

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

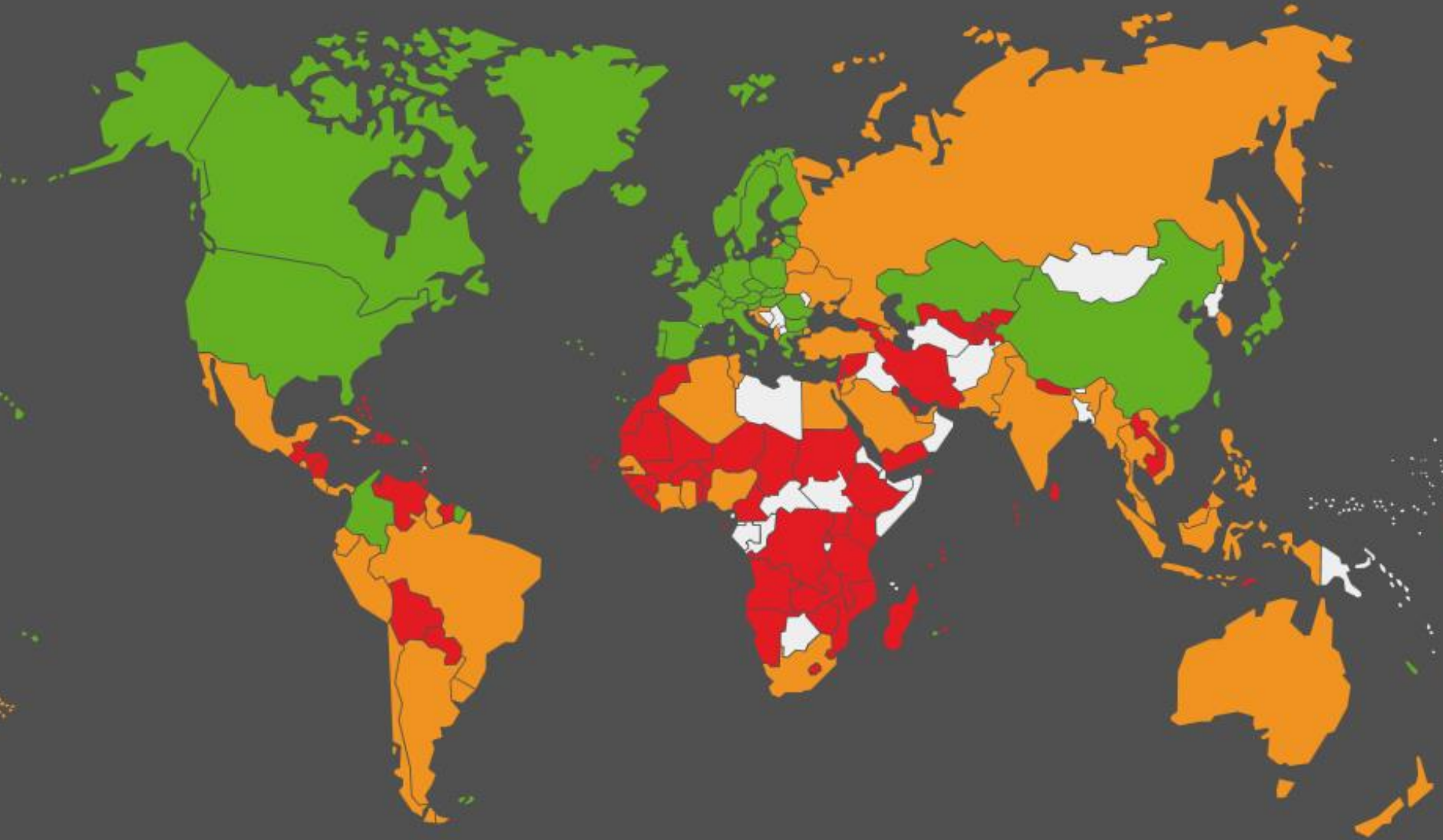
Lighting global major end use

IEA 2007:

2005: 2650 TWh/yr

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

-> Lighting regulations globally

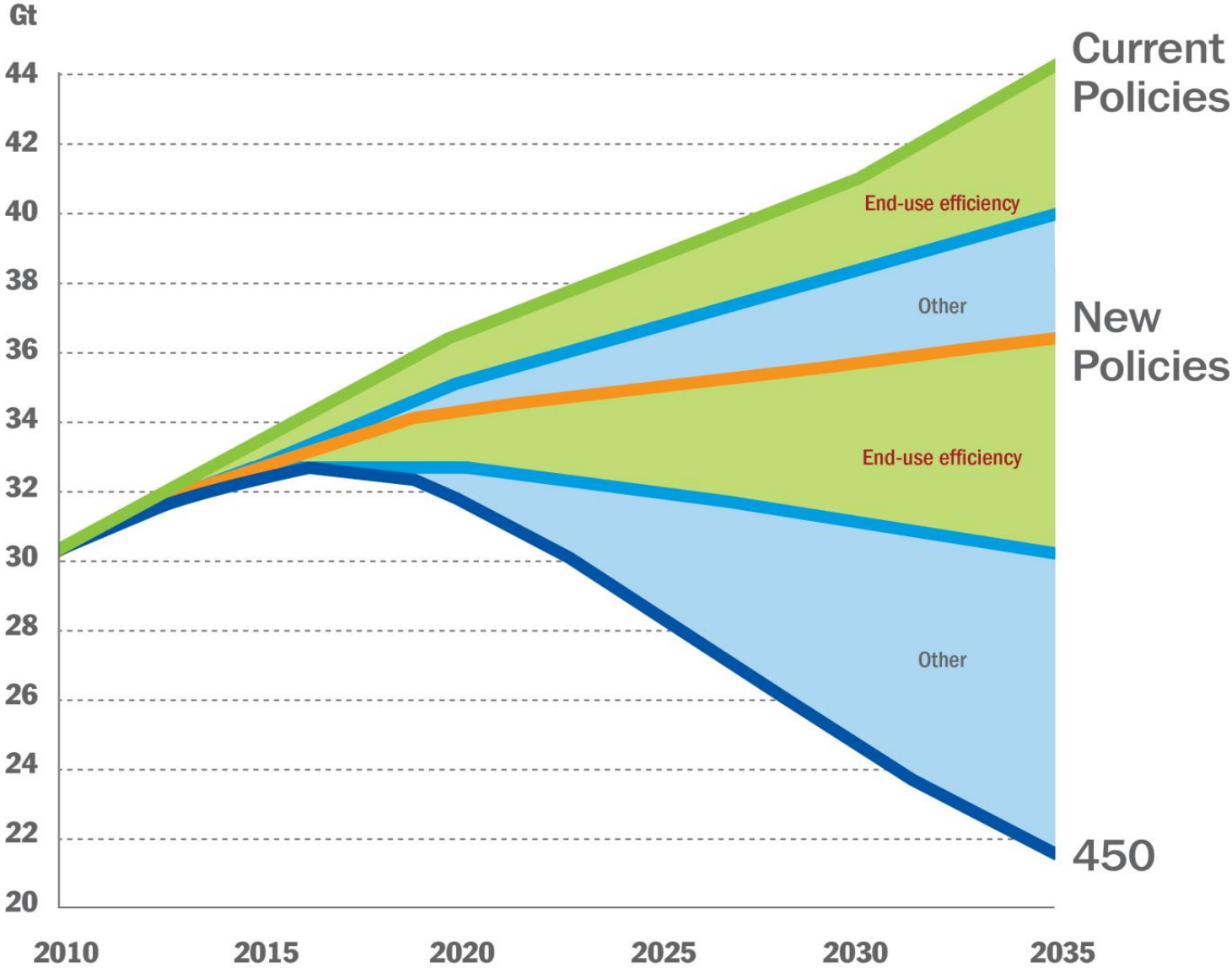


Lighting regulations in EU

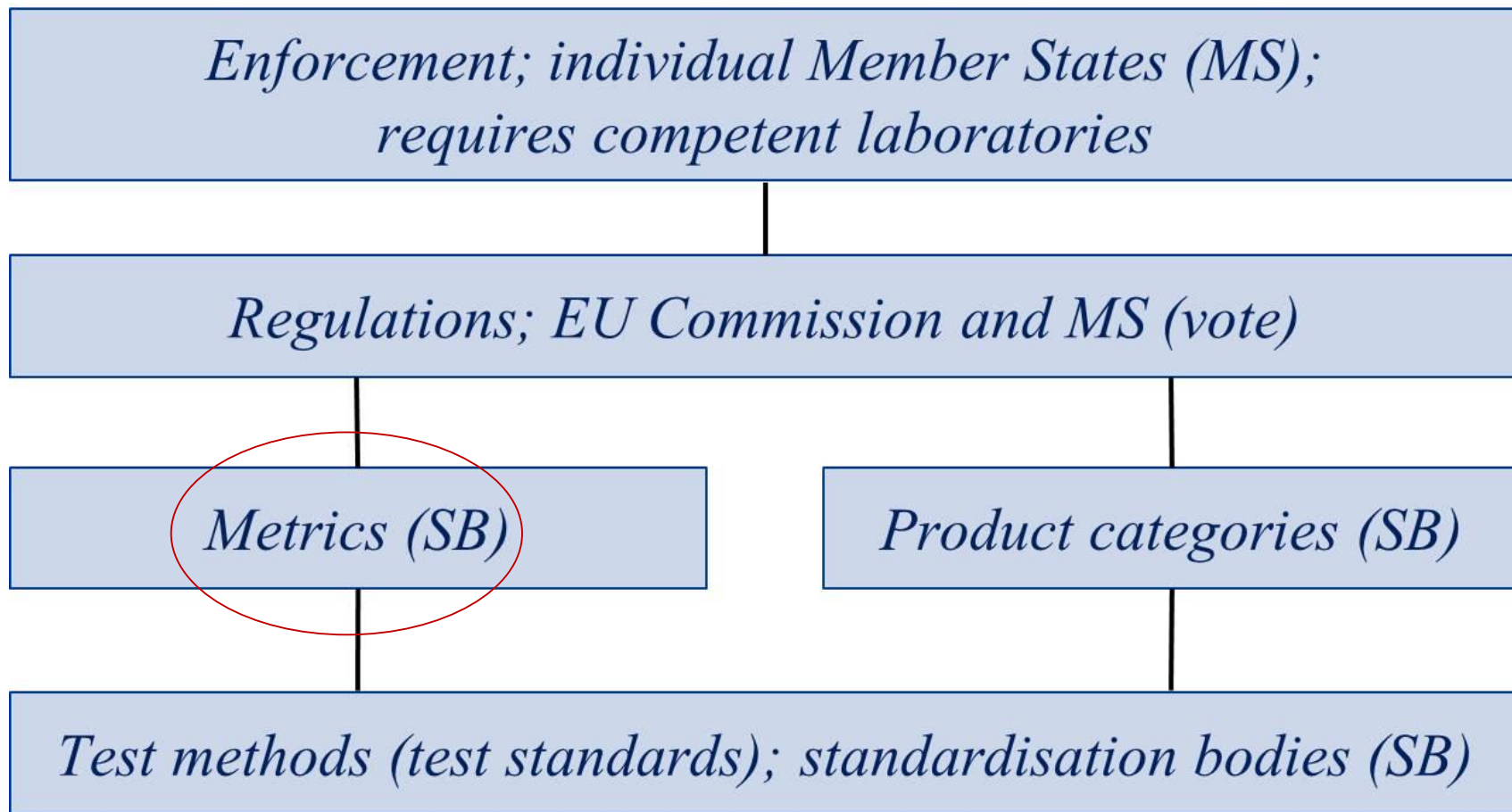
Four regulations aimed for lighting, annual savings from 2020 compared to a business-as-usual scenario

- 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*

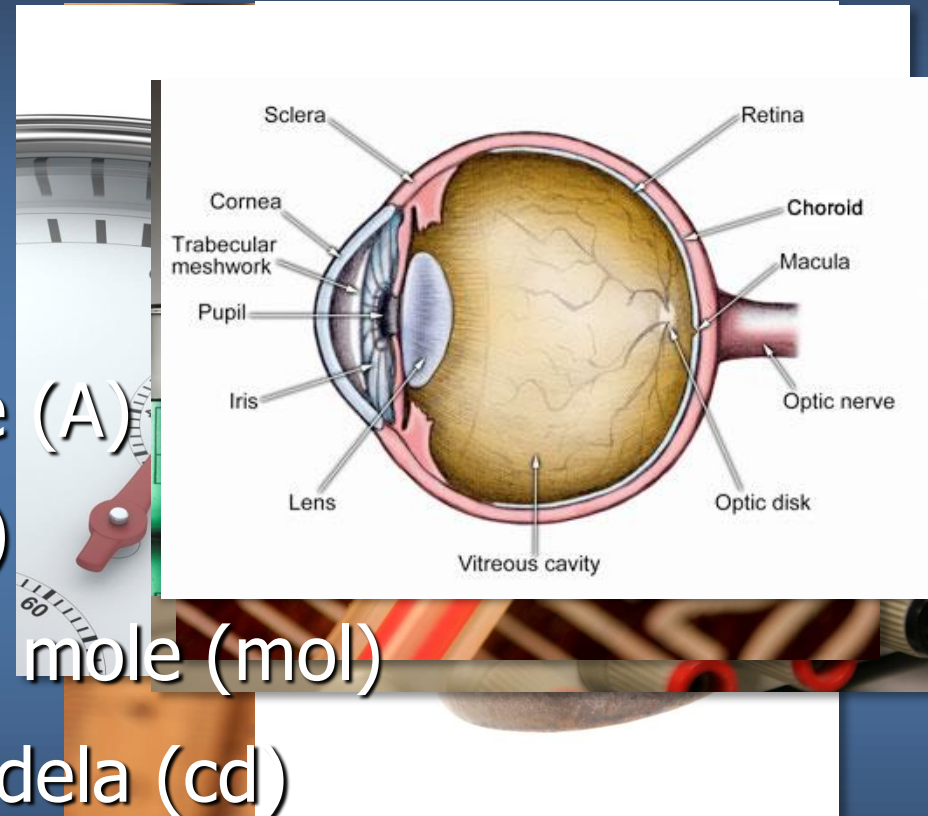


Regulations very efficient...but stand and fall with proper metrics, test methods etc! Topic today: the *metrics*



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 Measures
Mutual Recognition Agreement



International Commission on Illumination

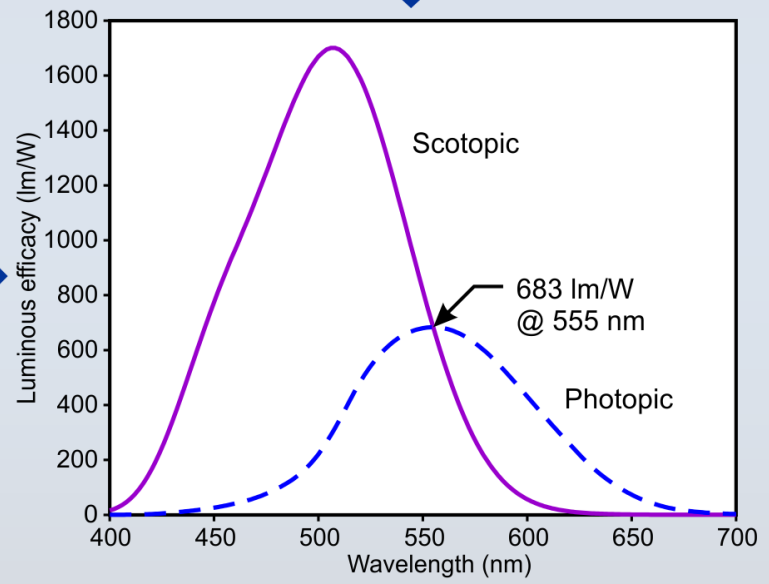
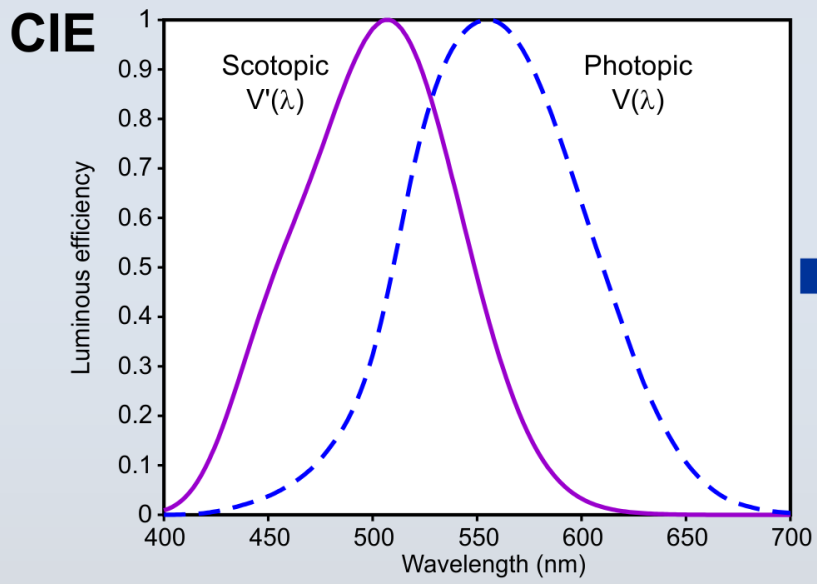
CIPM and CIE joint agreement

- ◆ 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 $1 \text{ cd} = 1/683 \text{ W/sr @ } 540 \times 10^{12} \text{ Hz}$



So what?

Design Lumens vs. Pupil Lumens & Usable Light

In lighting design there are two distinct kinds of lumen output produced by lamps. The first is called photopic or design lumens, which represent the relative sensitivity of the eye under intense light conditions. The second type of lumens are called scotopic, which represent the relative sensitivity of the eye under low light conditions. The amount of light registered by the cones in the human eye and is measured with a standard light meter. Scotopic lumens cannot be measured directly with a standard light meter. Scotopic lumens are measured with a scotopic meter and also controls pupil size directly affecting the amount of light that enters the eye. For lighting interior spaces, the amount of light that enters the eye is what matters.

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PHOTOPIC LUMENS AND SCOTOPIC LUMENS

What are they and why does it matter to me? By understanding how the human eye perceives light, an energy auditor can design an energy efficient project using less power and providing sufficient light levels. Thus meaning, more money back in your pocket at the end of the project.

Photopic lumens are the actual lumens read by any measuring device such as a footcandle meter. Scotopic lumens (or Pupil lumens) is a measurement based on how the human eye registers light. The more "bright white" the light is, the brighter the light will appear to the human eye. A real world example would be this:

Late at night you are driving down the street and you notice two parking lots that have different colors of light. One is more "bright white" and the other is "orange" in color.

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105-Watt High Watt CFL T5 MOG 5000K



HIGH-WATT CFL

Markets

- Restaurants
- Hospitality
- Retail

Applications

- Big Box/Grocery Retailers
- Convention Centers
- High/Low Bay Industrial
- Parking Garage
- Parking Lots
- Warehouses

Product Description

High Watt CFLs are designed to replace HID light bulbs in high bay applications for energy savings and higher ROI. They utilize an external ballast, which offers better heat management and maximum lumen maintenance and life.

This 105-watt High Watt CFL has a 5000K color temperature and provides 11,600 scotopic lumens. Please use with ballast ZB-1201 or ZB-1202.

Specifications

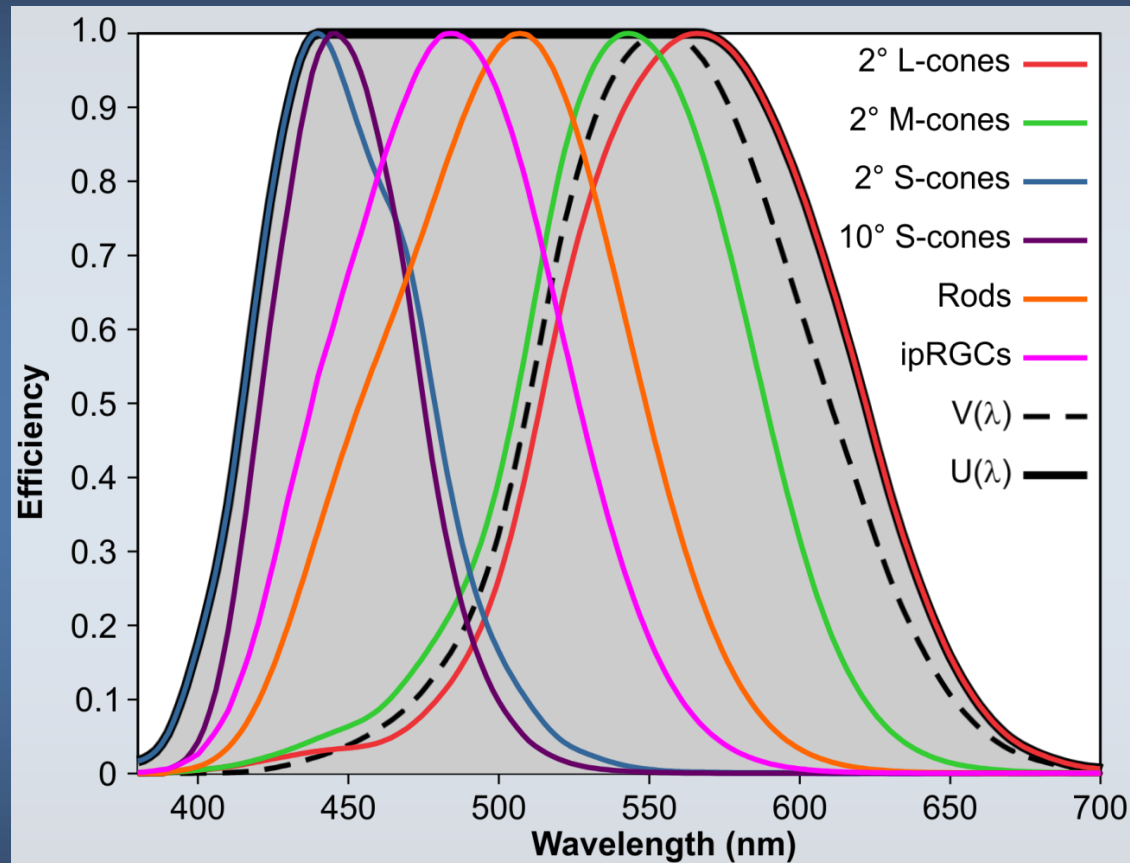
- Category
- Shape
- Product Brand
- Part Number
- Watts
- Base
- Average Rated Life
- Case Quantity
- Initial Lumens
- Mean Lumens
- Scotopic Lumens
- CRI
- Color Temp
- Burn Position

UL

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

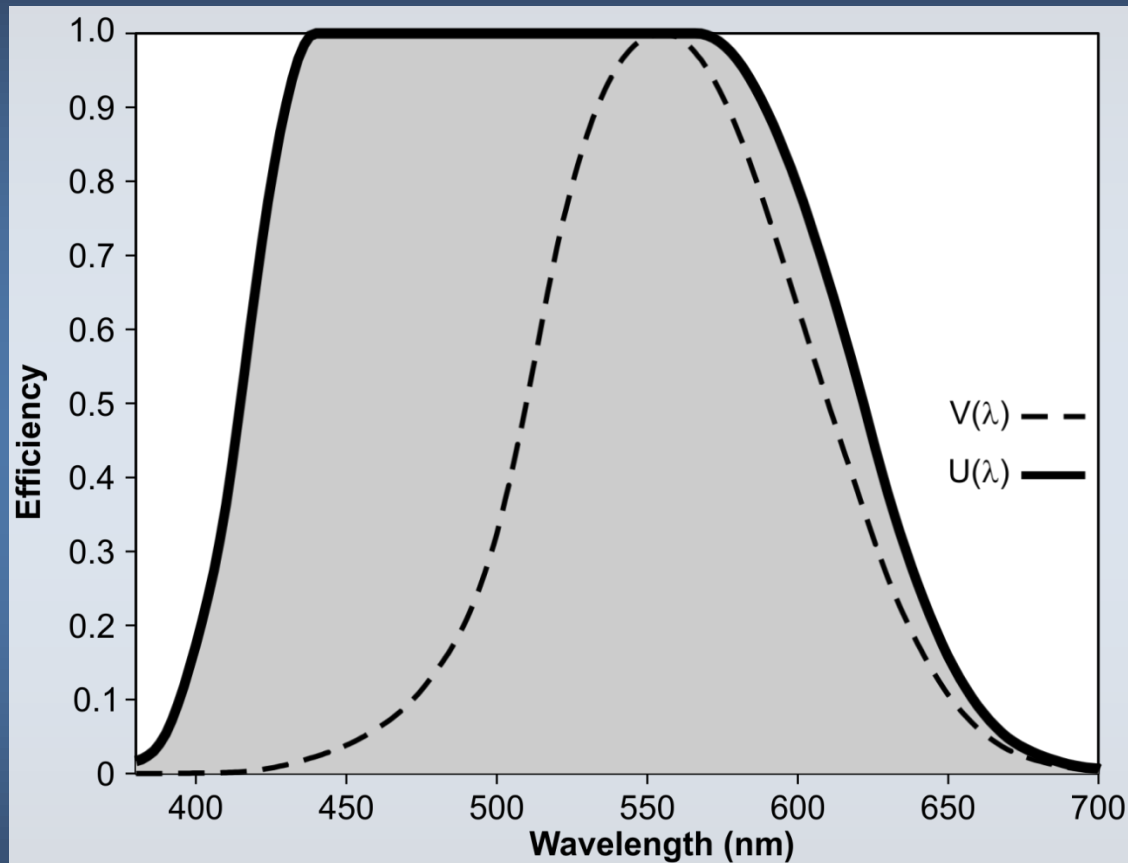
...but only 6300 "real lumens"

Trouble: $V(\lambda)$ too narrow to represent eye sensitivity



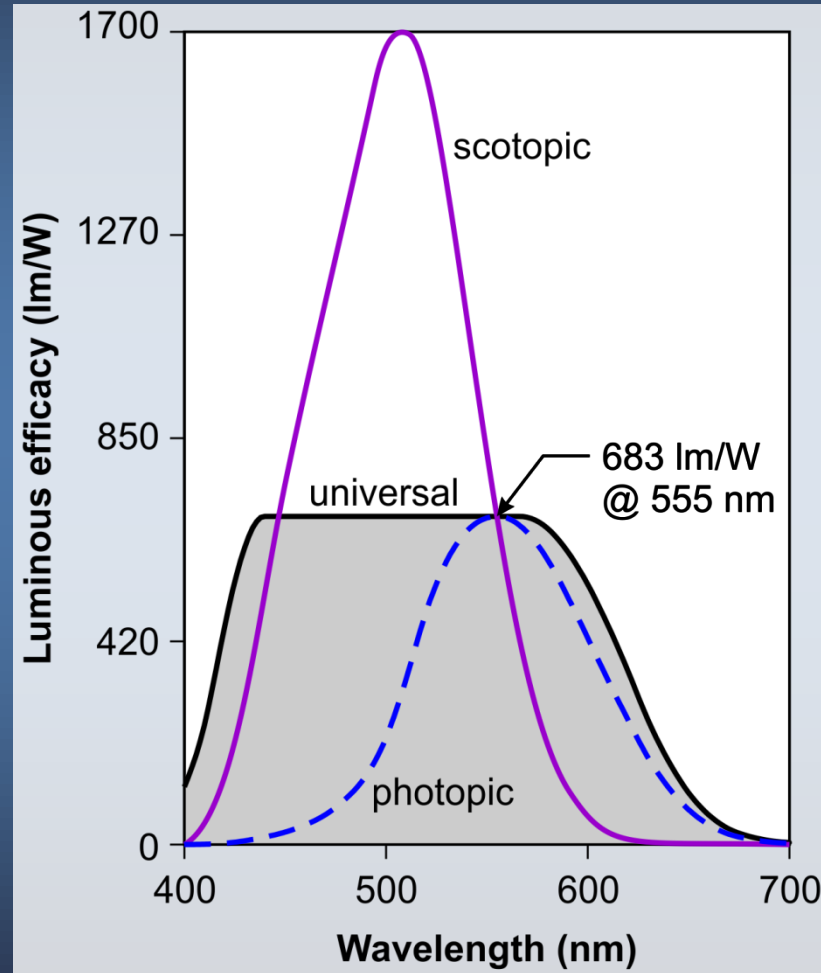
Building blocks for a universal luminous efficiency function, $U(\lambda)$ based upon all of the known photoreceptors in the human eye

Solution: Broaden efficiency function to $U(\lambda)$ to better represent eye sensitivity



AND...

Solution: Only one luminous efficiency function

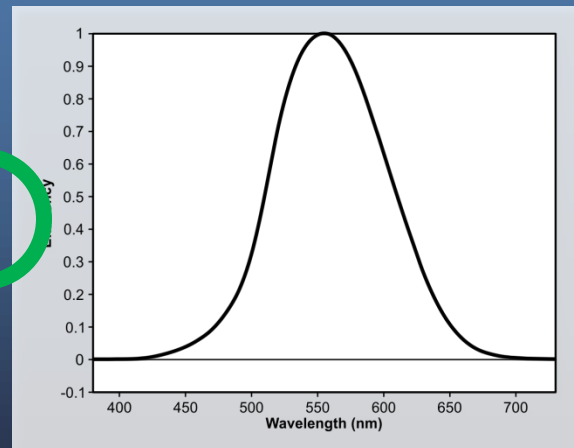
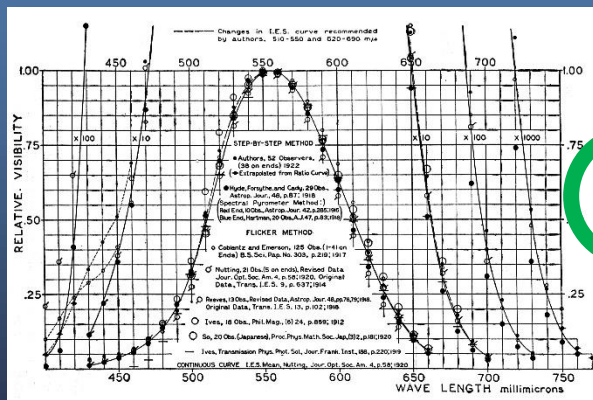


Trouble: No difference between light and lighting

- ◆ In 1924, neuroscience led to the photopic luminous efficiency function, $V(\lambda)$

1924 Neuroscience

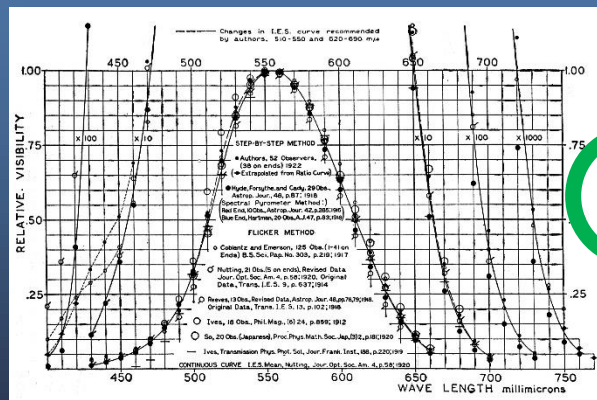
$V(\lambda)$



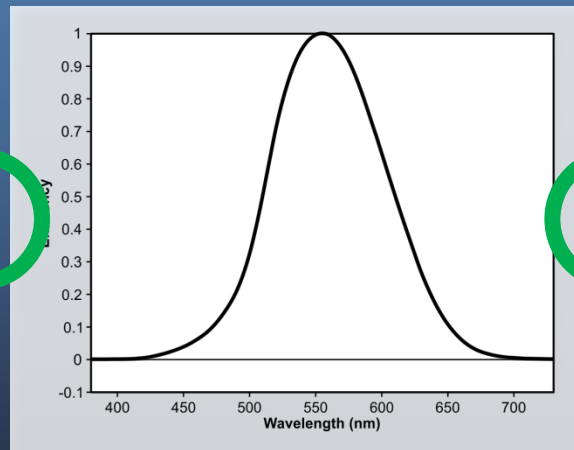
Trouble: No difference between light and lighting

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

1924 Neuroscience



The Benefit Metric



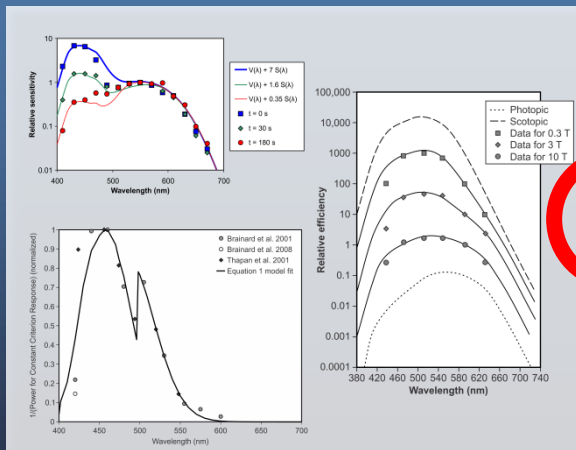
Lighting



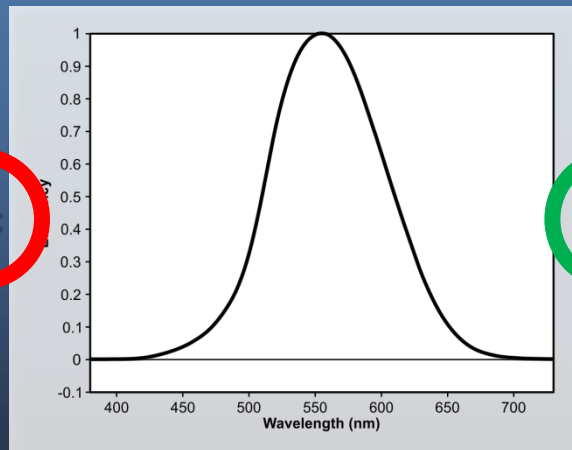
Trouble: No difference between light and lighting

- ◆ 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



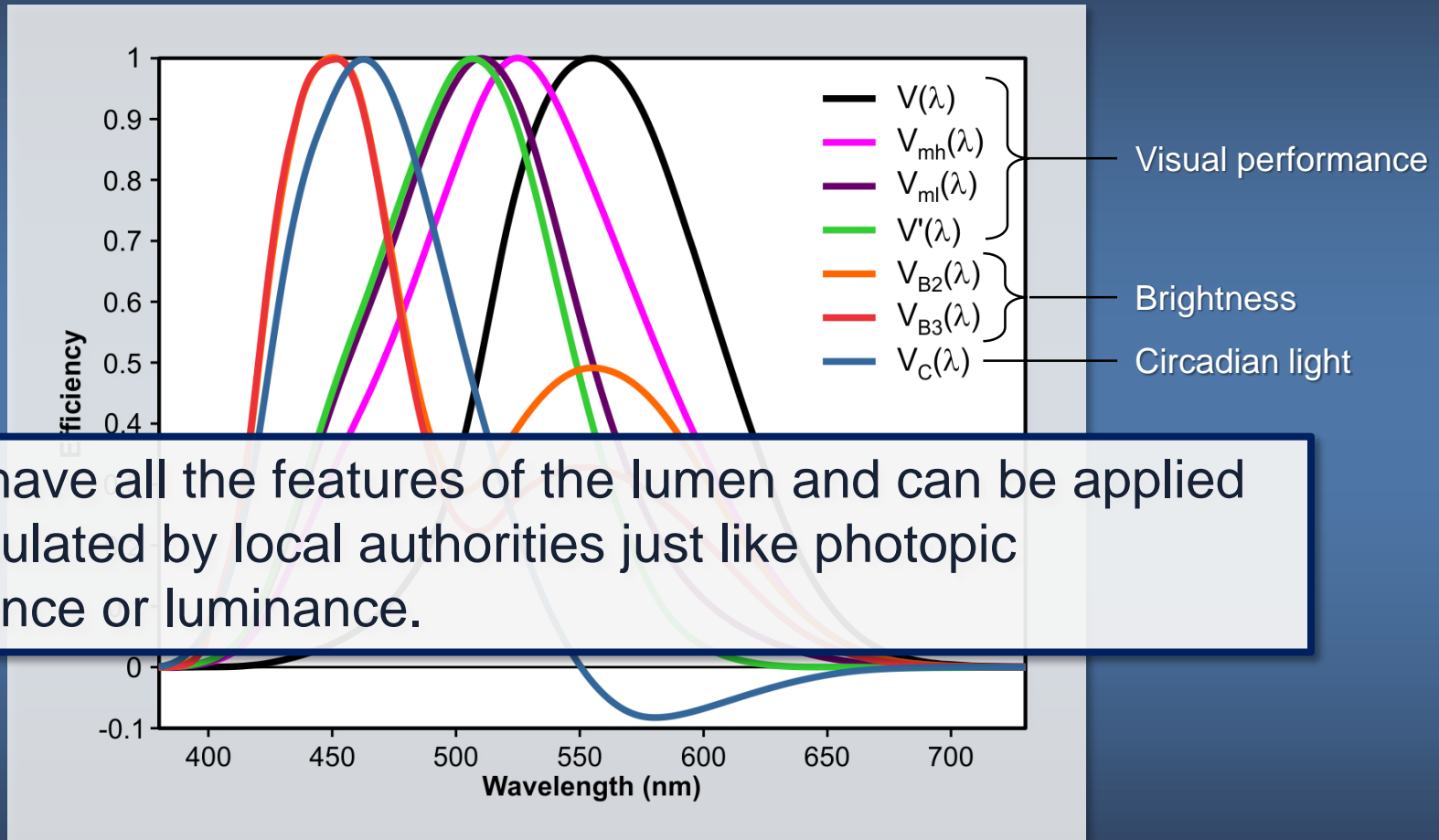
The Benefit Metric



Lighting



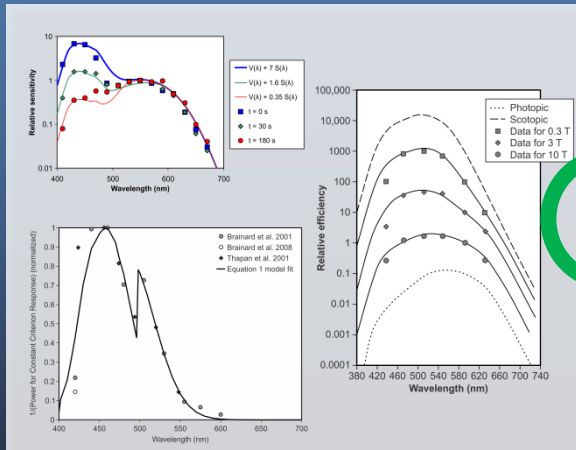
Benefit metric spectral weighting functions



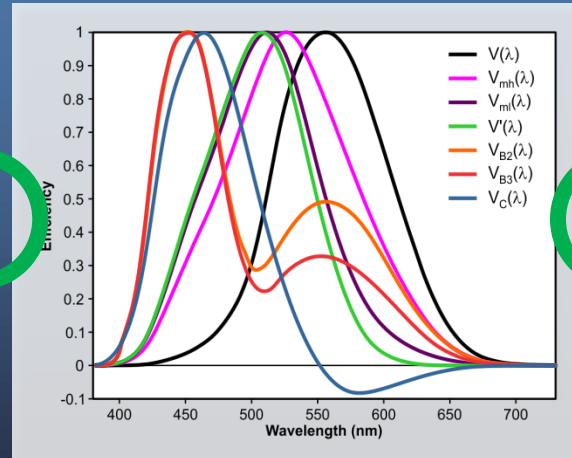
Benefit metrics

- ◆ 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



Benefit Metrics

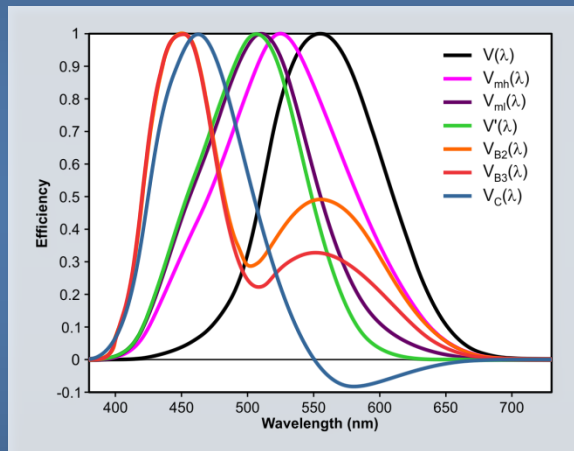


Lighting



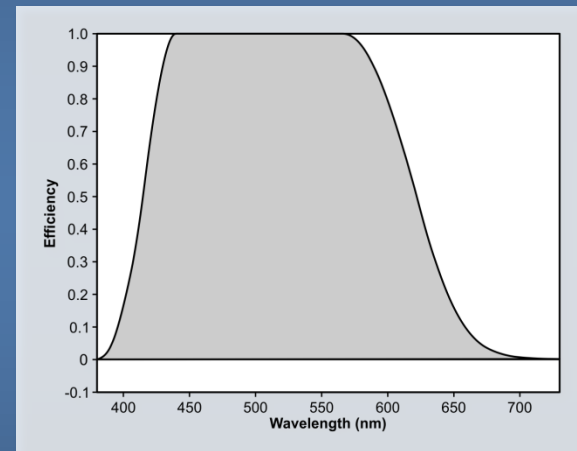
Solution: Separate light from lighting

Lighting



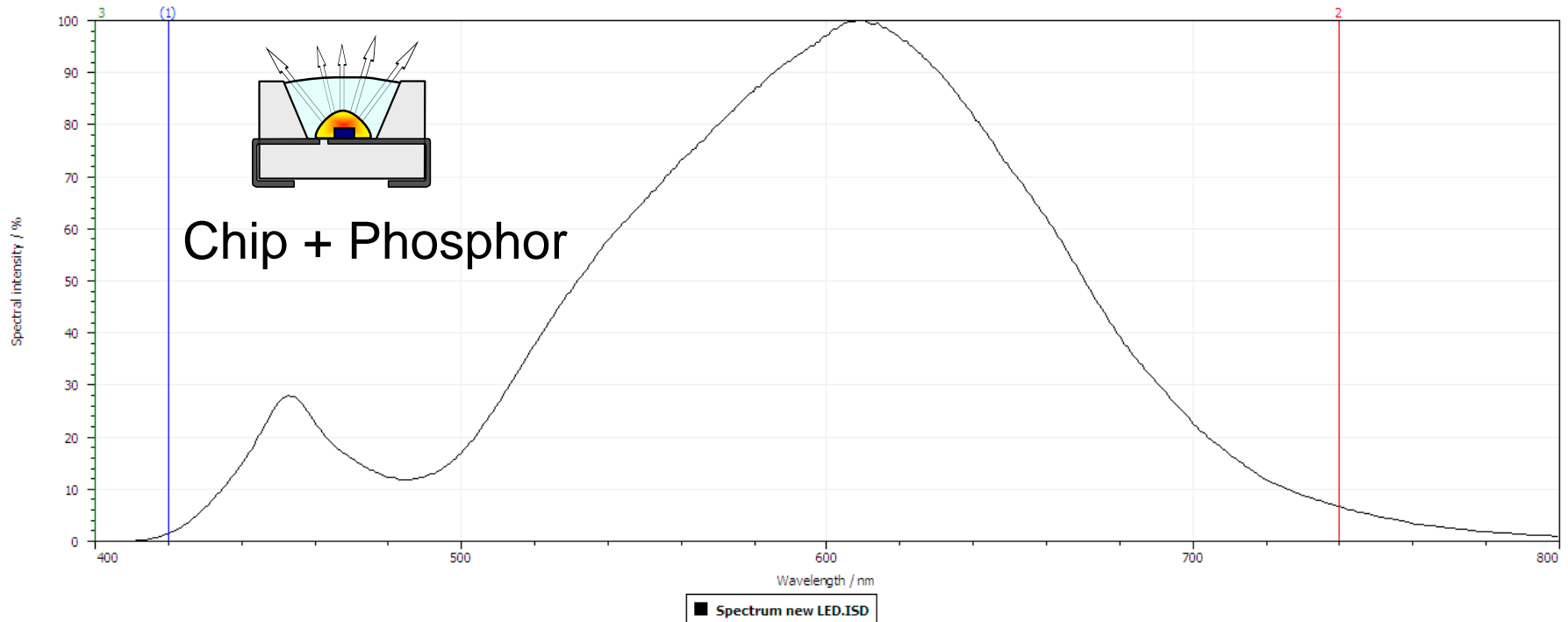
Benefit
metrics

Light



Universal luminous
efficiency function
 $U(\lambda)$

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

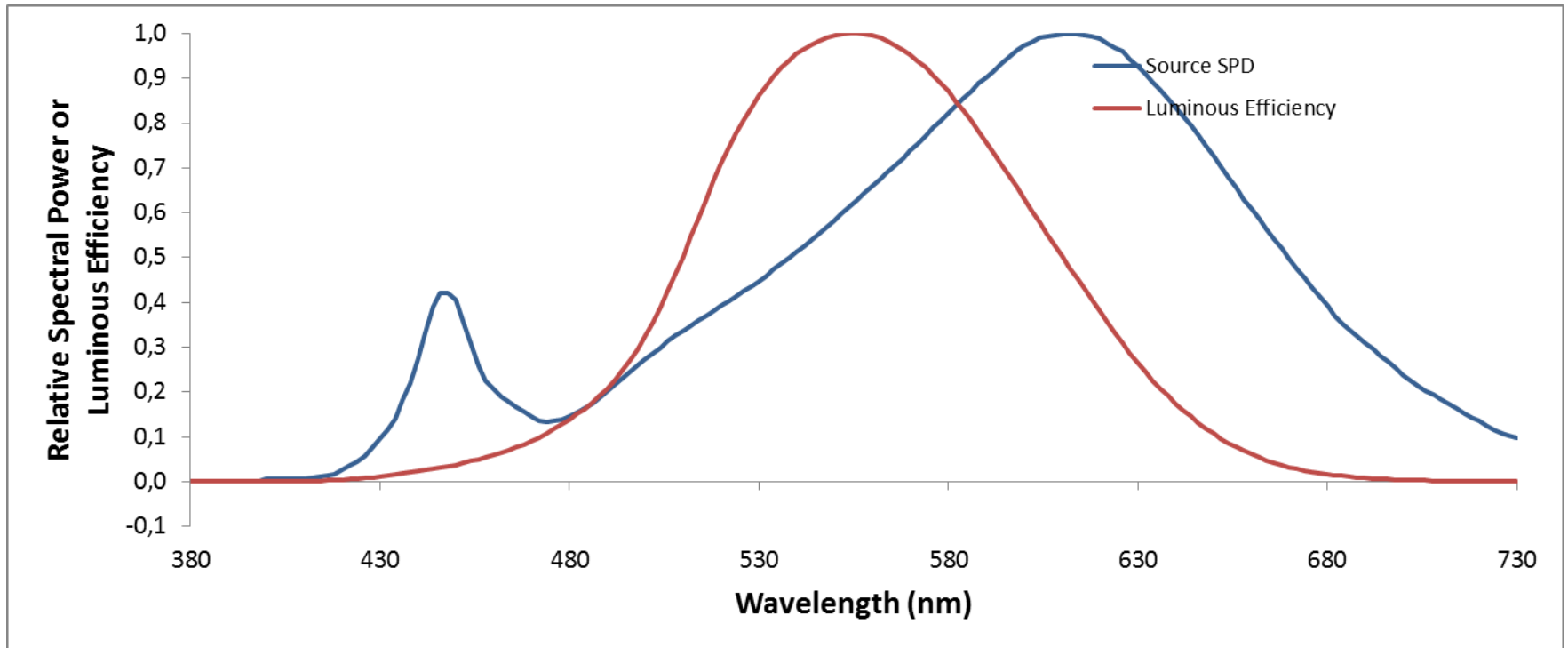
Many applications related to the correlated colour temperature (CCT)

- 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}):

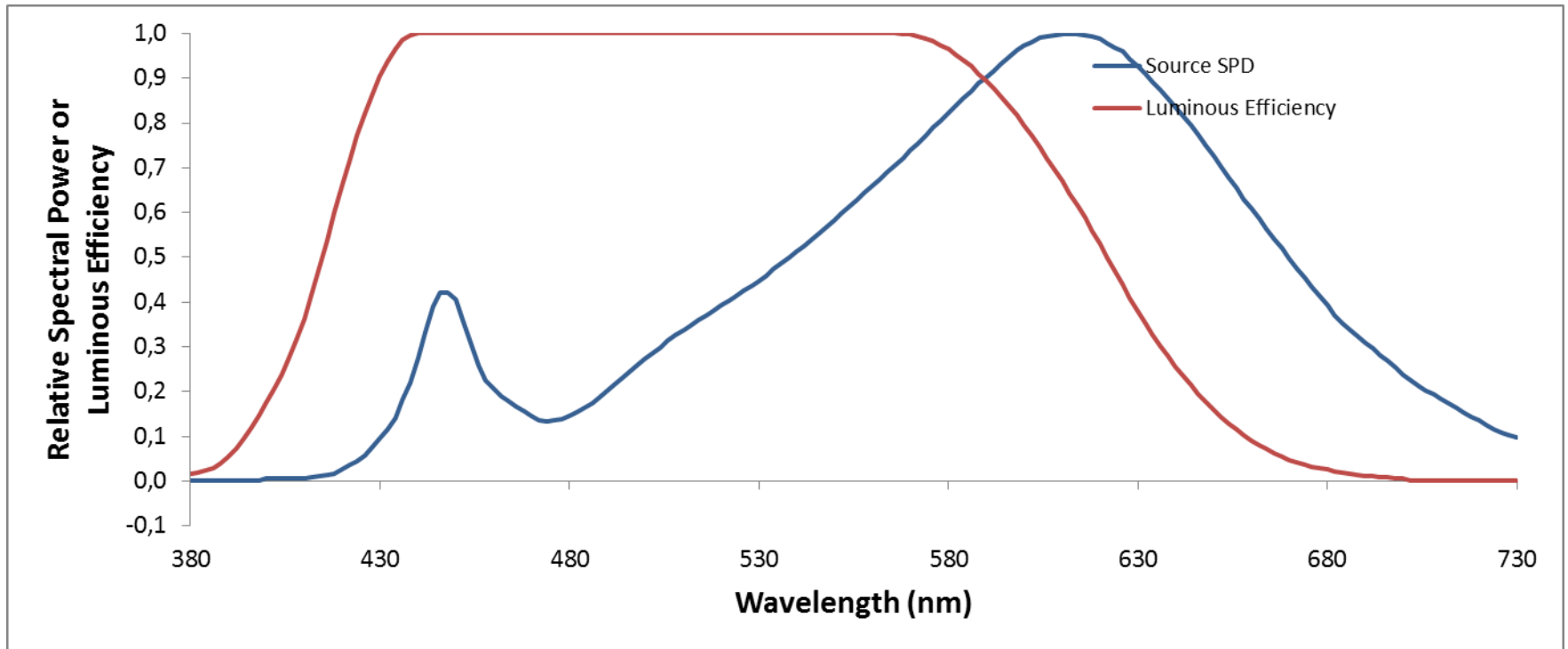
First ex: P_{lumen} & LED 2700 K \rightarrow 65 lm/W



Compared with

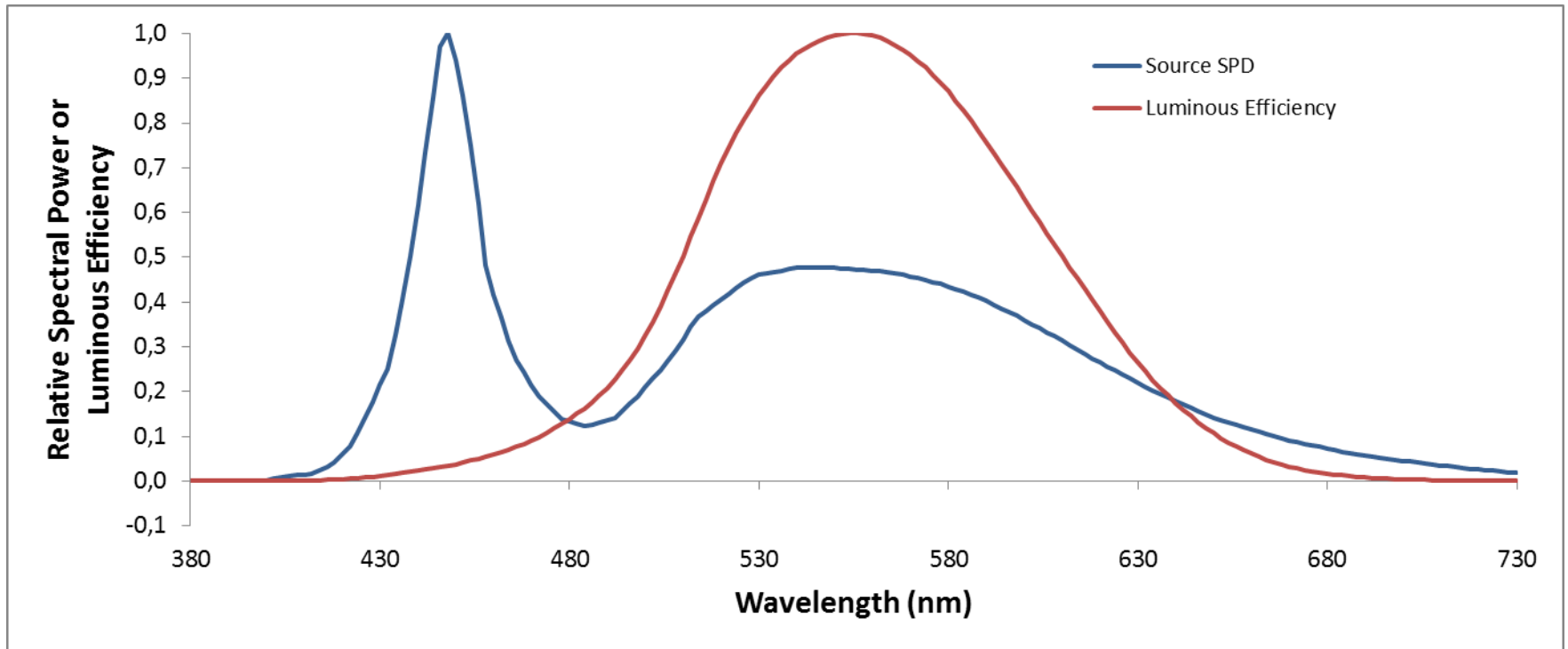
U_{lumen} & LED 2700 K -> 92 lm/W

$$U/P = 92/65 = 1.41$$



Second example:

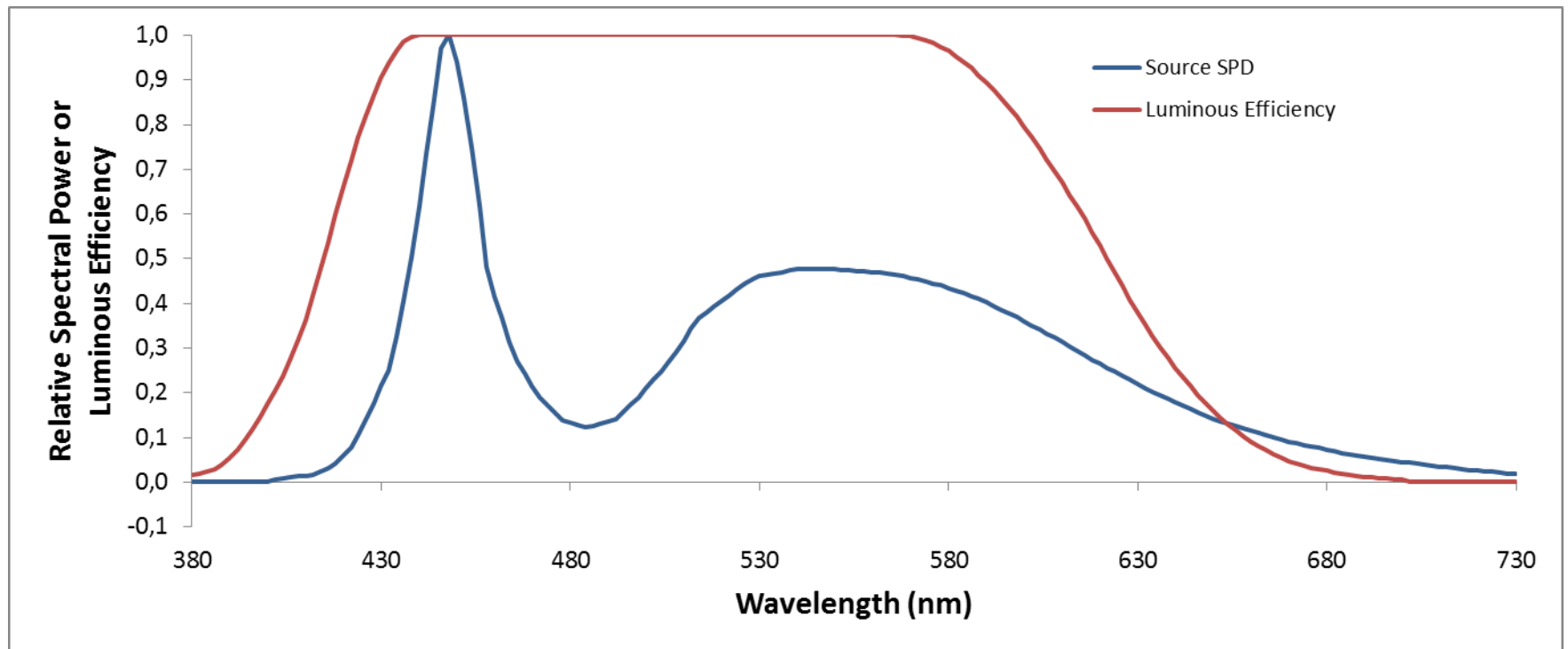
P_{lumen} & LED 6500 K -> 80 lm/W



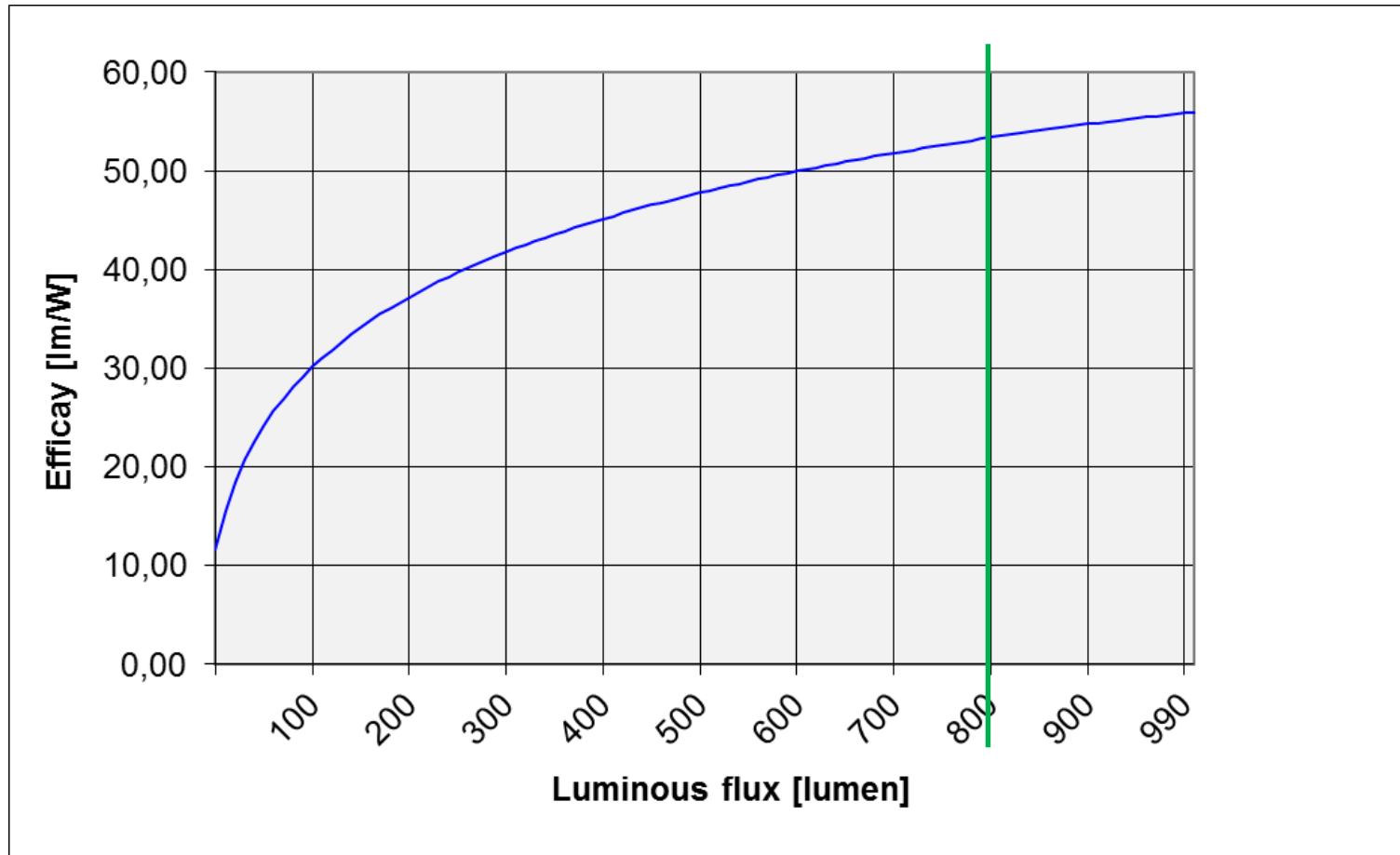
Compared with

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

$$U/P = 145/80 = 1.81$$



Example 1: regulation 244/2009 non-directional lamps



$$P_{\max} = 0.24\sqrt{\Phi} + 0.013 \Phi \rightarrow \eta_{\min} = \Phi / P_{\max} \text{ for frosted lamps}$$

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

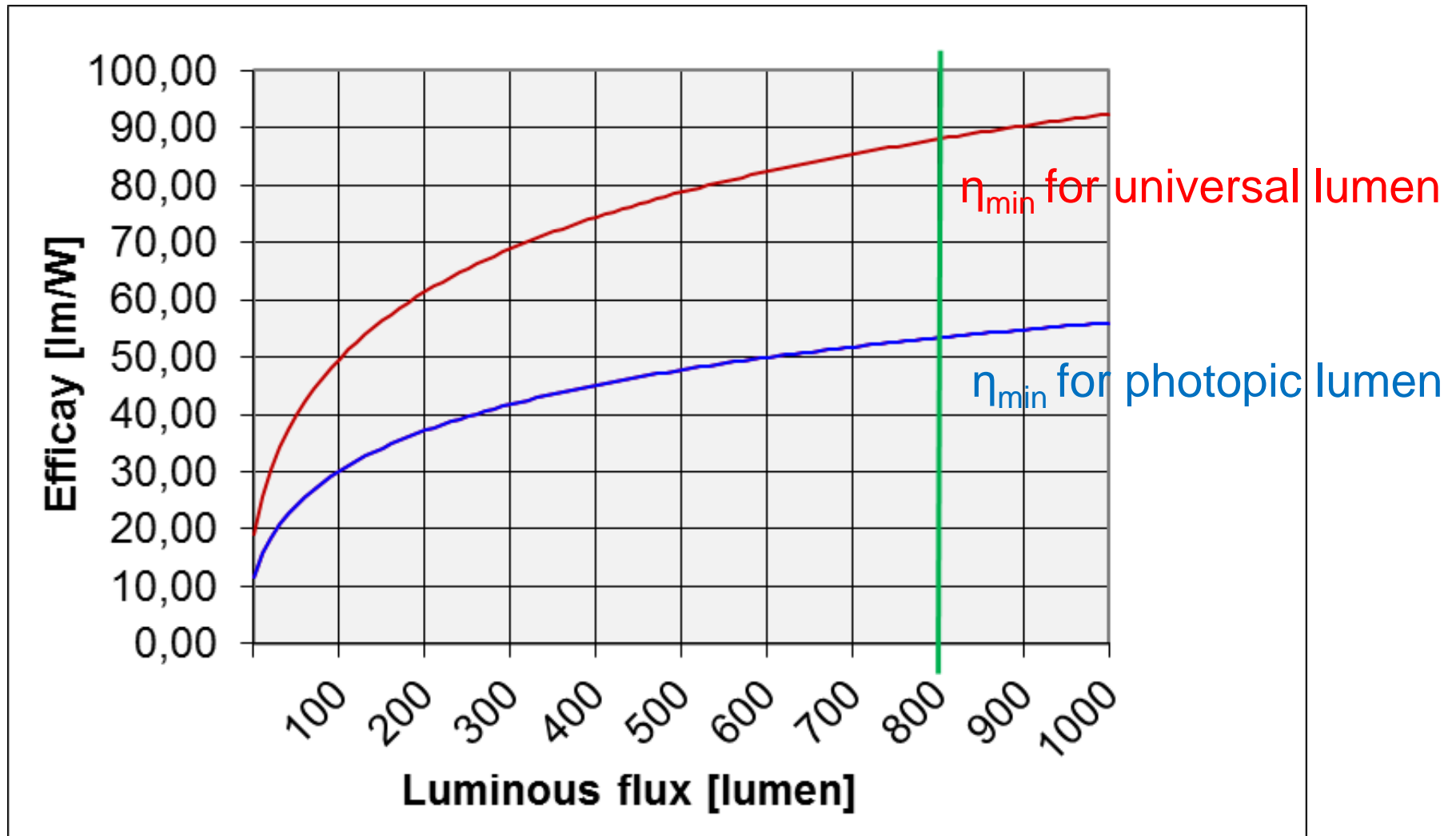
CFL 15 W -> min flux of 800 lm, or $\eta_{\min} = 53 \text{ lm/W}$

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 minimum levels -> 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*

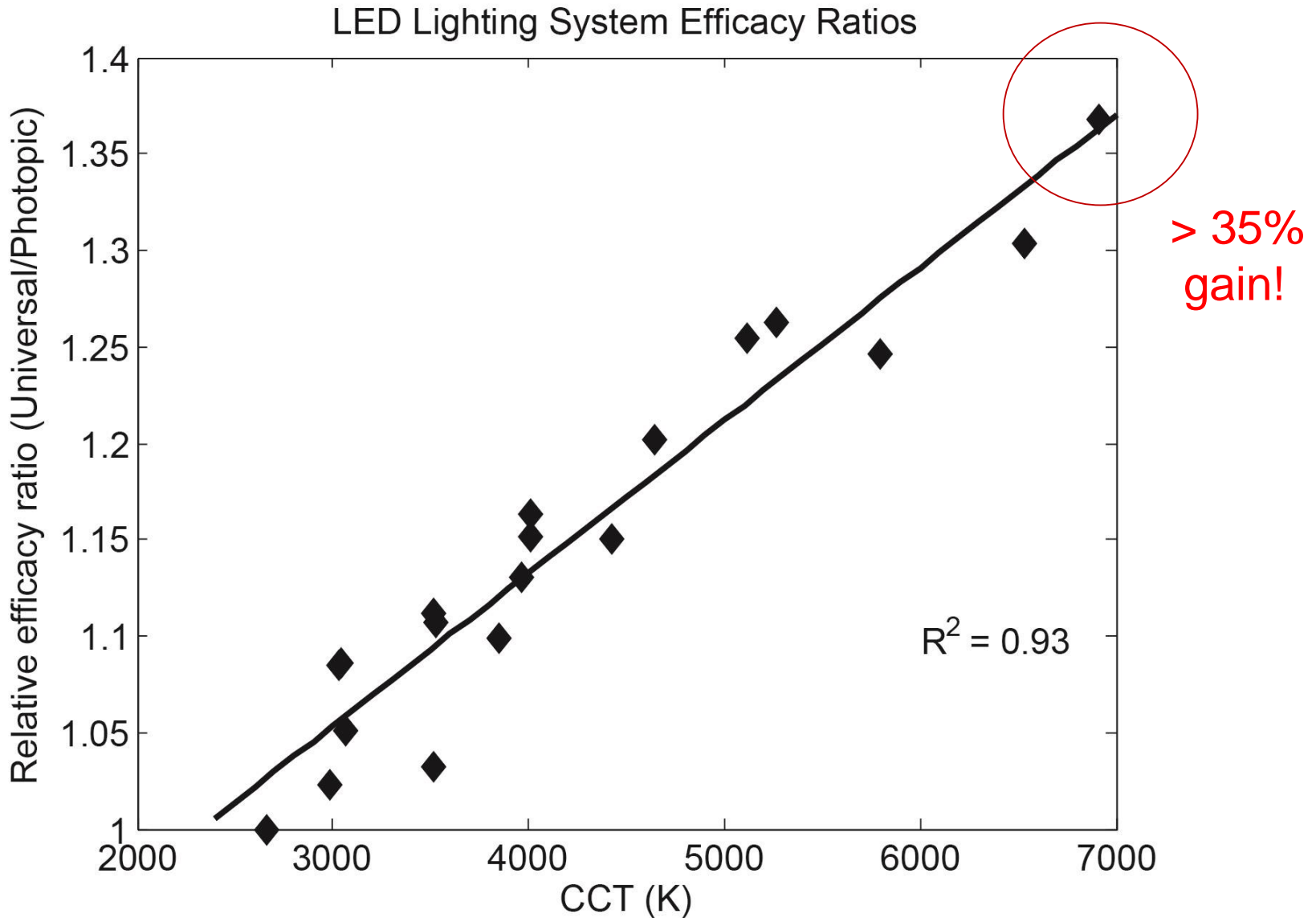
Example 1: regulation 244/2009 non-directional lamps



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



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!

