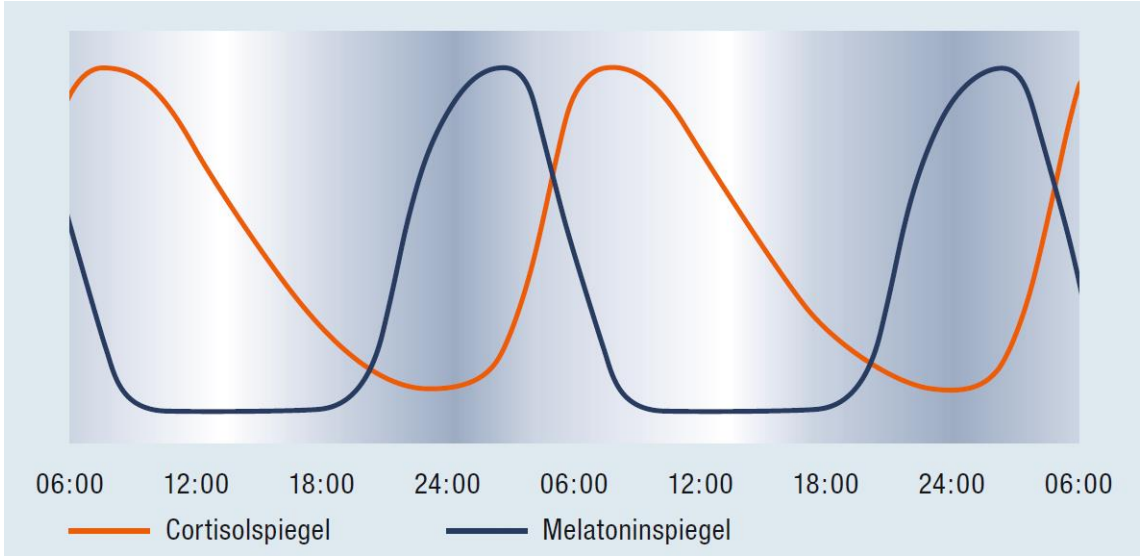
Bedienung


Kurz Drücken: Intensität erhöhen
Kurz Drücken: Intensität tiefer
Lang Drücken: Indirekt Licht ein
Lang Drücken: Indirekt Licht aus
Intensität verändern
Reset Knopf
Lang Drücken: Demo Mode ein
Lang Drücken: Demo Mode aus / Manuelle Einstellung Intensität und Farbtemperatur
Kurz Drücken: Farbtempratur erhöhen => kälteres/bläulicheres Licht
Kurz Drücken: Farbtempratur erniedrigen => wärmeres/ rötlicheres Licht
Farbtemperatur verändern



- Die melanopsinhaltige Fotorezeptoren im Auge sind für die Synchronisation der Inneren Uhr

Verantwort-liche Hor-mone für den circadianen Rhythmus



Verlauf der Hormonpegel für die Steuerung des menschlichen Tagesrhythmus (circadianer Rhythmus) Quelle: Osram

- Am Morgen steigt der Cortisolspiegel an. Damit wird der Mensch wach. Je aktiver der Mensch desto höher der Cortisolspiegel.
- Mit zunehmender Dunkelheit wird Melatonin freigesetzt, welches schlaffördernd ist.

Wirkung von blauem und rotem Licht

Blaues Licht (also kurzwelliges Licht) sendet über die Augen aufgenommen über das zentrale Nervensystem einen Impuls an die Zirbeldrüse, die das Schlafhormon Melatonin produziert, dass diese die Produktion drosseln soll. Dadurch wird der Mensch aktiv. Kurz: Blaues Licht verringert die Schlafhormonproduktion und macht fit und aktiv. Rotes Licht (langwelliges Licht) fördert die Melatoninproduktion. Der Mensch entspannt, wird müde und schläft ein. Sinnvoll ist es dementsprechend, morgens nach dem Aufstehen Licht mit einem hohen Blauanteil (kaltweißes Licht) zu verwenden (häufig in Leuchtstoffröhren). Abends in den letzten Stunden vor dem Schlafgehen sollte man auf blaues Licht verzichten. Licht mit einem hohen Rotanteil unterstützt den Organismus dabei, müde zu werden (denn das Schlafhormon Melatonin wird produziert).
http://www.rp-online.de/nrw/staedte/remscheid/freizeit/wie-man-den-schlaf-durch-licht-regulieren-kann-aid-1.3148149

Our motivation for developing the Smart Lighting Luminaires demonstrators

A performance mandate of the university are projects in the field of applied research and development.

Objective: Joint projects with industry partners

For this we need skills and knowledge which are in demand in the market
(Customer: SME and industry, Product: Engineering).

A selection of our expertise and know-how

- Light
- Electronics
- Sensors
- Optic

This must be known in the market!

Idea

A demonstrator that shows our competences and know-how relating to light which serves as an aid for the acquisition.

Implementation

Smart Lighting Luminaire Technology Demonstrators

Hochschule Luzern Technik & Architektur Competence Center Electronics

Specialists in analog and digital electronic solutions

Together with research associates, assistants and master's students, lecturers with industry experience carry out applied research and development in the pioneering fields of electronics.