The lumen revisited – implications for global lighting regulations

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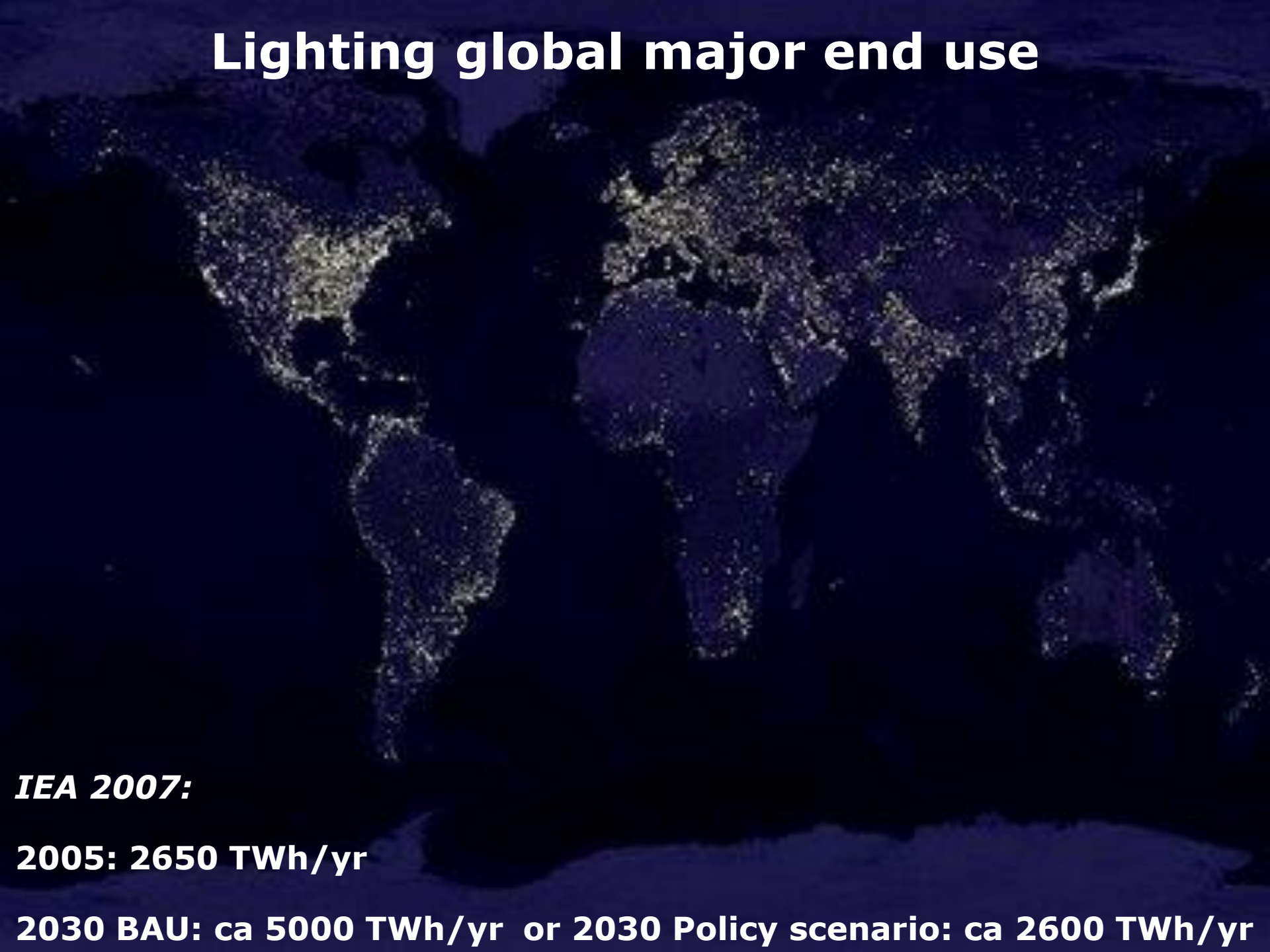
Content

- Background
- New definition of the measure for luminous flux (light), the lumen
- Why policy makers should care: Implications for lighting regulations
- Conclusions and summary

Lighting global major end use

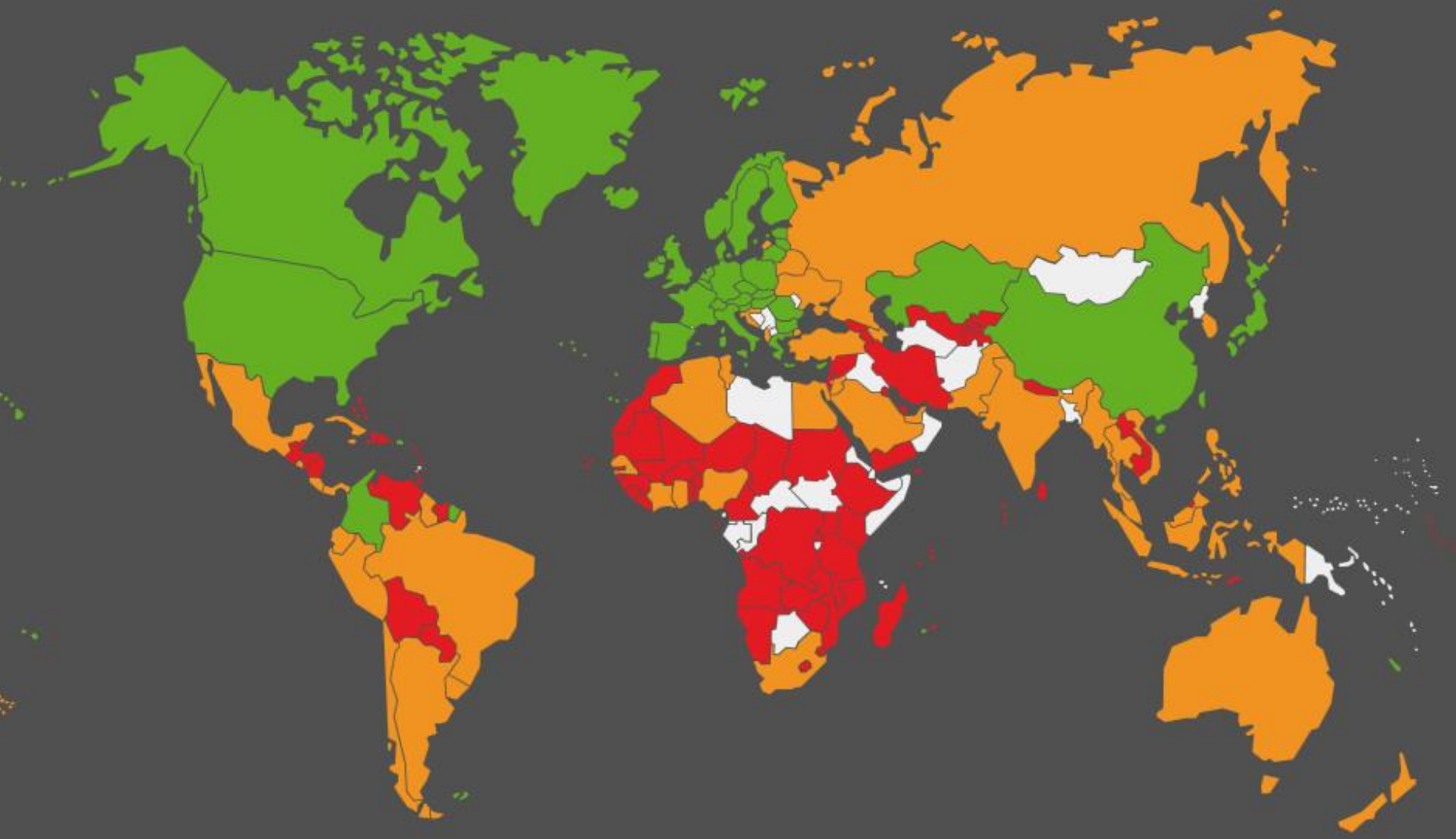


IEA 2007:

2005: 2650 TWh/yr

2030 BAU: ca 5000 TWh/yr or 2030 Policy scenario: ca 2600 TWh/yr

-> Lighting regulations globally

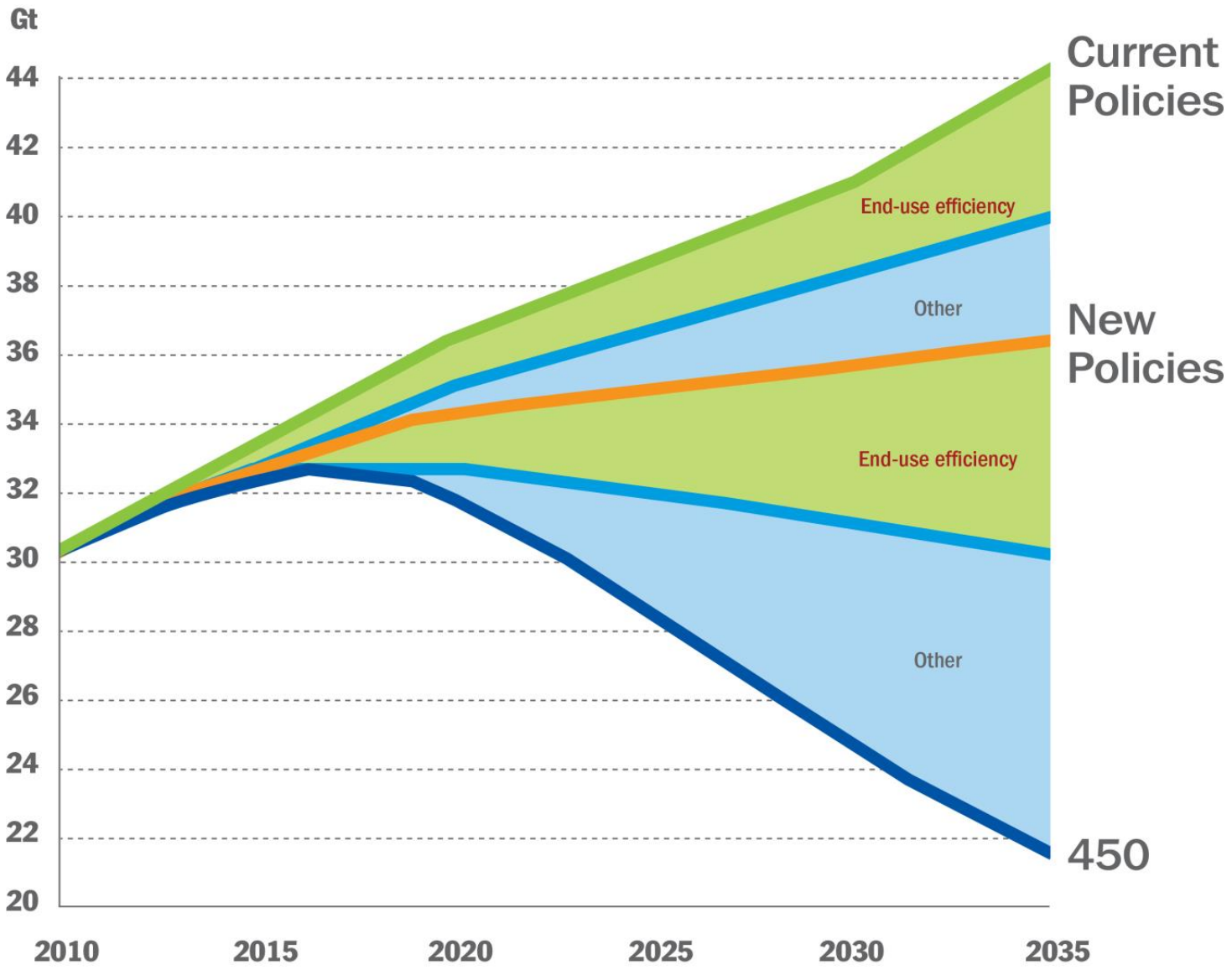


Lighting regulations in EU

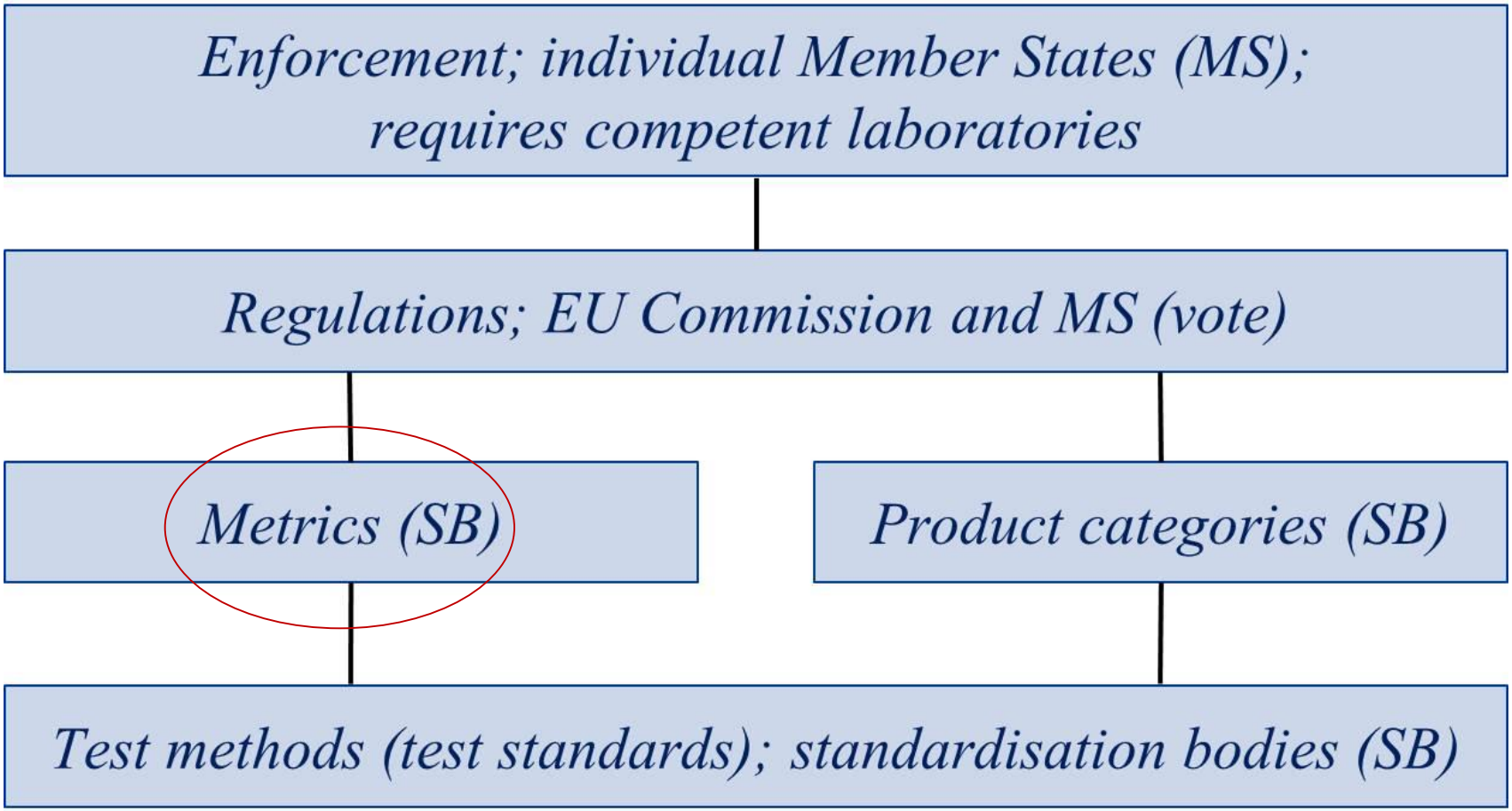
Four regulations aimed for lighting, annual savings from 2020 compared to a business-as-usual scenario

- Non-directional lighting:
  - Savings of 39 TWh per year
- Tertiary lighting:
  - Savings of 38 TWh per year
- LED and directional lighting +
- *Revised* labelling regulation
  - Savings of 25 TWh per year
- In all: savings of 102 TWh annually from 2020!

IEA estimates of current policies: huge *gap*

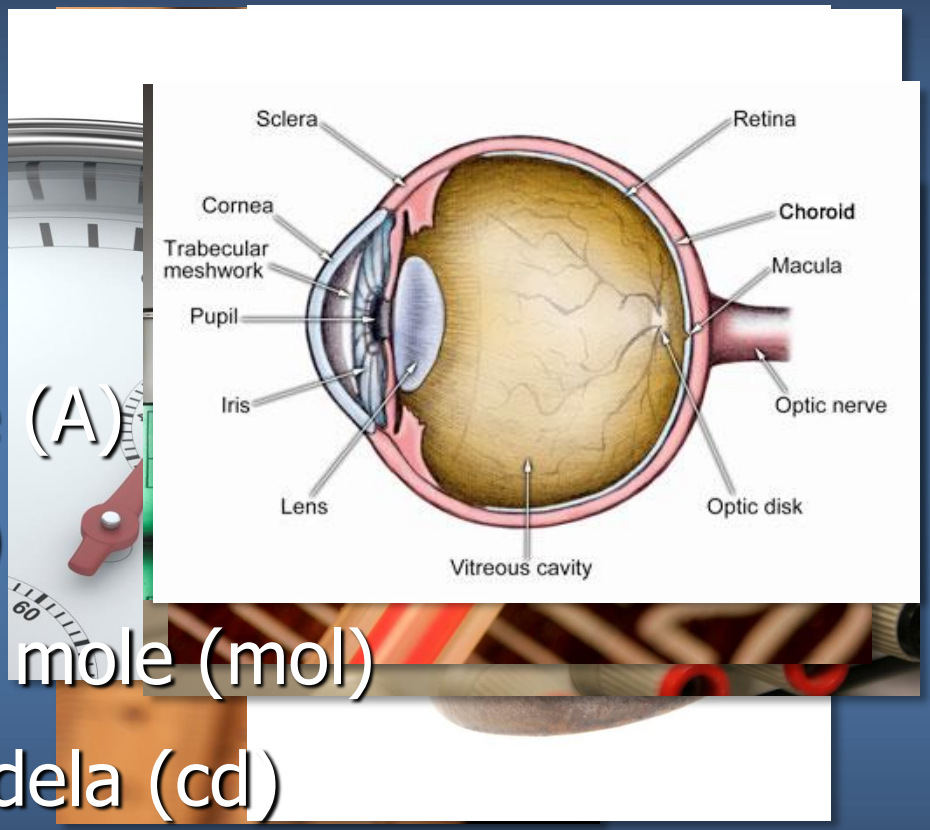


Regulations very efficient…but stand and fall with proper metrics, test methods etc! Topic today: the *metrics*



Fundamental quantities and units of measurement

- Length: meter (m)
- Mass: kilogram (kg)
- Time: second (s)
- Electric current: ampere (A)
- Temperature: Kelvin (K)
- Amount of a substance: mole (mol)
- Luminous intensity: candela (cd)



The only unit of measurement based on humans

Two regulating bodies for luminous intensity

International Committee for Weights and Me
Mutual Recognition Agreement

International Commission on Illumination

CIPM and CIE joint agreement

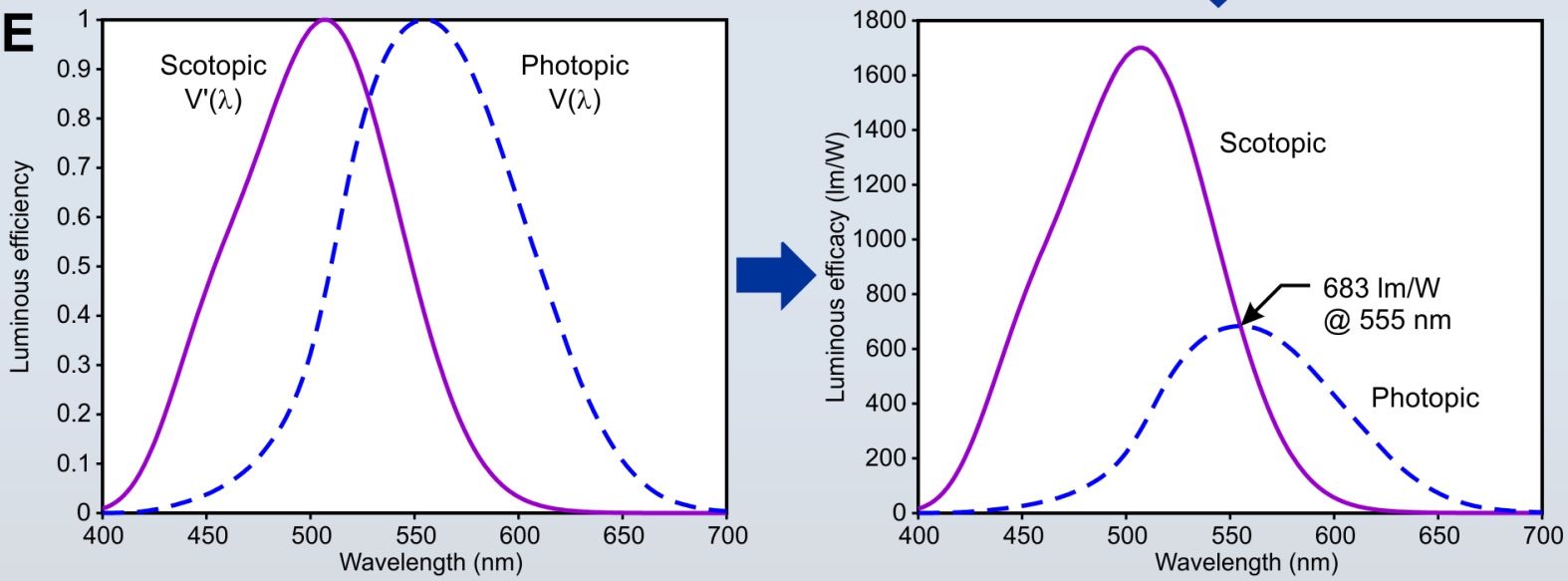
- The CIPM's responsibility is for the definition of the photometric unit (candela, cd) in the SI system
- The CIE's responsibility is for the standardization of luminous efficiency functions [$V(\lambda)$, $V'(\lambda)$, etc.]
  - "The CIE action spectra for the human eye in various states of adaptation (photopic, mesopic and scotopic), for various field sizes (2°, 10°) and various other conditions (visual environment, age of observer, etc.) as the CIE may decide to standardize."

Thus, there can be multiple definitions of light!

Trouble: Multiple definitions of light

CIPM 1 cd = 1/683 W/sr @ 540 x 10^{12} Hz

CIE

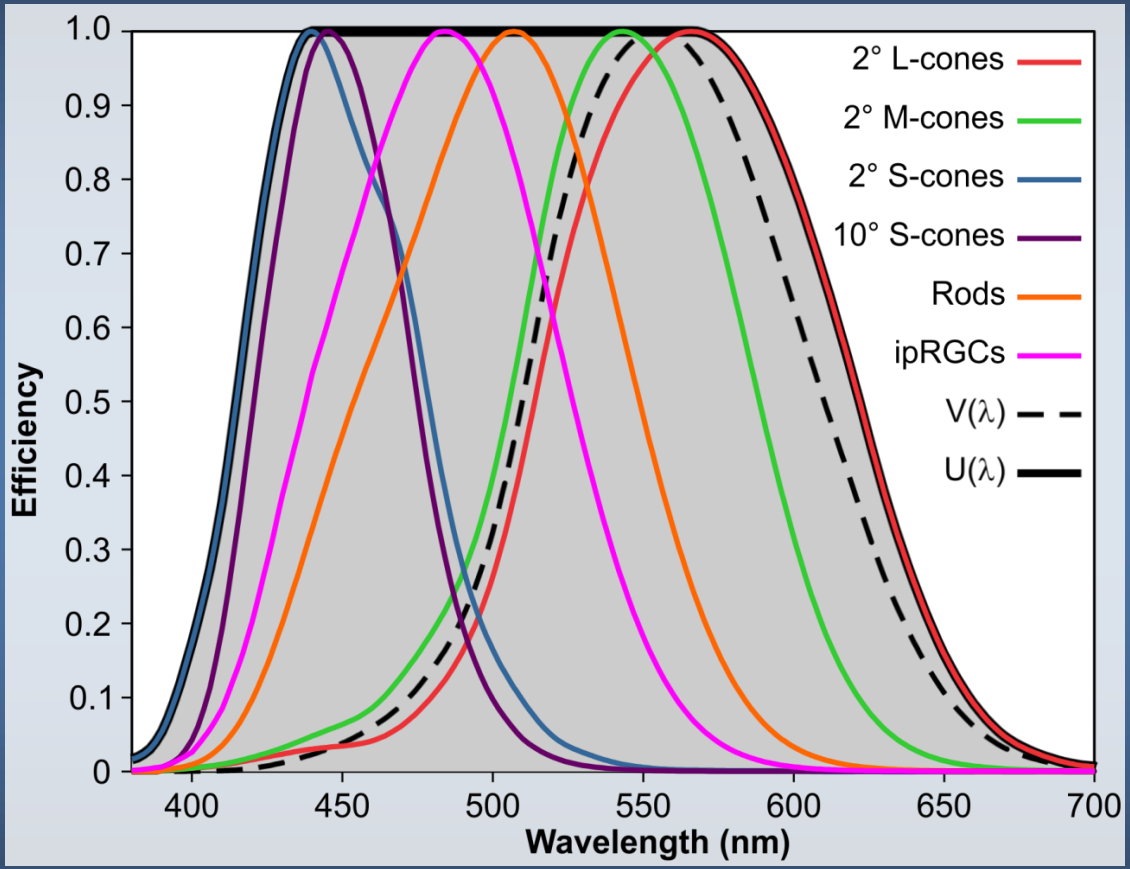


So what?

"This 105-watt High Watt CFL has a 5000K color temperature and provides 11,600 scotopic lumens."

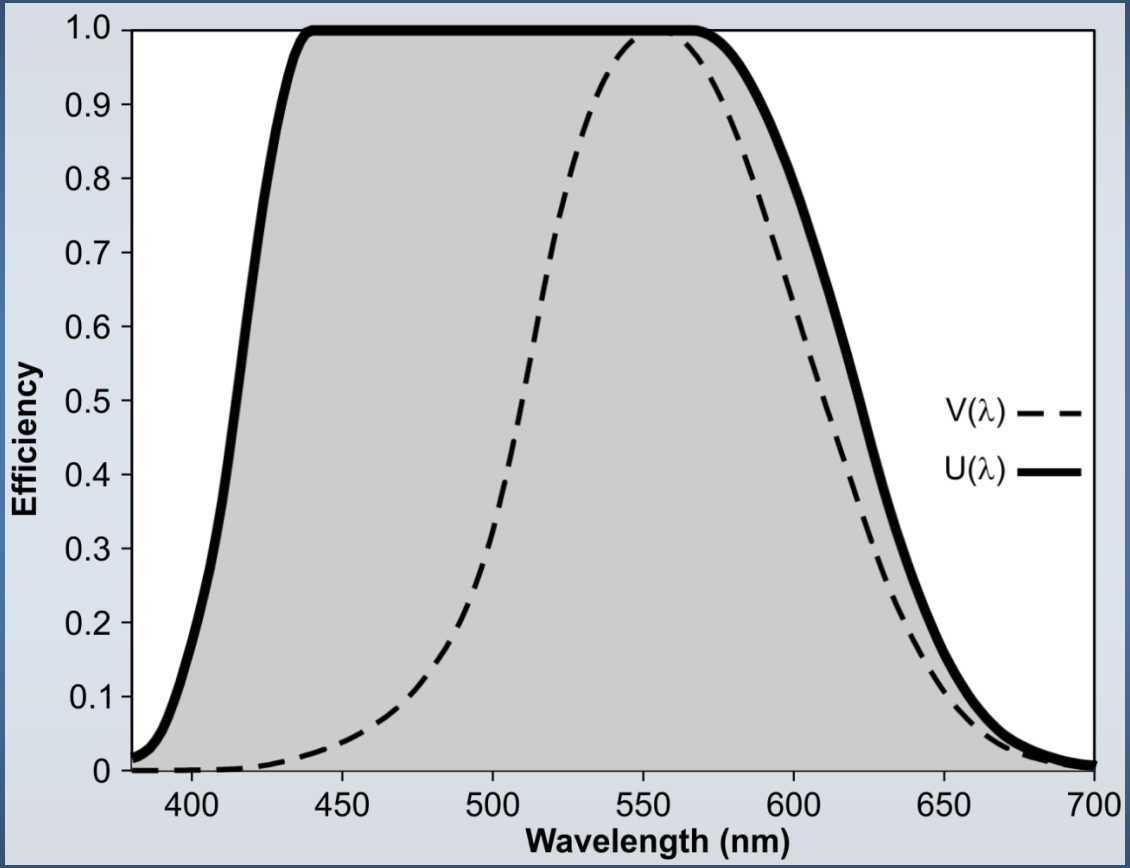
…but only 6300 "real lumens"

Trouble: V(λ) too narrow to represent eye sensitivity



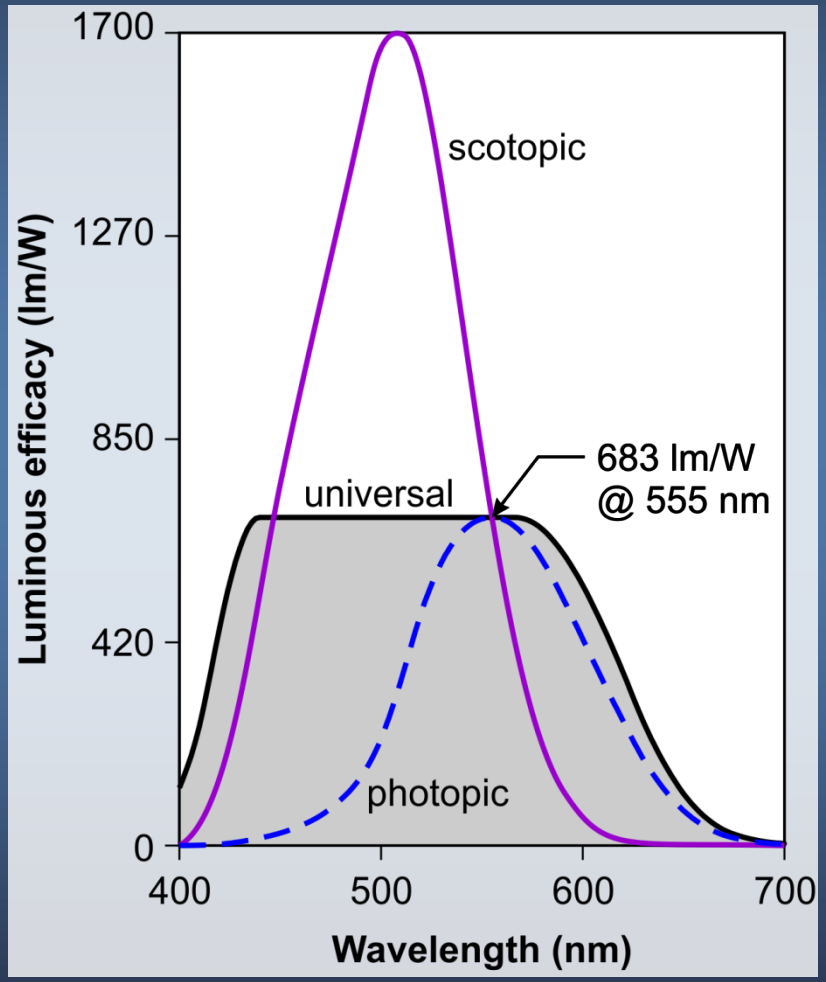
Building blocks for a universal luminous efficiency function, U(λ) based upon all of the known photoreceptors in the human eye

Solution: Broaden efficiency function to U(λ) to better represent eye sensitivity



AND…

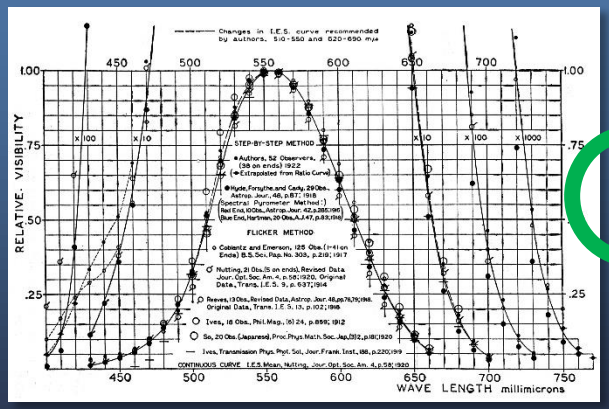
Solution: Only one luminous efficiency function



Trouble: No difference between light and lighting

- In 1924, neuroscience led to the photopic luminous efficiency function, V(λ)

1924 Neuroscience



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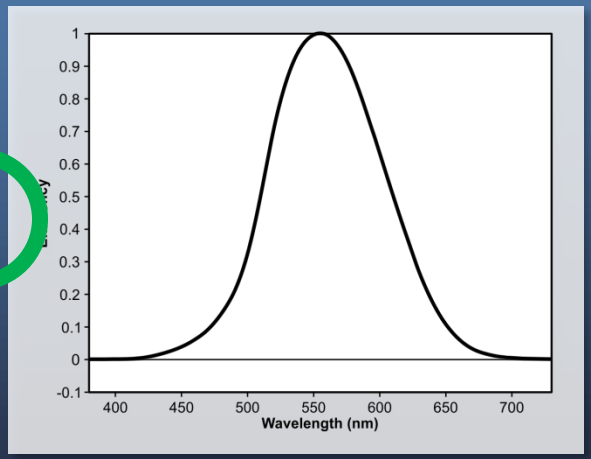
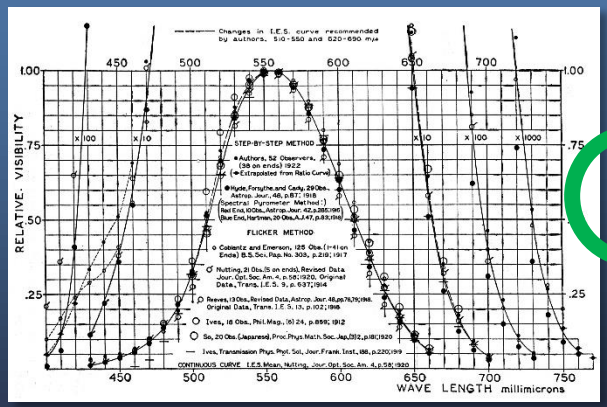
V(λ)



Trouble: No difference between light and lighting

- In 1924, neuroscience led to the photopic luminous efficiency function, V(λ), which became the basis for all lighting standards and, implicitly, the benefit that lighting delivers

1924 Neuroscience



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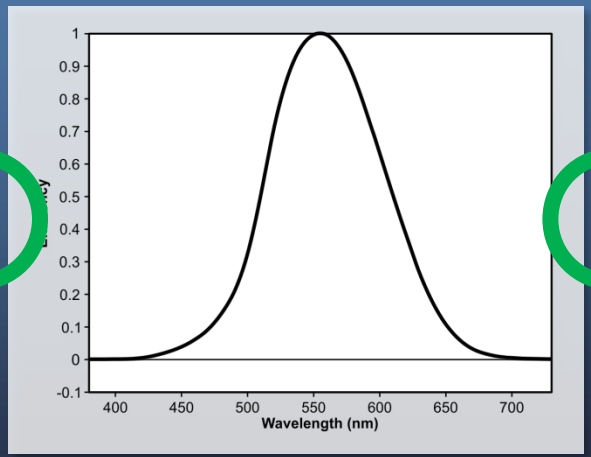
The Benefit Metric



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Lighting

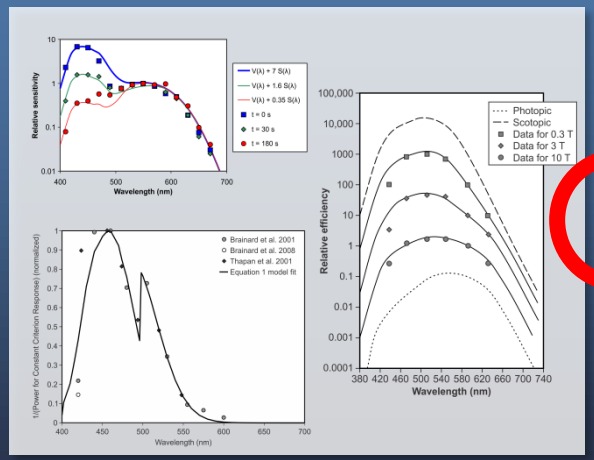
Trouble: No difference between light and lighting

- Since 1924, we have learned a great deal about how the eye responds to optical radiation
- Lighting has not capitalized on that information so the benefit is unchanged – all specifications based upon photopic illuminance

2014 Neuroscience

The Benefit Metric

Lighting



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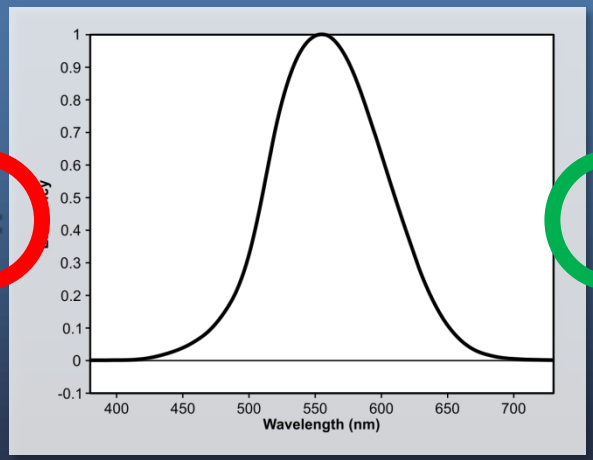

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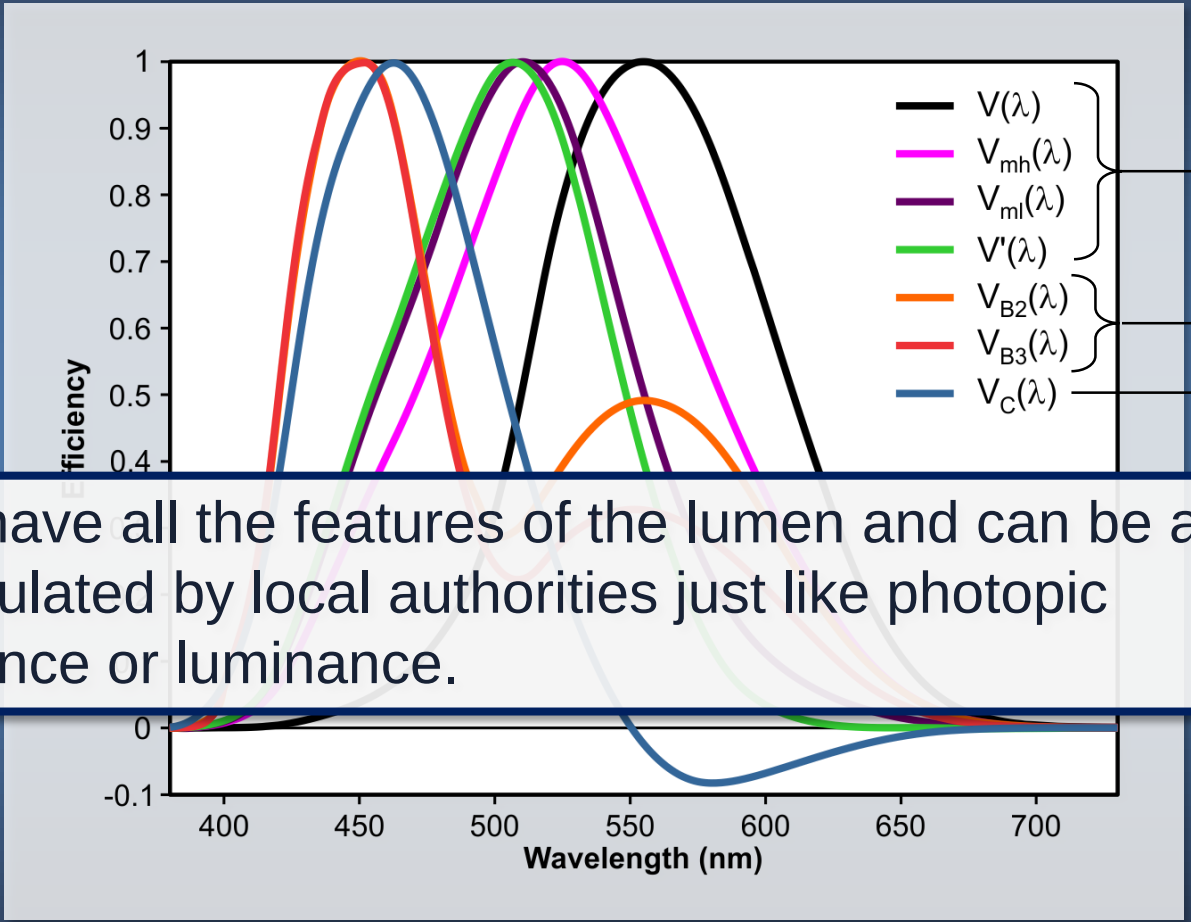
Benefit metric spectral weighting functions

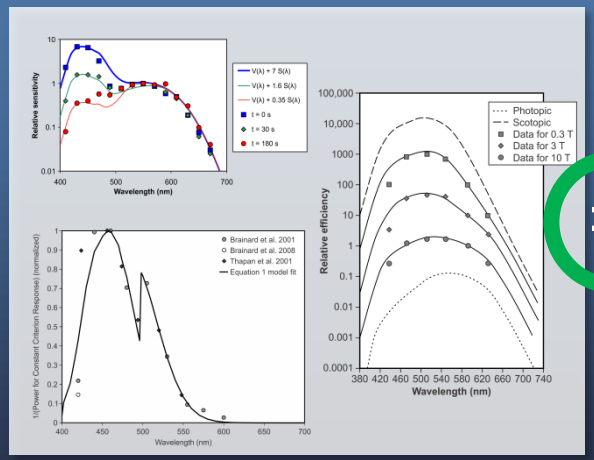


These have all the features of the lumen and can be applied and regulated by local authorities just like photopic illuminance or luminance.

Benefit metrics

- Benefit metrics, based upon what we have learned since 1924, can provide society with more valuable lighting (benefit/cost) than photopic illuminance alone
- Lighting applications are independent of the definition of light

Neuroscience



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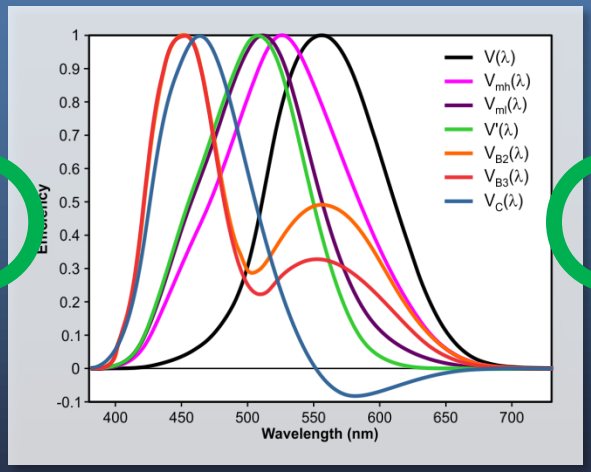
Benefit Metrics



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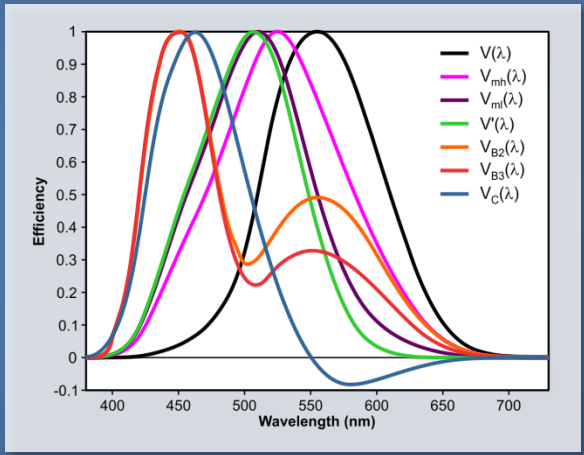
Lighting

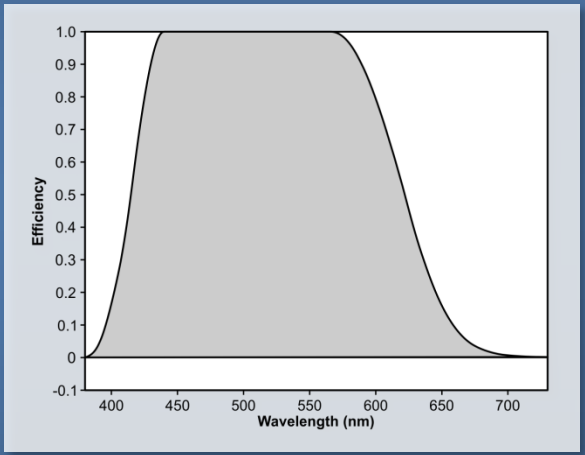
Solution: Separate light from lighting

Lighting



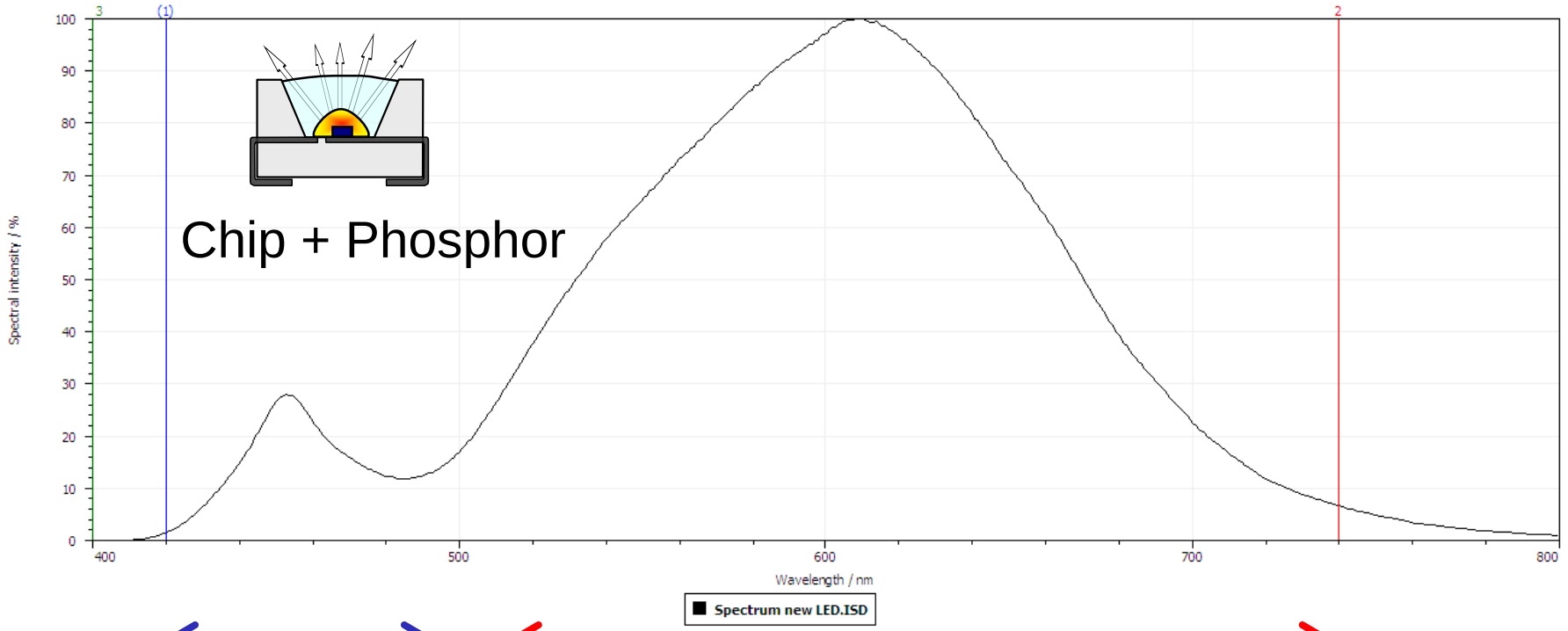
Benefit metrics

Light



Universal luminous efficiency function U(λ)

LED coming more and more: can *vary* the spectrum



Blue peak from the chip

Blue -> green - red in the phosphor

Overall white, but with *varying* correlated colour temperature

Lighting applications

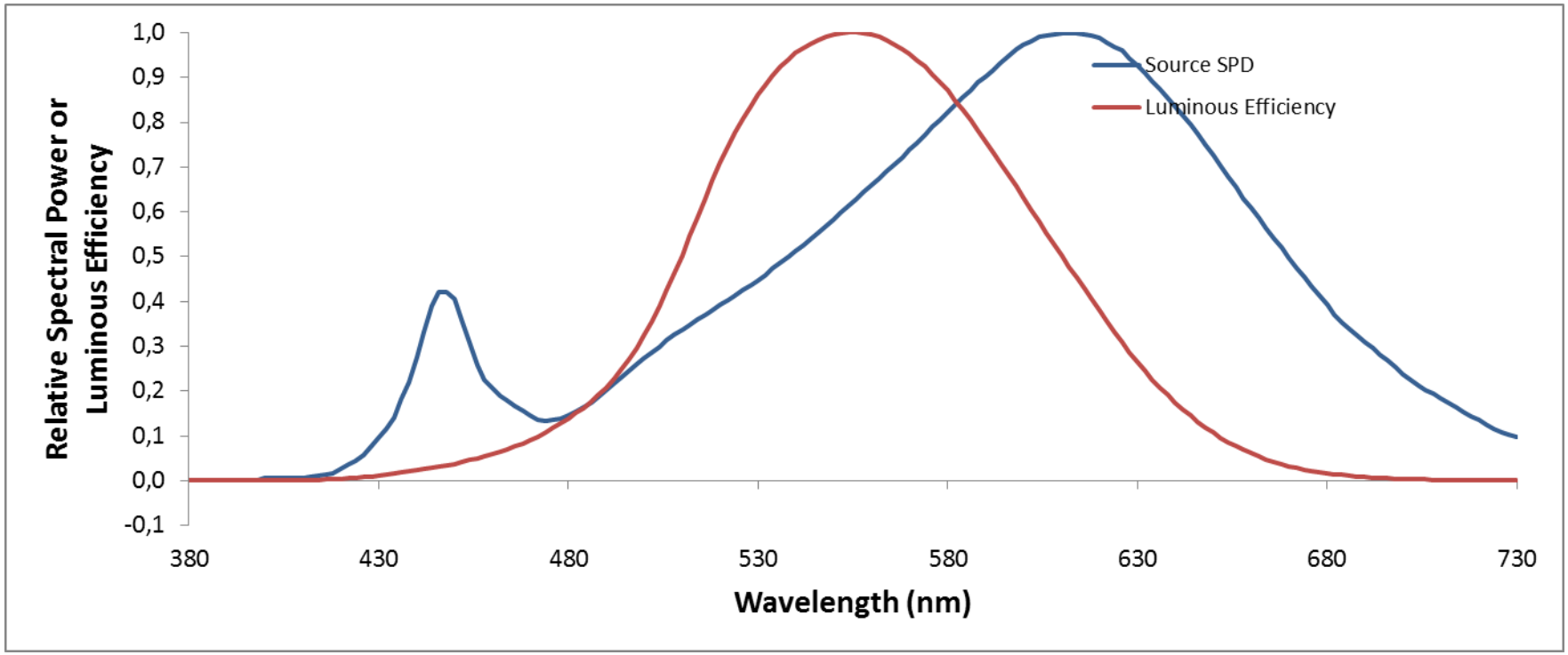
Many applications related to the correlated colour temperature (CCT)

- Cosy lighting: 2700 K
- Office lighting: 4000 K
- Street lighting, high brightness: 5-6000 K
- Etc

… but current legislation is based on the photopic lumen only, which *favour low CCT*… will lead to waste of energy for high CCT applications!

How to recalculate photopic lumen (P_{lumen}) to universal lumen (U_{lumen}):

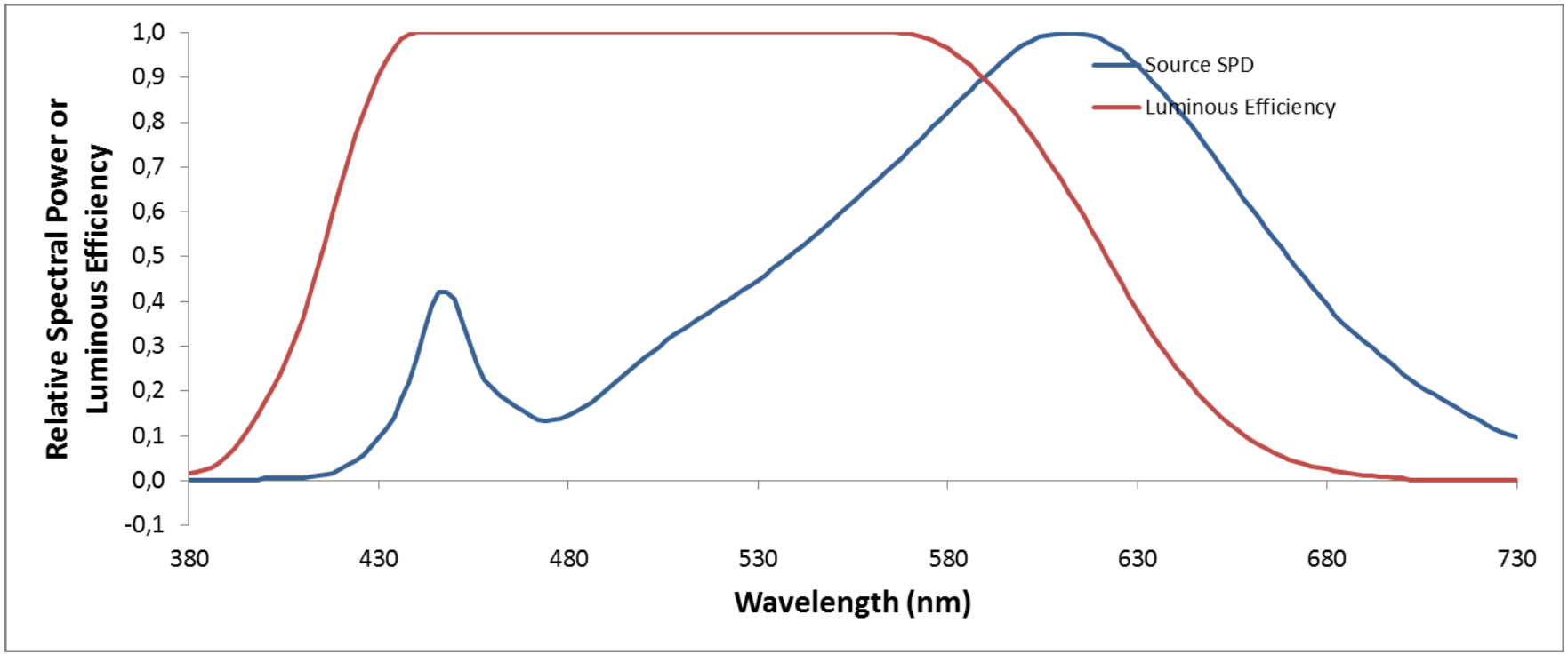
First ex: *P_{lumen} & LED 2700 K -> 65 lm/W*



Compared with

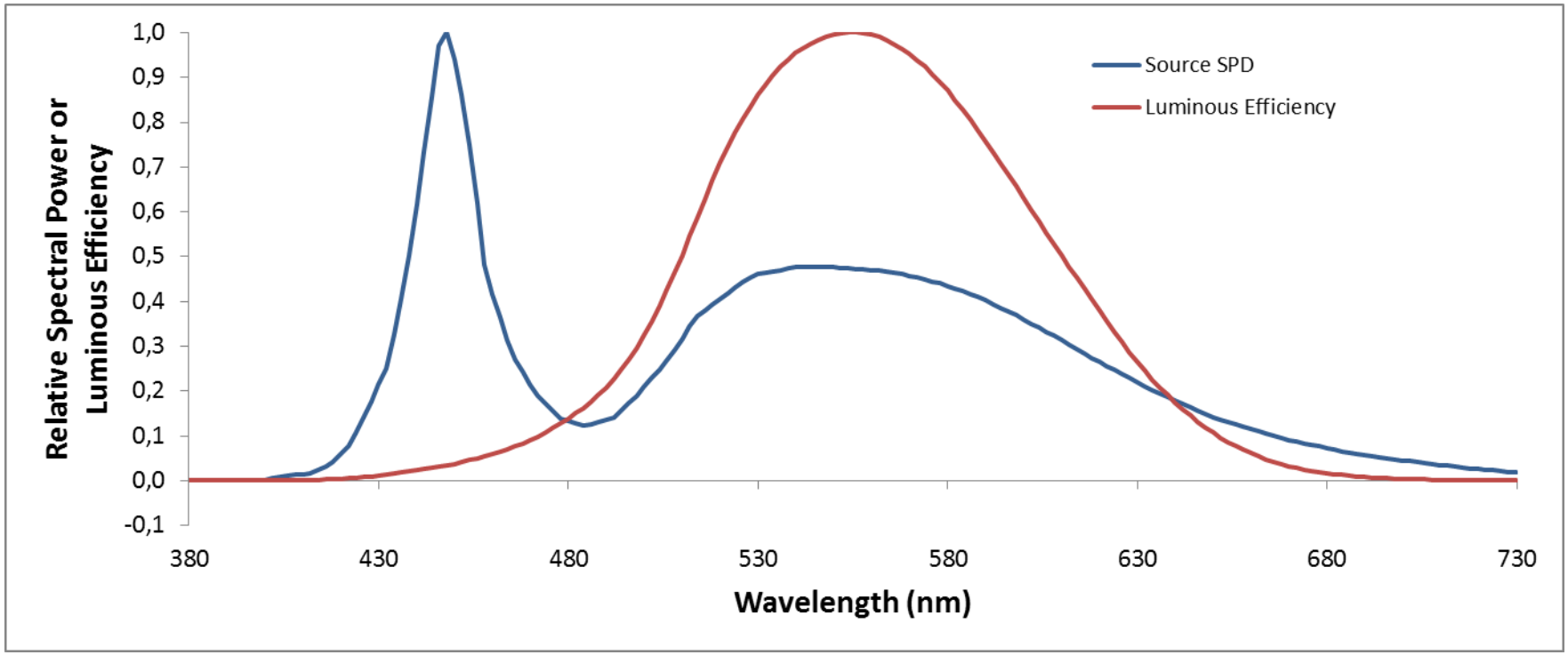
U_{lumen} & LED 2700 K -> 92 lm/W

U/P = 92/65 = **1.41**



Second example:

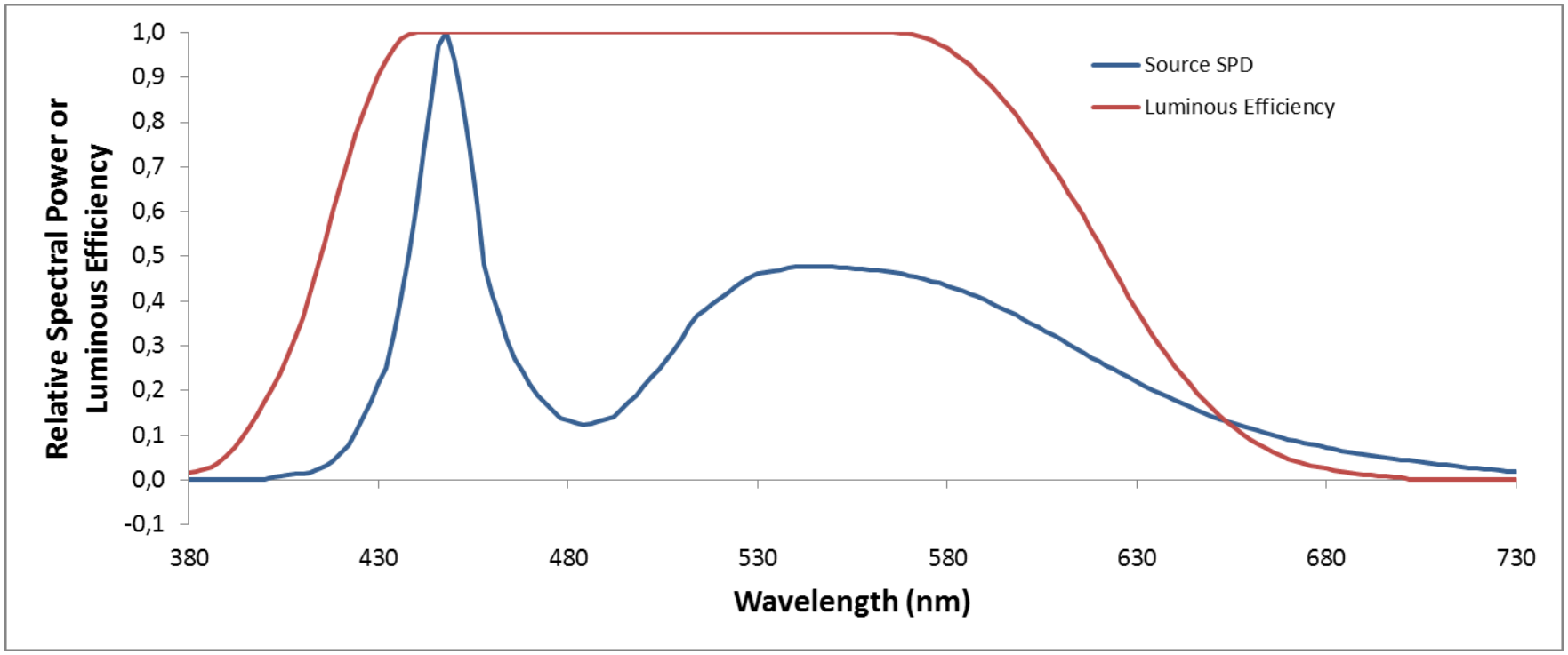
P_{lumen} & LED 6500 K -> 80 lm/W



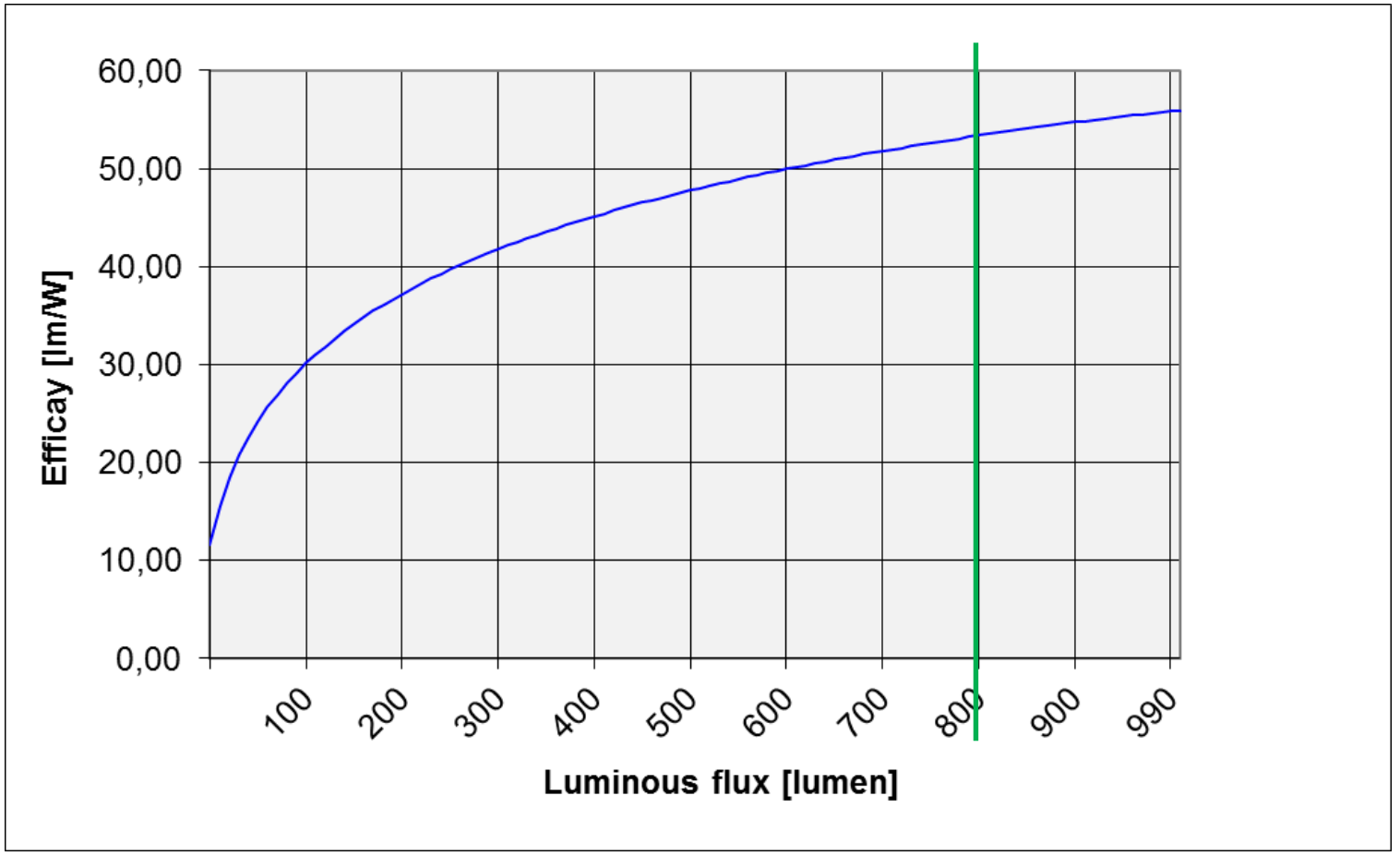
Compared with

U_{lumen} & LED 6500 K -> 145 lm/W

U/P = 145/80 = **1.81**



Example 1: regulation 244/2009 non-directional lamps



$P_{max} = 0.24\sqrt{\Phi} + 0.013\,\Phi$ -> $\eta_{min} = \Phi / P_{max}$ for frosted lamps

Example (cont): regulation 244/2009 non-directional lamps

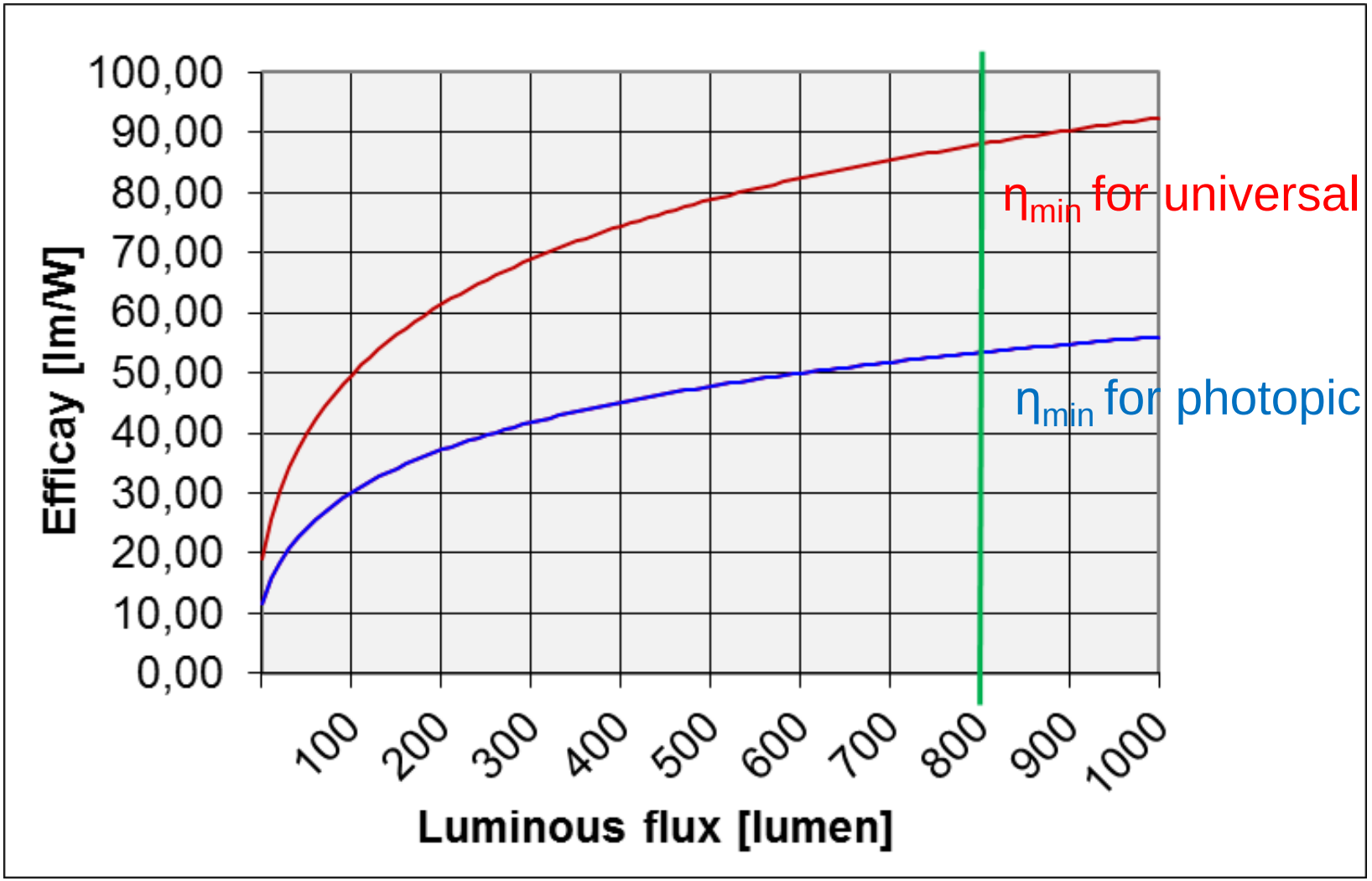
CFL 15 W -> min flux of 800 lm, or η_{min} = 53 lm/W

Light source	Photopic lm/W	Universal lm/W	Relative gain	Relative efficacy ratio
CFL, 15 W	61	85	1.39	1.00
Samsung 362A 2700 K (warm)	84.6	127.6	1.51	1.09
Samsung 362A 6500 K (cool)	94.0	178.7	1.90	1.37

Table -> CFL and all LEDs comply. Now two options:

1. Tighten the minimilevels -> only the LEDs will comply, can go down 9.7 – 10.8 W for the same flux
1. Go further: use universal lumen -> possible to tighten it *even further, yielding even more savings: can go down to 7.0 – 9.9 W for the same flux*

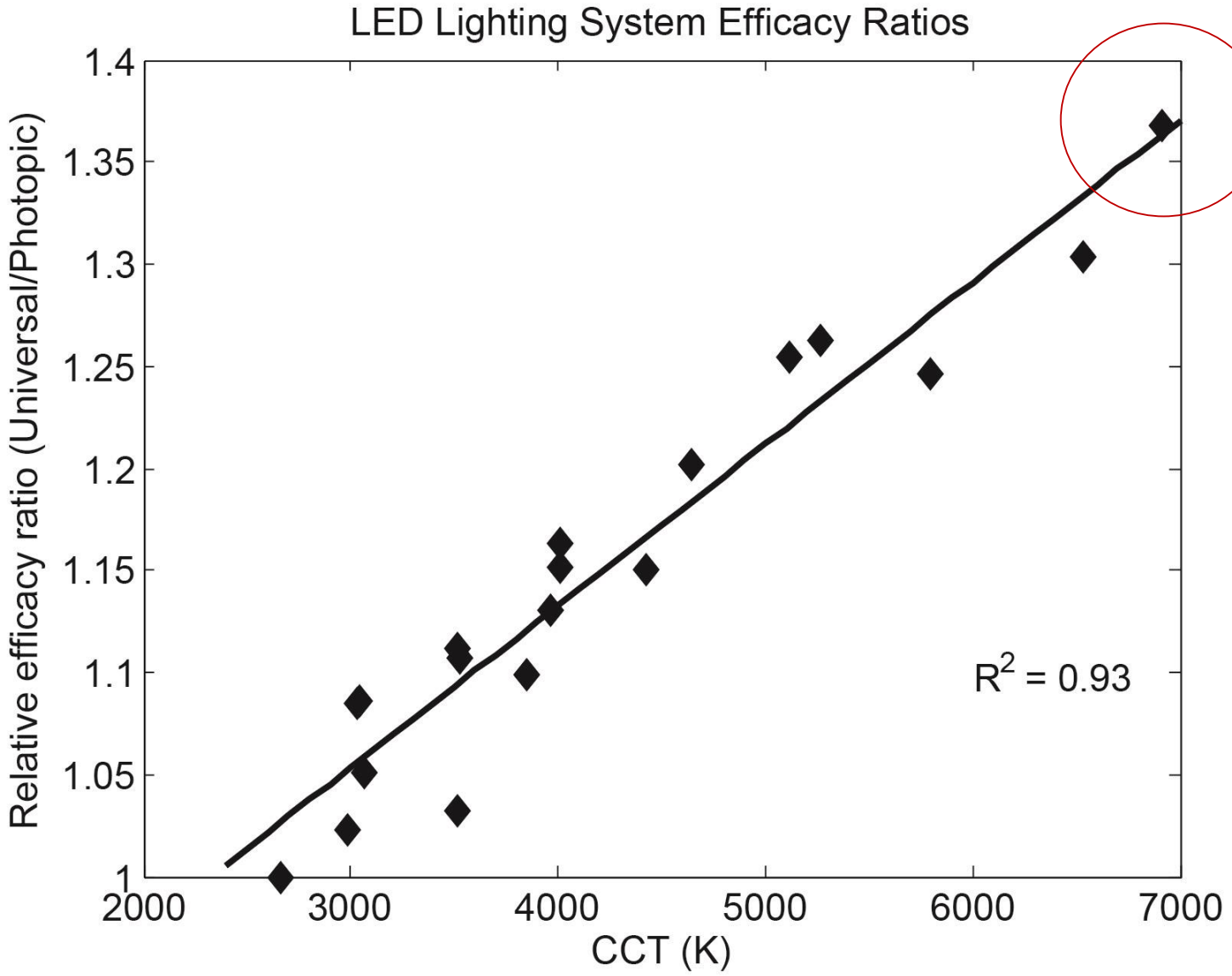
Example 1: regulation 244/2009 non-directional lamps



Example 2: exploring the relative efficacy ratio vs CCT more in detail

Manufacturer	CCT (K)	Photopic efficacy (lm/W)	Universal efficacy (lm/W)	Relative gain (U/P)	Relative efficacy ratio
Reference: CFL, 15 W	-	61	85	1.39	1.00
Philips Lumileds	2660	61.0	84.8	1.39	1.00
Philips Lumileds	2990	64.8	92.2	1.42	1.02
Philips Lumileds	3520	61.0	94.3	1.55	1.12
Philips Lumileds	4010	64.8	103.7	1.60	1.15
Philips Lumileds	5800	80.0	138.7	1.73	1.24

The relative efficacy ratio vs CCT



> 35% gain!

Should be possible to utilise in the regulations

Conclusions and summary

- New understanding of the neurological response of the eye call for a new definition of the candela and the lumen
- Many regulations for lighting based on the old definition, the photopic lumen
- Lighting major end use, a lot to gain on better regulations
- Very good example why policy makers need to engage in research and standardisation work
- This case: work in progress


Thank you for your attention!