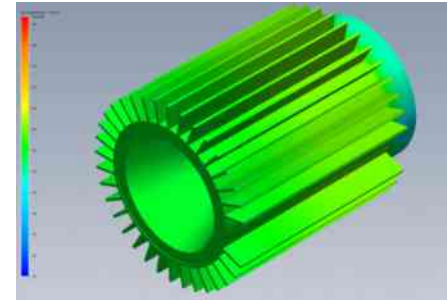




Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research



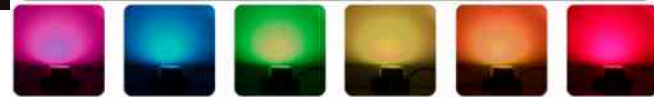
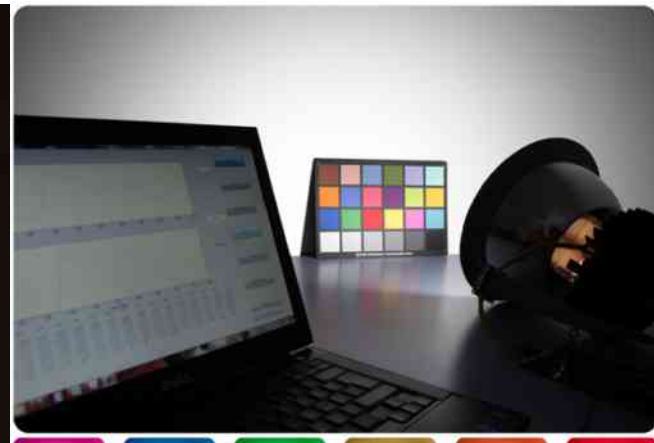
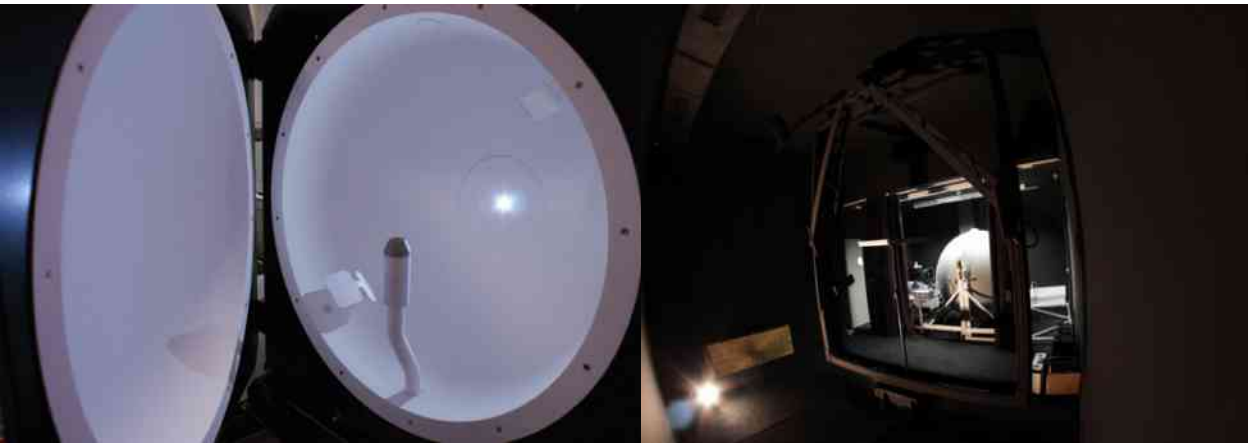
Lighting materials and intelligent light sources: Present status and future prospects

Dr. Josep Carreras
Head of the Lighting Group (IREC)



Energy Institute
in Barcelona, Catalonia

<http://www.irec.cat>



IREC^R

Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

LEDs: the known...

LEDs:

Im / W

- Most used figure of merit
- More about physics
- **Competitive advantage**

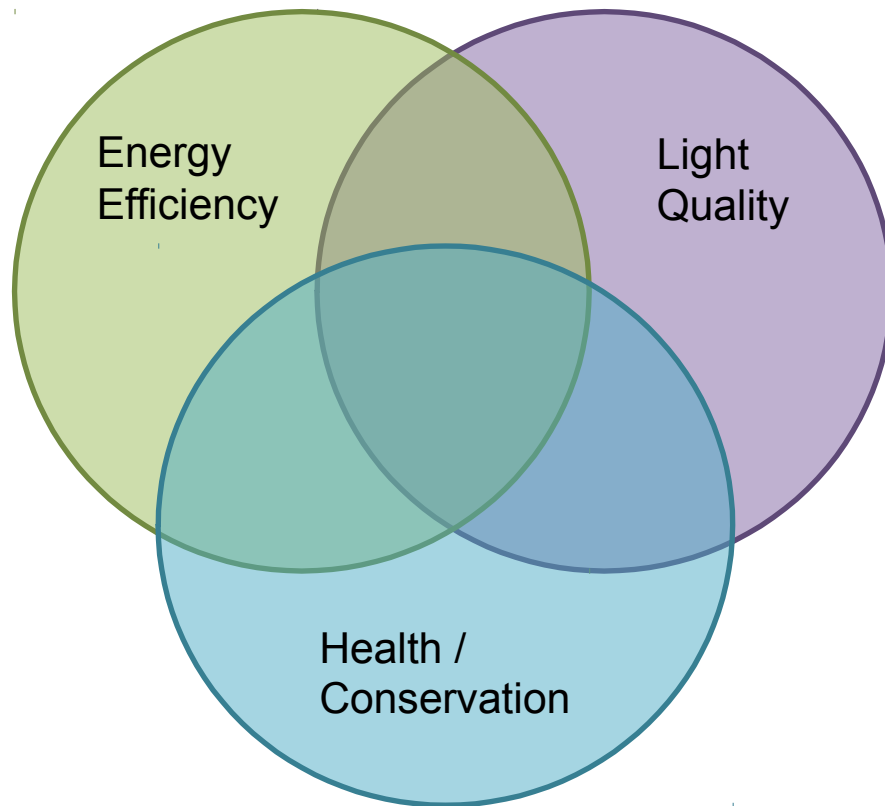
Material's side

- Quantum Efficiency
- Extraction Efficiency
- Manufacturability
- Cost
- Wavelength availability

LEDs: the not so known...

Lighting

ICT

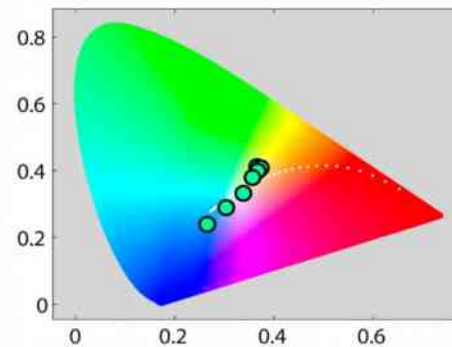
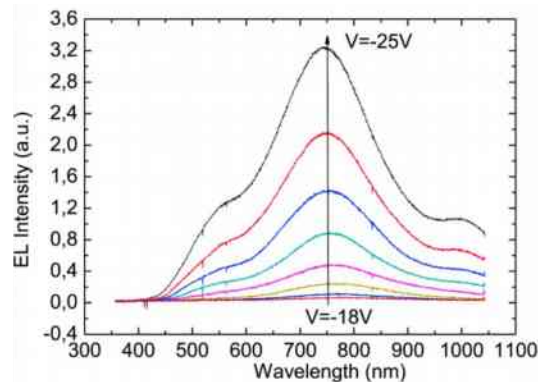
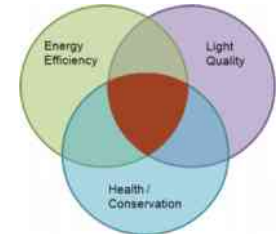
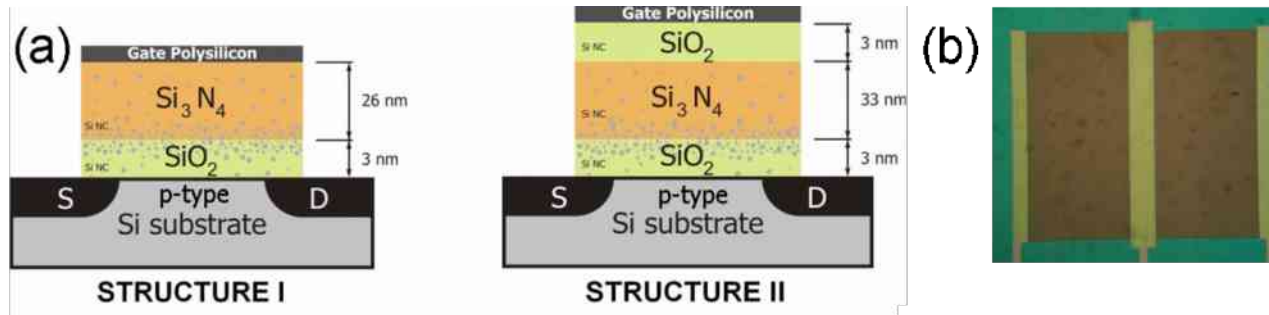


- Digital control of light intensity
- Digital control of spectral content
- Fast pulse modulation

Bridge Lighting <-> ICT
Disruptive!

Materials. SSSL: Silicon Solid State Lighting

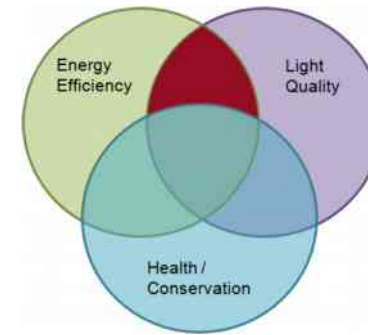
Color dependence on voltage



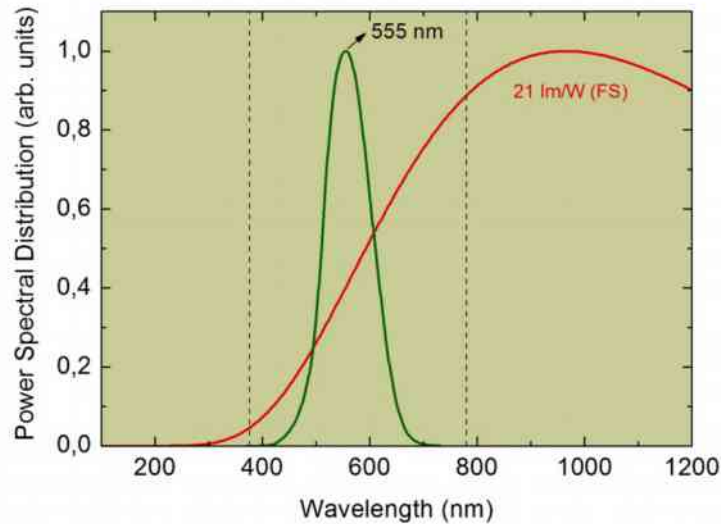
CCT	LER (lm/W)
3000K	363
5500K	313
8000K	288

Turn on point: **20%** in quantum + extraction efficiency

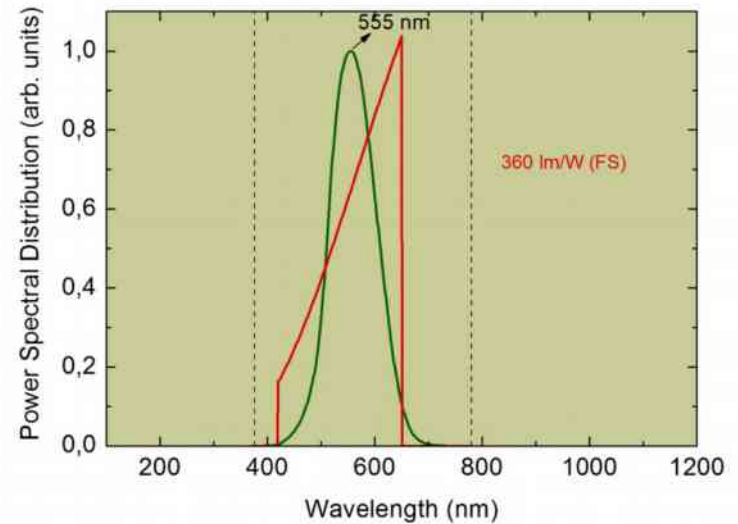
Theoretical limits in efficacy for natural light emulation



Spectral narrowing @3000K

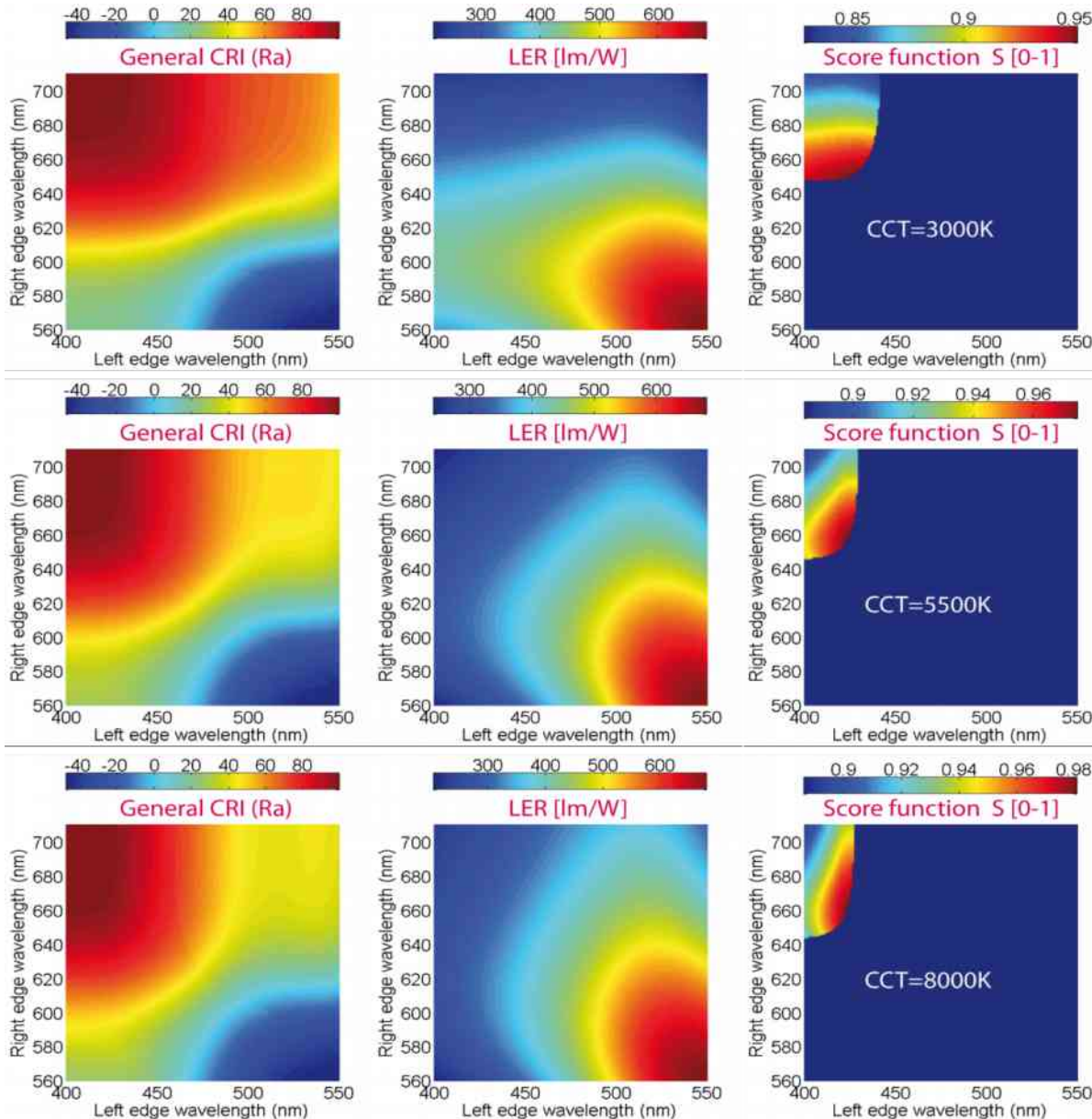
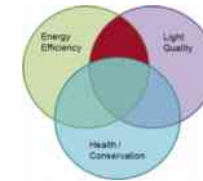


Ra=100, Efficacy=21 lm/W



Ra=91, Efficacy=360 lm/W

Efficacy Limits



Example of designed light content:

CRI > 90
 Efficacy > 200 lm/W
 $\Delta uv < 0.0054$

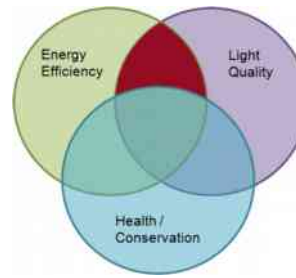
With $\Delta uv < 0.0054$:

3000K
 CRI = 90.5
Efficacy ≤ 363 lm/W

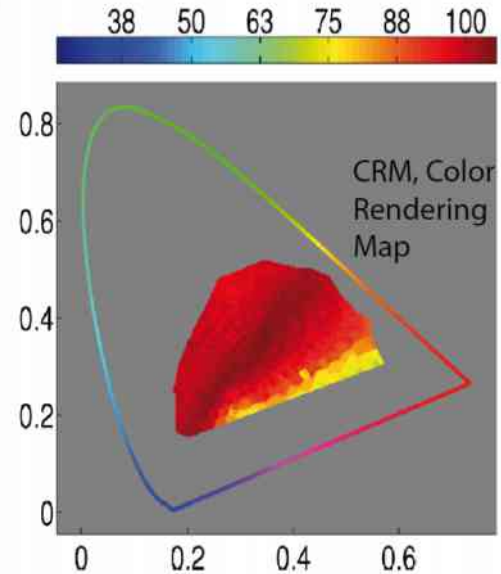
5500K
 CRI = 95.4
Efficacy ≤ 313 lm/W

8000K
 CRI = 96.6
Efficacy ≤ 288 lm/W

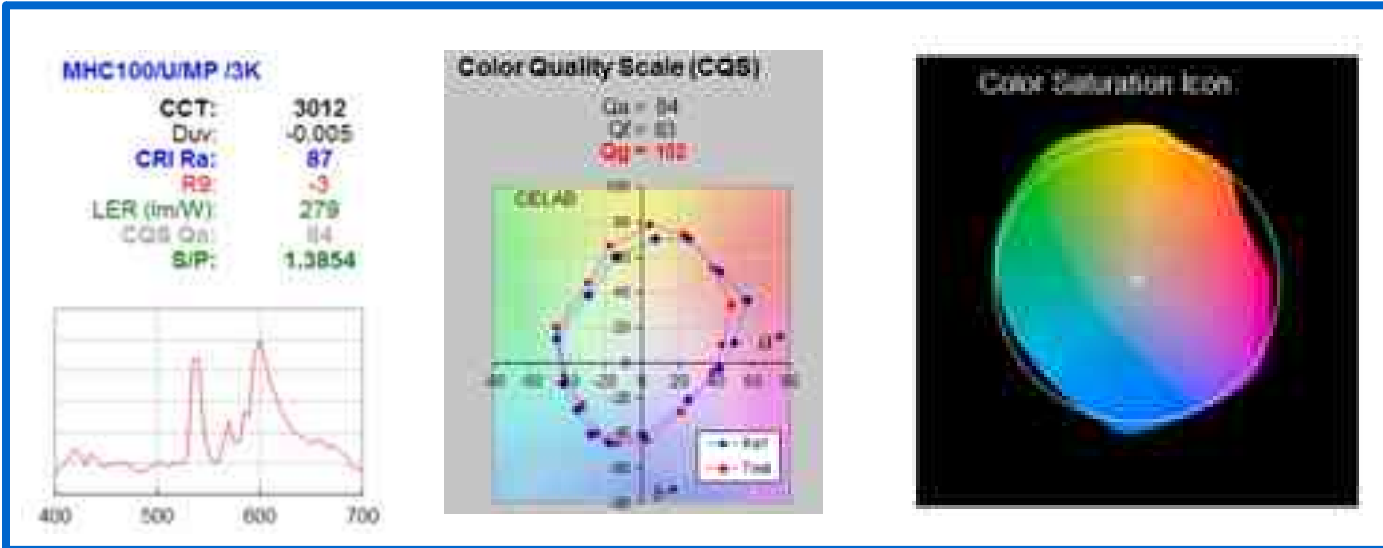
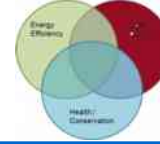
Results @5500K



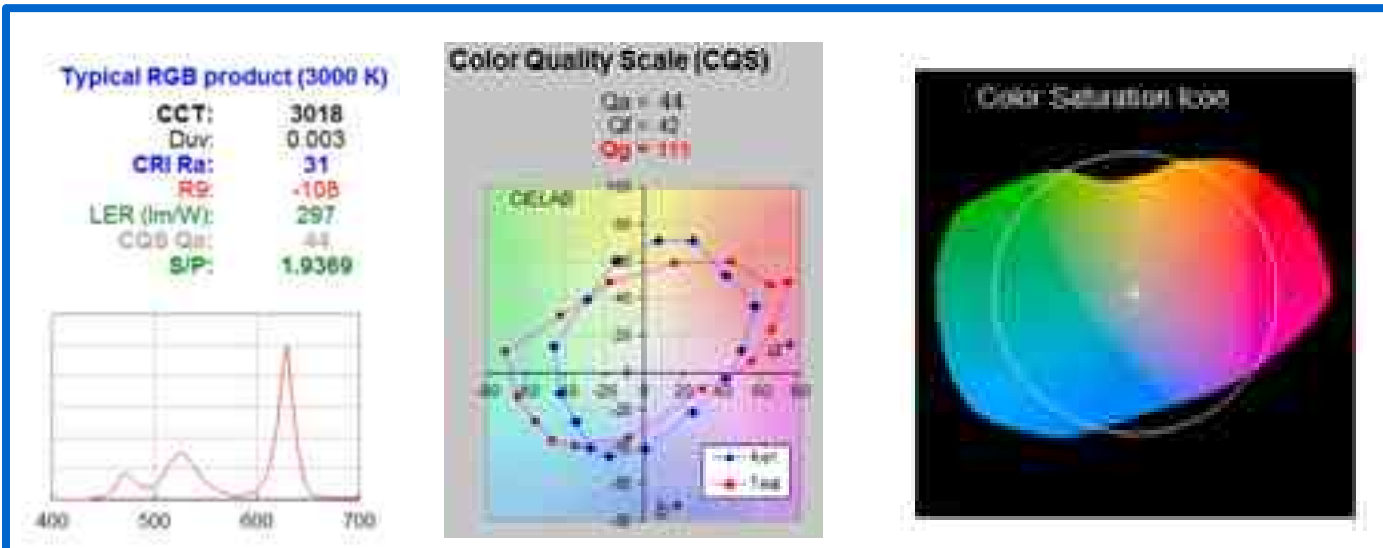
Emulation at 5500K . Target Efficacy = 314.92 lm/W		
$E_{ff} = 315 \text{ lm/W}$ $Ra = 94.4$ $S = 0.972$ $\Delta_{uv} = 0.0054$ $\Delta\lambda = [421, 653]$ $CCT = 5620K$ $R_{9-12} = 85.7$	$E_{ff} = 262 \text{ lm/W}$ $Ra = 99.2$ $S = 0.916$ $\Delta_{uv} = 0.0021$ $\Delta\lambda = [421, 709]$ $CCT = 5370K$ $R_{9-12} = 98.4$	$E_{ff} = 313 \text{ lm/W}$ $Ra = 95.4$ $S = 0.975$ $\Delta_{uv} = 0.0053$ $\Delta\lambda = [424, 658]$ $CCT = 5490K$ $R_{9-12} = 88.6$



Color Fidelity vs. Preference

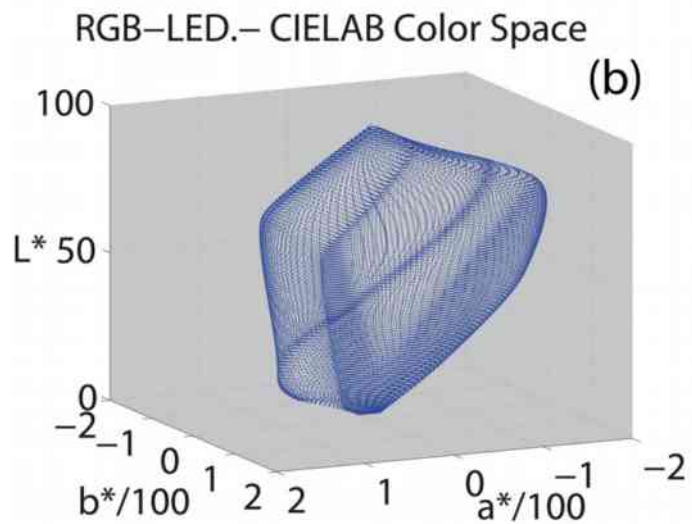
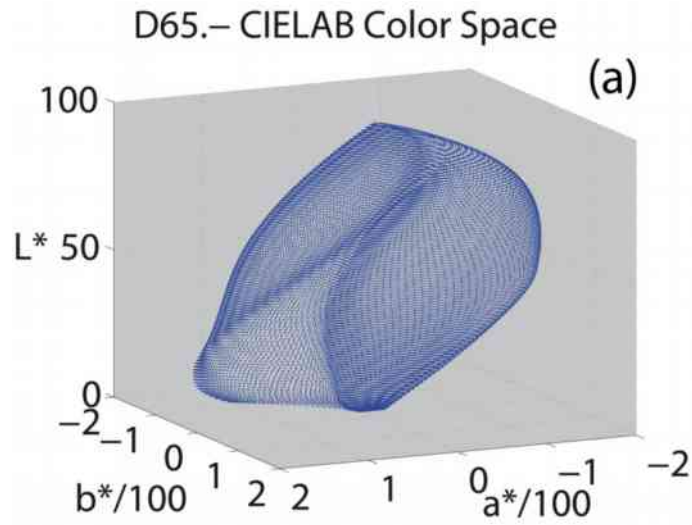


Ra = 87
 Qg = 102



Ra = 31
 Qg = 111

How do we measure colorfulness?

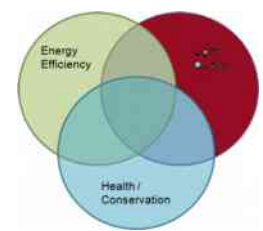


The Optimal Color Solid is unique for every light source and represents its maximum attainable colorfulness.

$$Q_g = 100 \left(\frac{GamutArea_{test}}{GamutArea_{ref}} \right)_{CIELAB}$$

$$O_c = 100 \left(\frac{Vch_{test}}{Vch_{ref}} \right)_{CIELAB}$$

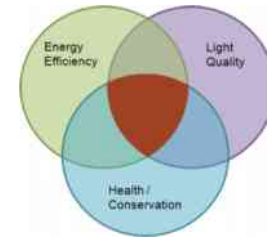
CRI and Colorfulness give different information



121-spectra database, representing a realistic snapshot of the currently available technologies

	CRI	Qa	Qg	Oc
CRI	1	0.9496	0.6188	0.5773
Qa	0.9496	1	0.7319	0.6064
Qg	0.6188	0.7319	1	0.7913
Oc	0.5773	0.6064	0.7913	1

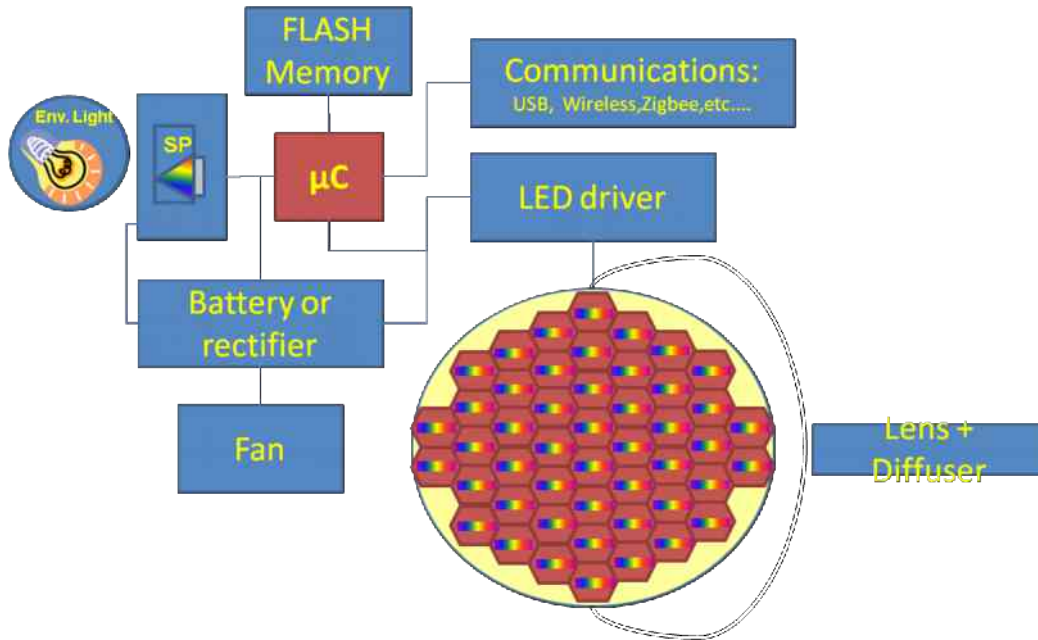
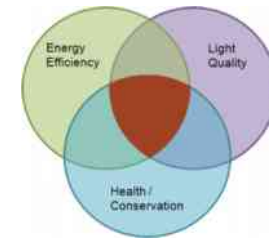
Tunable Light Engines



Spectrally tunable LED light engine

- Spectral reproduction by combining multiple narrowband LEDs
- Spectra-on-demand
- Possibility to adapt spectrum to lighting needs

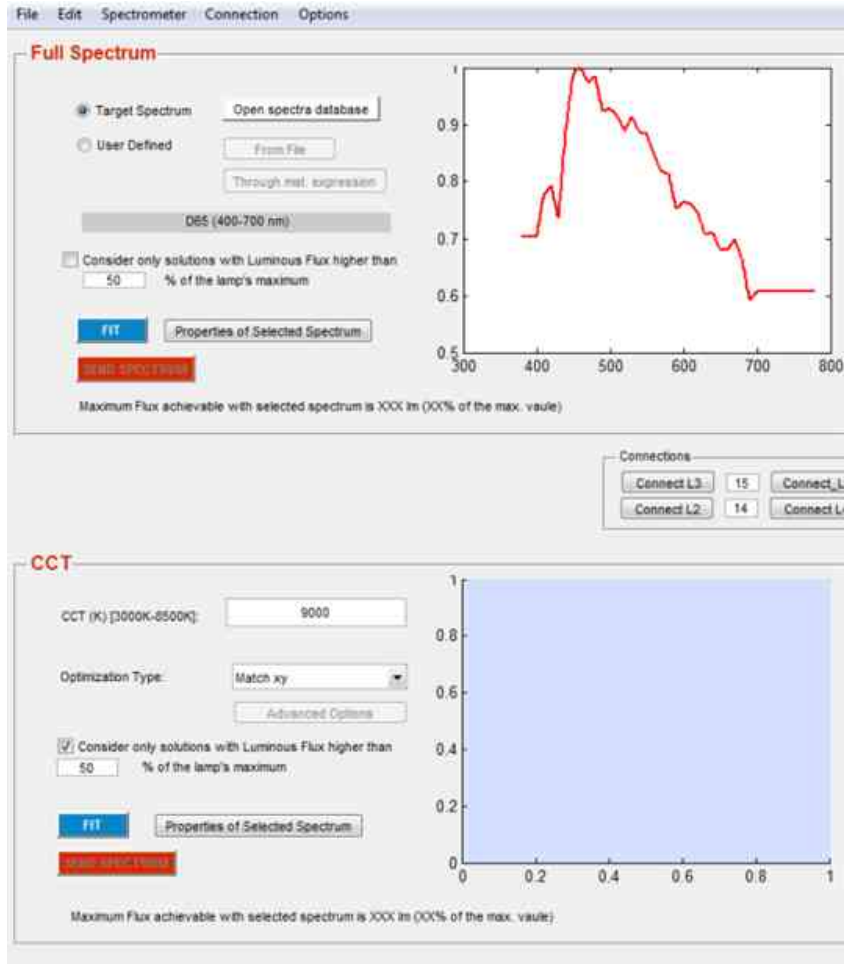
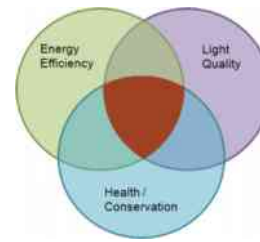
Light Engine. Technical description



- **Thermal management**
- ✓ Safe operating region
- ✓ Spectral change with temperature
- ✓ **Active thermal compensation!**

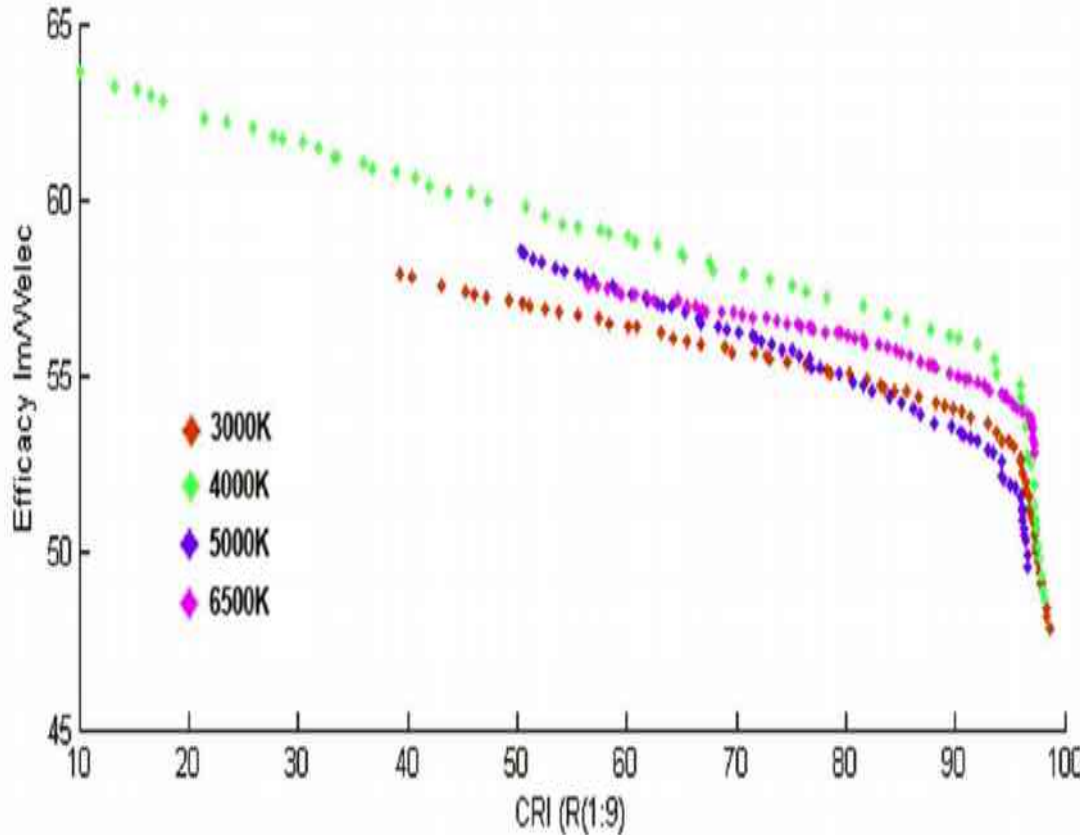
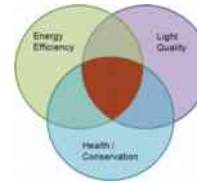
- **12 monochromatic LED channels**
- **CC PWM SMPS driver for each channel**
- **Microprocessor: drivers + comms**
- **Optical design**
- ✓ Mixing chamber
- ✓ Engineered diffuser
- ✓ **Reflector**
- ✓ **Integrated spectrophotometer**
 - ✓ Calibration
 - ✓ Spectral data surroundings

Tunable Light Engines Software



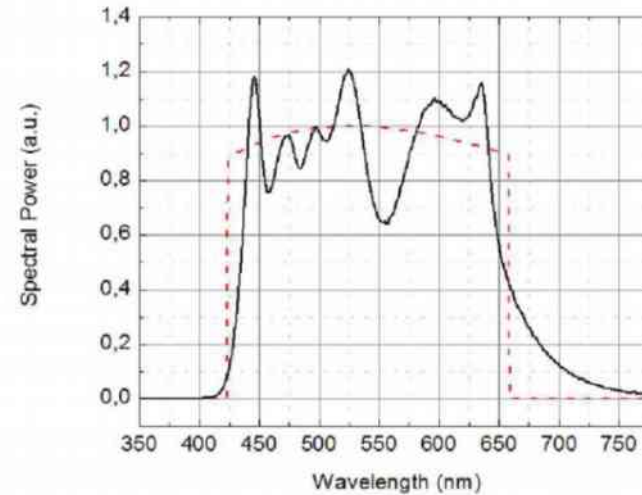
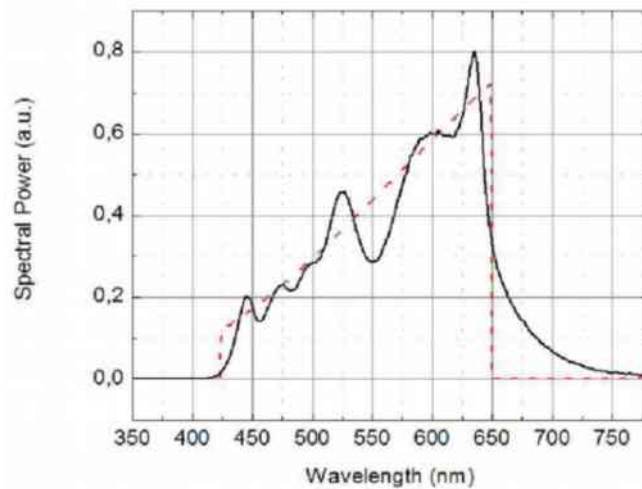
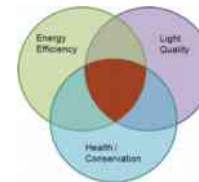
- **Version for smartphones / tablets**
- **Optimization and reproduction algorithms**
- ✓ Optimize for CR while keeping x, y
- ✓ Optimize for Efficacy while keeping x, y
- ✓ Set minimum CR value and optimize

Tunable Light Engines Optimizations Algorithms



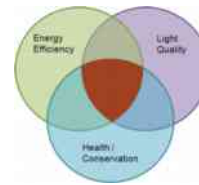
- **Multi – objective algorithms**
 - Finding optimal spectrum + fulfilling constraints
- **Genetic Algorithm**
 - Optimization for CRI vs Electrical efficiency (3000K, 4000K, 5000K, 6500K) while keeping results within MacAdam ellipses near BB locus

Tunable Light Engines. Results



	3000K	5500K
LER (lm/W)	325	300
R_a	92.3	90.6
Δ_{UV}	0.003	0.002
CCT (K)	3067	4887
R_9	56	84.2
R_{9-12}	82	83.8

Spectrally Tunable Room



- 6 ceiling-mounted light sources
- Modular room
- Wireless communications
- **Visual and non-visual effects of spectral, temporal and spatial changes in lighting**



Version 2.0

ECO2 project in the City of Justice (Barcelona)

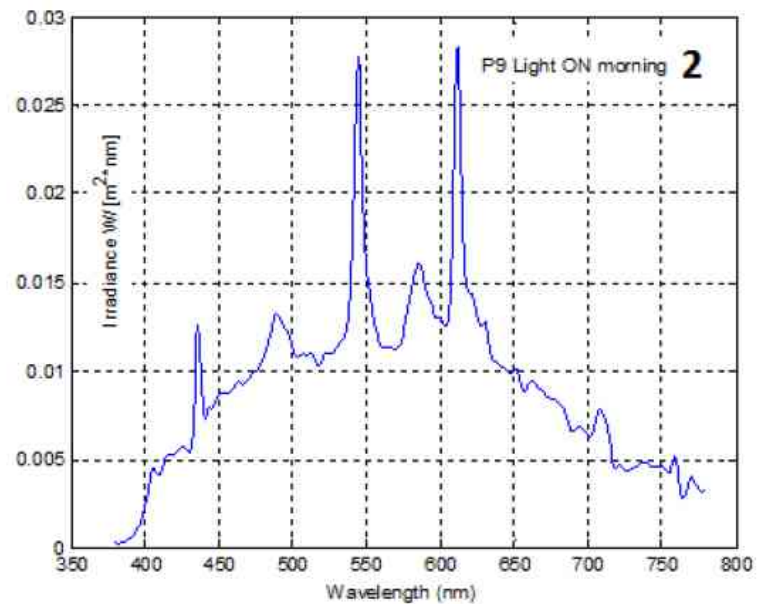
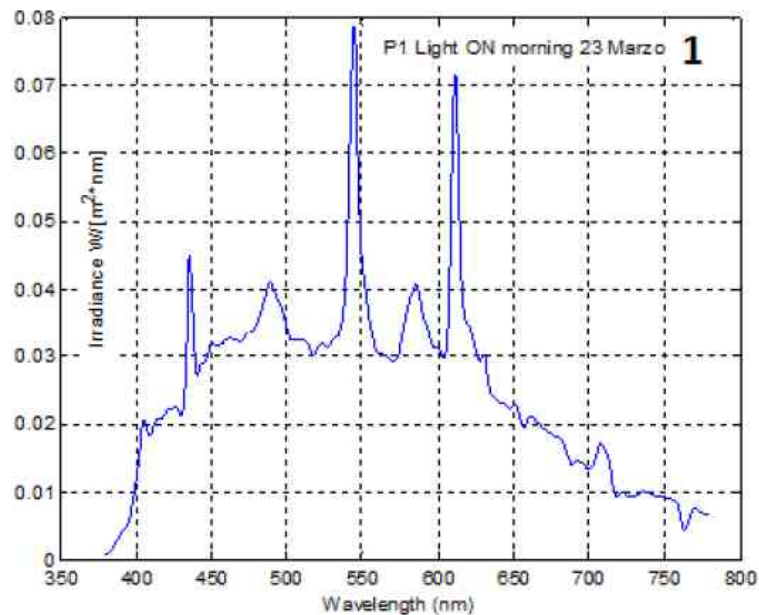
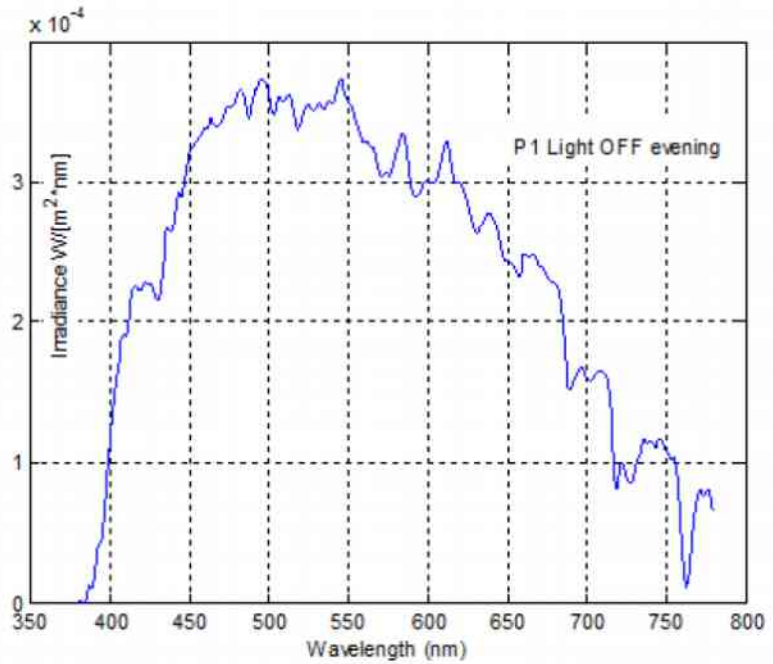
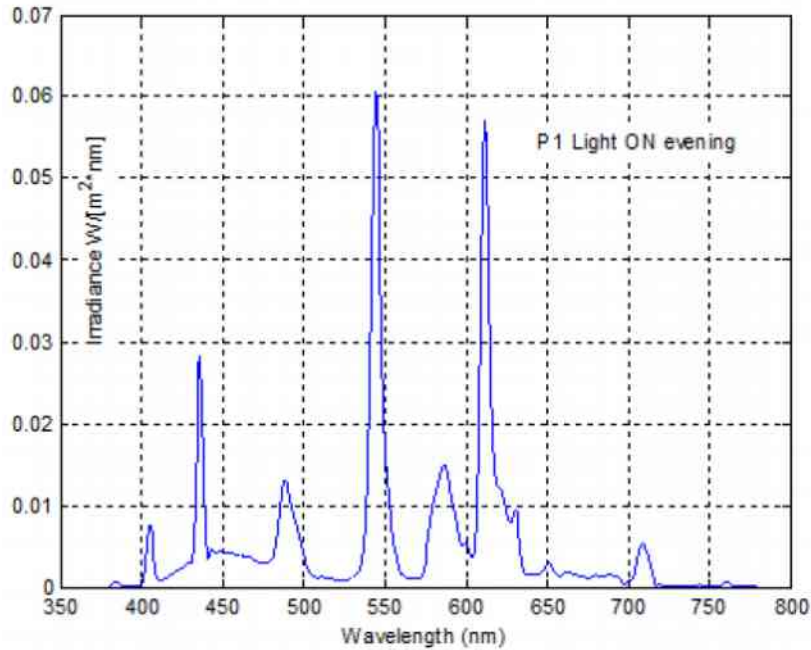


40.000 luminaires
Wireless Network of Sensors
Energy Harvesting

- Photovoltaic
- Thermal
- Water flow
- Wind speed
- Vibrations
- WiFi



Daylight and artificial light decomposition



New spin-off from IREC

www.omicronlighting.com



OMICRON LIGHTING

THANK YOU!!