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A Practical Photometer for CIE Performance Based Mesopic Photometry System

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Mesopic vision is a visual condition between photopic and scotopic vision
- Most street lighting scenarios are in the mesopic range

Mesopic luminance range: 0.001 – 10cd/m^2

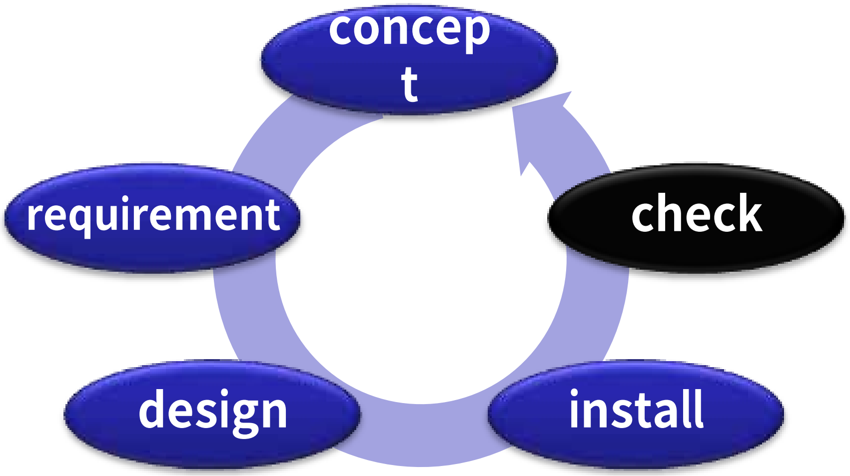
To apply CIE 191 mesopic photometry system to lighting application, we need an in-situ measurement method

Recent CIE activities regarding mesopic photome

- CIE 191 “Recommended System for Mesopic Photometry Based on Visual Performance” was published (2010.10)
- CIE TC2-65: Photometric Measurements in the Mesopic Range was started (2009.6)

No instruments are available to measure mesopic quantities

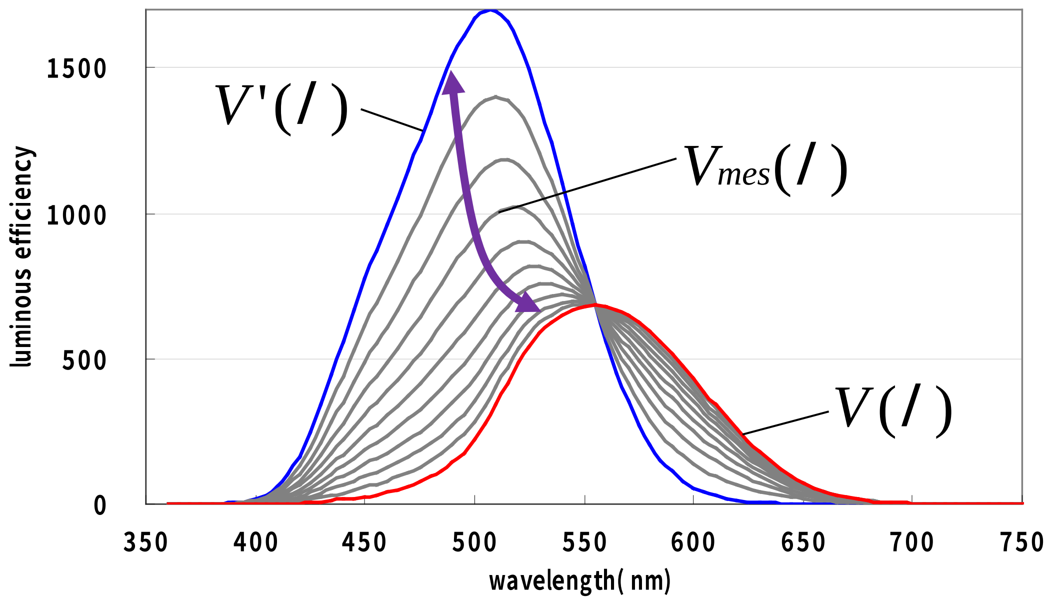
We can’t confirm whether installed lighting meets its requirements or not!



CIE 191 Review: The photometry system recommended in CIE191(1)

CIE 191 defined the mesopic spectral lumious efficiency $V_{mes}(\lambda)$ as a simple combination of $V(\lambda)$ and $V'(\lambda)$

$V_{mes}(\lambda)$ shape depends on m



$$M(m)V_{mes}(\lambda) = mV(\lambda) + (1-m)V'(\lambda) \quad \text{for } 0 \le m_n \le 1$$

$$L_{mes} = \frac{683}{V_{mes}(\lambda_0)} \int V_{mes}(\lambda) L_e(\lambda) d\lambda$$

$V_{mes}(\lambda)$:mesopic spectral sensitivity

L_{mes} :mesopic luminance

$V_{mes}(\lambda_0)$:the value of $V_{mes}(\lambda)$ at 555nm

$M(m)$:a noromalizing function such that $V_{mes}(\lambda)$ attains a maximum value of 1

$L_e(\lambda)$: spectral radiance in $Wm^{-2}sr^{-1}m^{-1}$

The coefficient m is calculated from the mesopic luminance of an adaptation field, but the adaptation field is NOT defined.

$$m_0 = 0.5$$

$$L_{mes,n} = \frac{m_{(n-1)} L_p + (1 - m_{(n-1)}) L_s V'(\lambda_0)}{m_{(n-1)} + (1 - m_{(n-1)}) V'(\lambda_0)}$$

$$m_n = a + b \log_{10}(L_{mes,n})$$

Calculated using iterative approach

L_p :the photopic luminance of the adaptation field

L_s :the scotopic luminance of the adaptation field

$V'(\lambda_0)$:683/1699 is the value of scotopic spectral luminous efficiency function at λ_0 =555nm

a :parameter(=0.7670)

b :parameter(=0.3334)

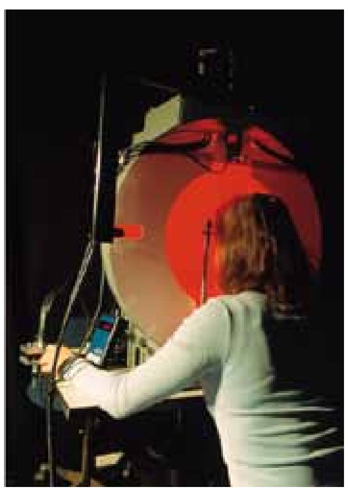
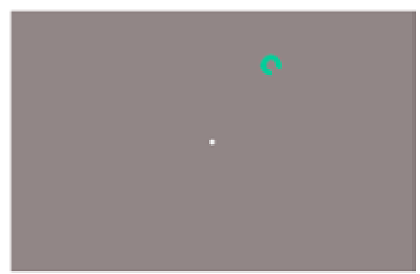
The value of L_{mes} obtained by the equations above is the mesopic luminance of the visual adaptation field. The mesopic luminance of objects in the visual adaptation field is obtained according to equations (2) and (3) using the value of m determined for the adaptation field.

- CIE 191:2010

CIE 191 Review: The setups of experiments CIE191 is based on

CIE 191 is based on experiments setups of which have wide background scene

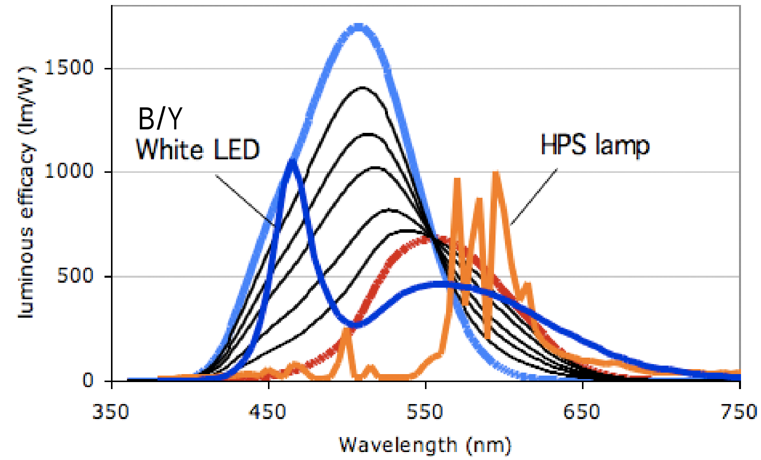
(Freiding et al. 2007, Walkey et al. 2007, Varady et al. 2007, He et al. 1997,1998)

Setup name	Modified Goldman perimeter	Large uniform hemisphere	Computer controlled CRT display	Driving Simulator
	HUT, FINLAND	HUT, FINLAND	CU, UK	TNO, NETHERLANDS
stimuli	Size:1.5 x 2deg. WL: 4-500, 5-600, 6-700nm Position: 0(fovea), 10°	Size: 0.29deg. WL: LED (red, amber, green, cyan) Position: 0(fovea), 10deg.	Size: 2deg. Landolt C WL: no mentioned (broad band) Position: 10deg.	Size: 2deg. WL: same as BG(broad band) Position: 10deg.
back-ground	Size: 180x180deg. Source: 4000K MH luminance: 0.01, 0.1, 1, 10cd/m^2	Size: 180x180deg. Source: 5400K FL luminance: 0.1, 1, 10cd/m^2	Size: 23 x 36deg. CRT:7003K(x,y)=(0.305,0.323) luminance: 0.01, 0.03, 0.1, 1, 10cd/m^2	Size: 30 x 120deg. projector: white, yellow, red, blue luminance: 0.01, 0.1, 1, 10cd/m^2
image				

High S/P ratio light sources (ex. LEDs) will be more efficient for street lighting

$$S/P = \frac{K'_m \int S(\lambda) V'(\lambda) d\lambda}{K_m \int S(\lambda) V(\lambda) d\lambda}$$

$S(\lambda)$: spectral distribution of the light source

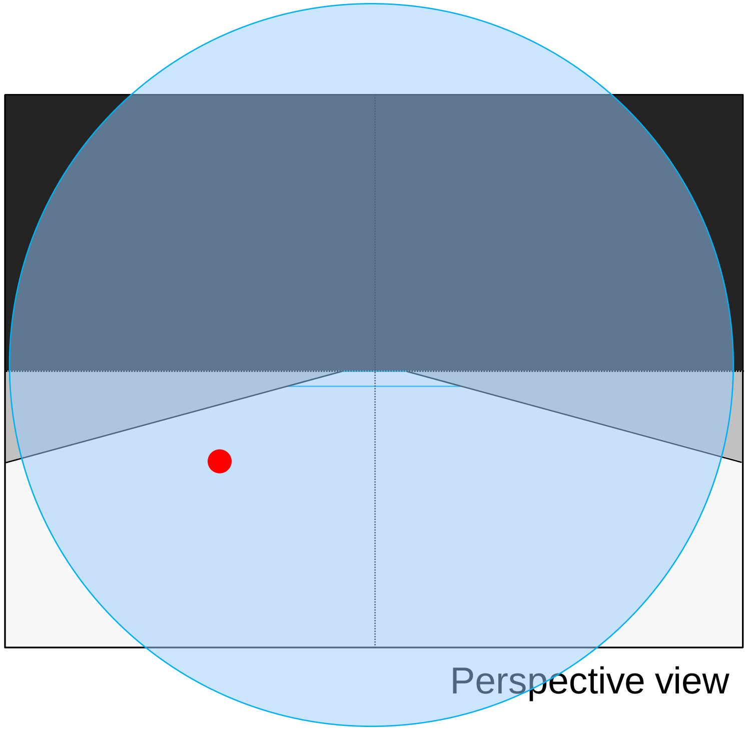


	S/P	Photopic luminance cd·m^{-2} 0,01	0,03	0,1	0,3	0,5	1	1,5	2	3	5
LPS ~	0,25	-75 %	-52 %	-29 %	-18 %	-14 %	-9 %	-6 %	-5 %	-2 %	0 %
	0,45	-55 %	-34 %	-21 %	-13 %	-10 %	-6 %	-4 %	-3 %	-2 %	0 %
HPS ~	0,65	-31 %	-20 %	-13 %	-8 %	-6 %	-4 %	-3 %	-2 %	-1 %	0 %
	0,85	-12 %	-8 %	-5 %	-3 %	-3 %	-2 %	-1 %	-1 %	0 %	0 %
	1,05	4 %	3 %	2 %	1 %	1 %	1 %	0 %	0 %	0 %	0 %
	1,25	18 %	13 %	8 %	5 %	4 %	3 %	2 %	1 %	1 %	0 %
MH warm white ~	1,45	32 %	22 %	15 %	9 %	7 %	5 %	3 %	3 %	1 %	0 %
	1,65	45 %	32 %	21 %	13 %	10 %	7 %	5 %	4 %	2 %	0 %
	1,85	57 %	40 %	27 %	17 %	13 %	9 %	6 %	5 %	3 %	0 %
LED cool white ~	2,05	69 %	49 %	32 %	21 %	16 %	11 %	8 %	6 %	3 %	0 %
	2,25	80 %	57 %	38 %	24 %	19 %	12 %	9 %	7 %	4 %	0 %
MH daylight ~	2,45	91 %	65 %	43 %	28 %	22 %	14 %	10 %	8 %	4 %	0 %
	2,65	101 %	73 %	49 %	31 %	24 %	16 %	12 %	9 %	5 %	0 %

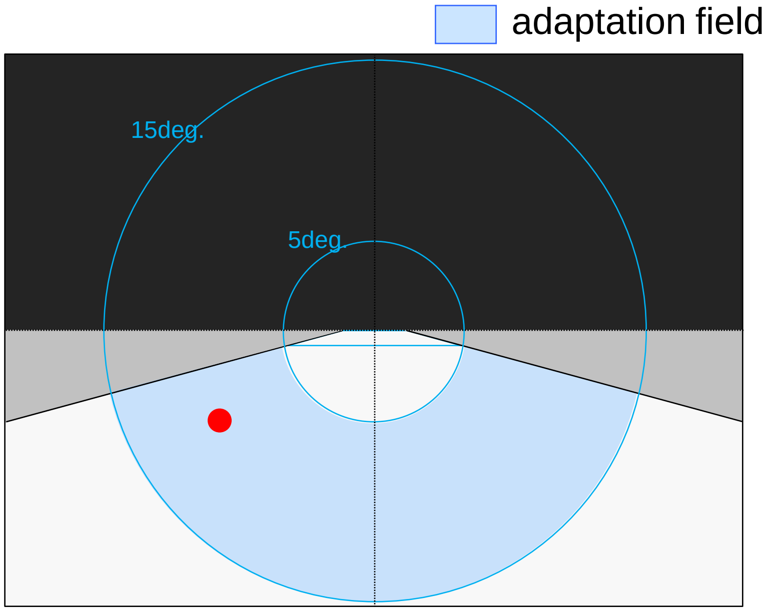
Adaptation field: key issue for measurement of mesopic luminance

The adaptation field depends on adaptation mechanism - Global or Local?

- **Global adaptation is dominant**



- **Local adaptation is dominant**



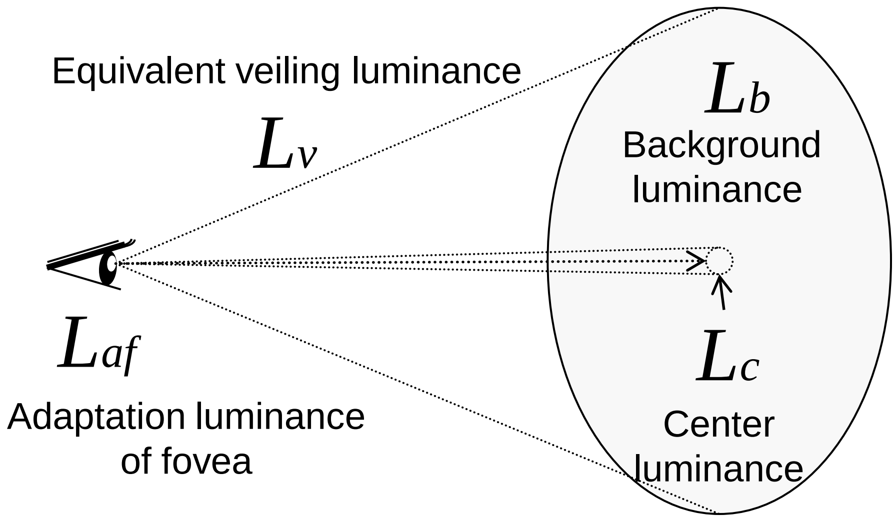
Illuminance meter type is better

Luminance meter type is better

Adaptation field: Adaptation luminance of fovea in past studies

Fovea cells adapt to sum of center luminance and equivalent veiling luminance when it adapt to luminance pattern distributed wide field of view

(Holladay 1926, Crawford 1936, Moon & Spencer 1943, Fry et al. 1963)



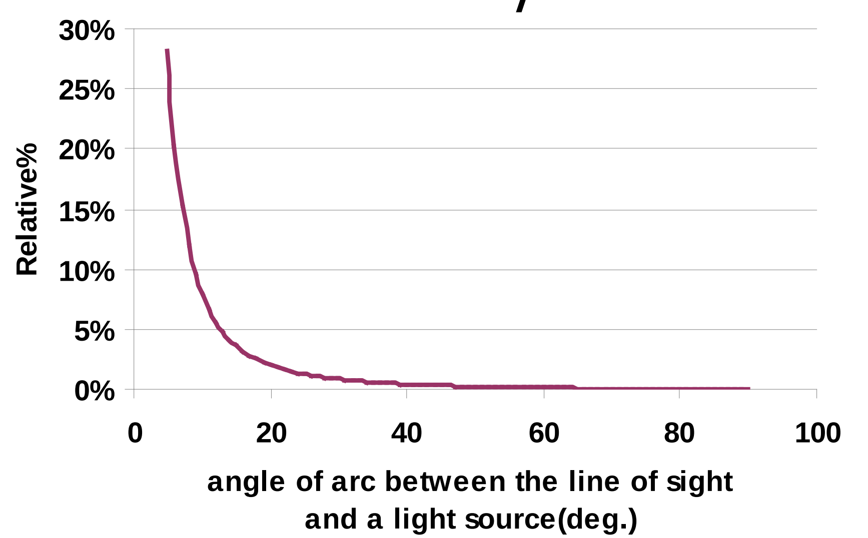
$$L_{af} = L_c + L_v$$

Ex. at uniform 1cd/m^2 2π field of view

$$L_{af} \approx 1.048(\mathrm{cd/m^2})$$

Equivalent veiling luminance:
Luminance at the fovea caused by light coming from peripheral field of view and scattered in eye

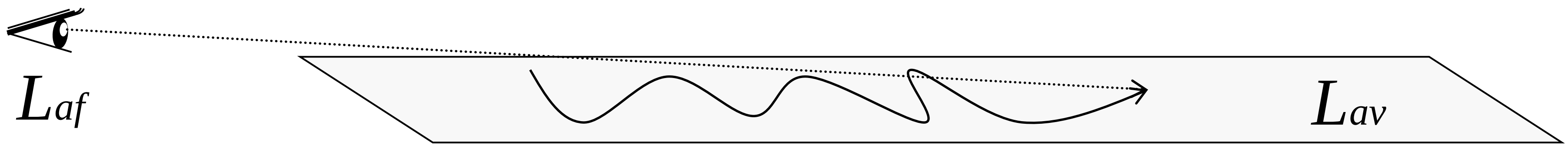
$$L_v = k\int_0^{2\pi}\int_0^{\frac{\pi}{2}} \frac{L(\theta,\phi)\sin\theta\cos\theta}{\theta^2} d\theta d\phi$$



Average luminance of a road surface is defined as an adaptation luminance of fovea

(Definition of Threshold Increment TI in CIE 140-2000)

L_v Equivalent veiling luminance



L_{af}

Adaptation luminance of fovea

L_{av}

average luminance of the road surface

$$L_{af} = L_c + L_v$$

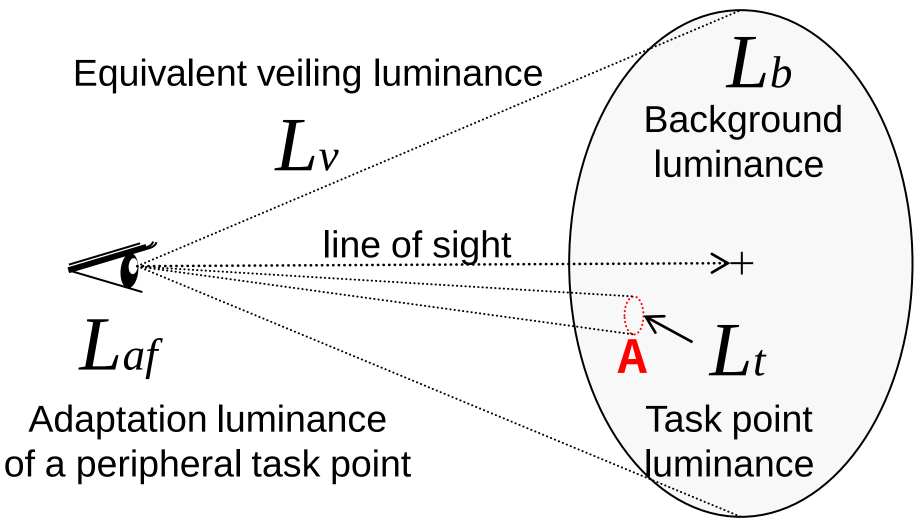
At the road lighting scene in night time…

Since the line of sight scans everywhere road surface $L_c = L_{av}$

Luminance of peripheral field of view is low enough $L_v << L_c$

\ L_{af} » L_{av}

Peripheral cells also adapt to sum of task point luminance and equivalent veiling luminance?

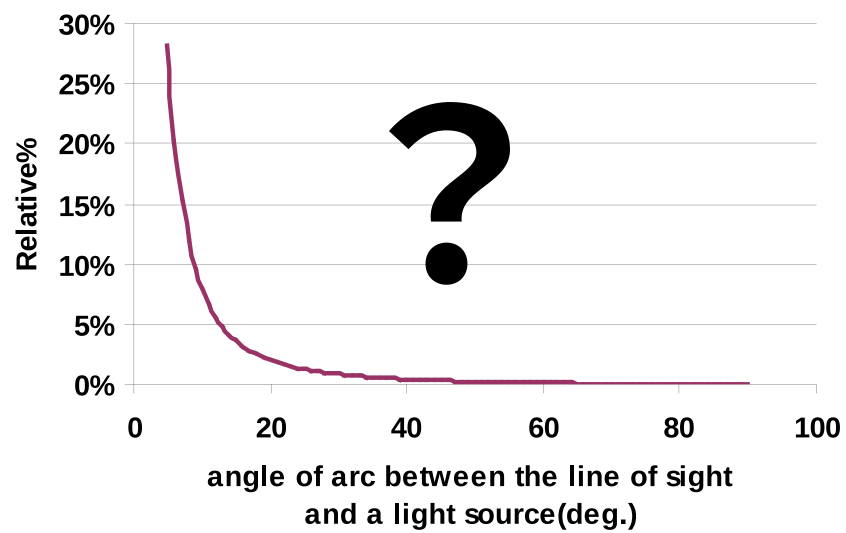


$$L_{af} = L_t + L_v$$

Equivalent veiling luminance:

Luminance at the fovea caused by light coming from peripheral field of view and scattered in eye

$L_v = ?$ **Angle characteristics is unknown**



We need evidences how luminance of other field of view affect the task performance at point A.

Output quantities: Which quantities are used to evaluate street lighting?

Both luminance and illuminance are measured to evaluate street lighting

CIE	
CIE 115:2010	luminance

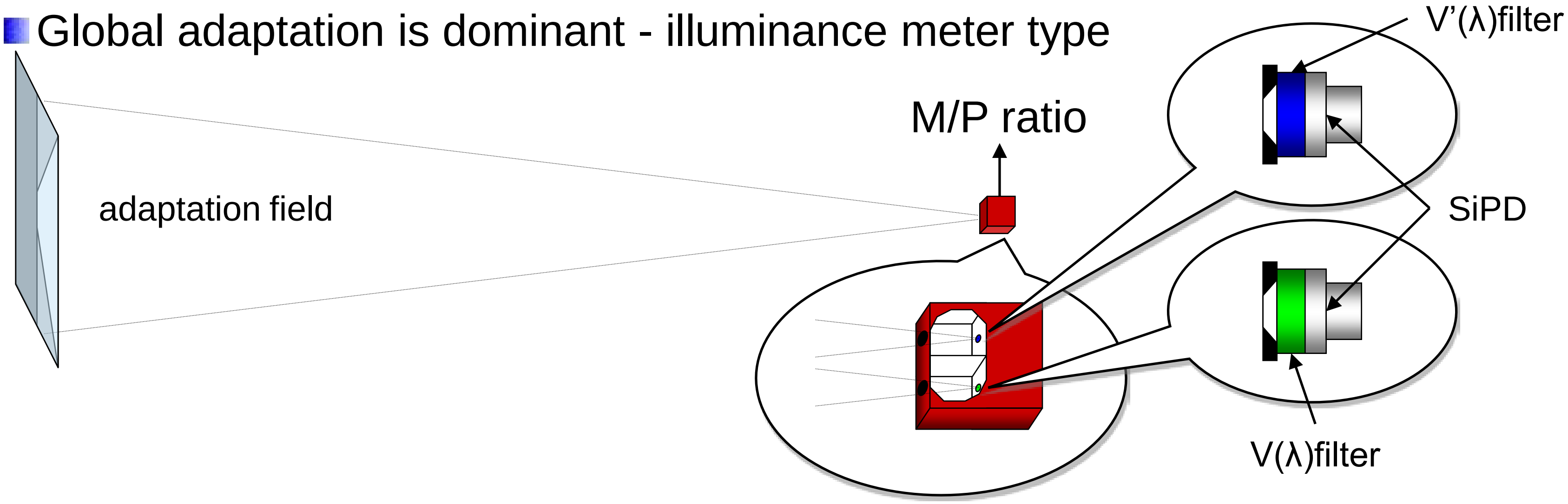
<table>
<tr><th colspan="2">Japan</th><th colspan="2">USA</th><th colspan="2">Europe</th></tr>
<tr><td rowspan="2">JIS
Z 9111</td><td rowspan="2">luminance
For drivers
illuminance
For pedestrian</td><td>IESNA</td><td></td><td rowspan="2">EN
13201</td><td rowspan="2">luminance
ME/MEW-Series
(medium to high driving speed)
illuminance
CE-Series
(conflict areas :shopping streets, roundabouts, queuing areas etc.)</td></tr>
<tr><td>AASHTO</td><td>luminance
illuminance</td></tr>
<tr><td>MLIT
Road Lighting Book</td><td>luminance</td><td>State Government Traffic Lighting Manual, etc.</td><td>illuminance</td><td></td><td></td></tr>
</table>

Output quantities: M/P ratio meter: an idea for mesopic photometry

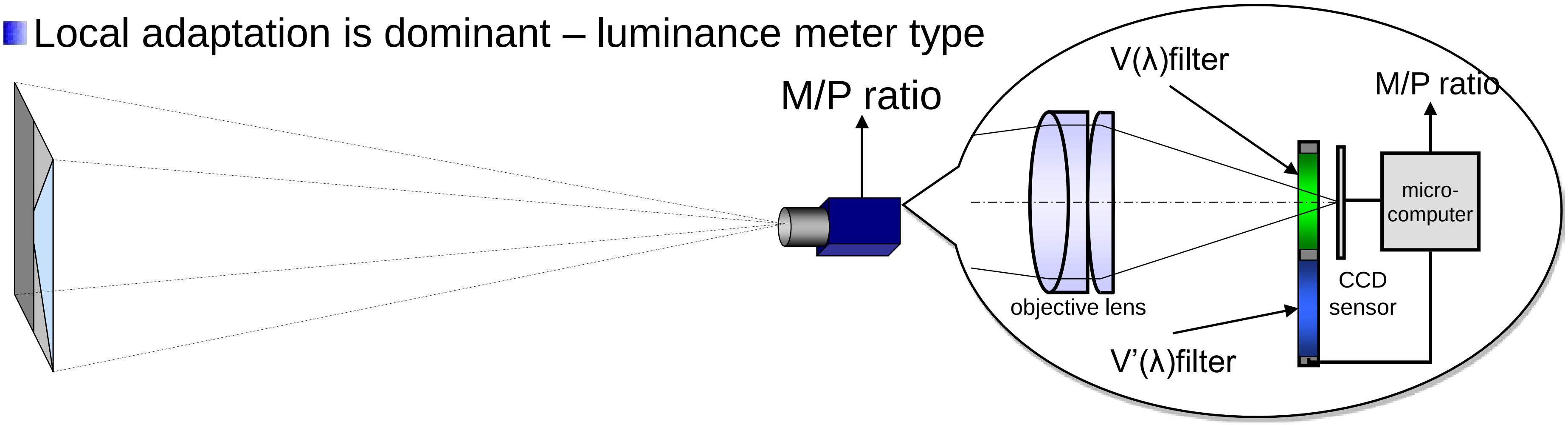
M/P ratio* is useful to adjust the output of existing photometry instruments

* m/p ratio – ratio of the mesopic luminance to the photopic luminance at the adaptation field

- Global adaptation is dominant - illuminance meter type

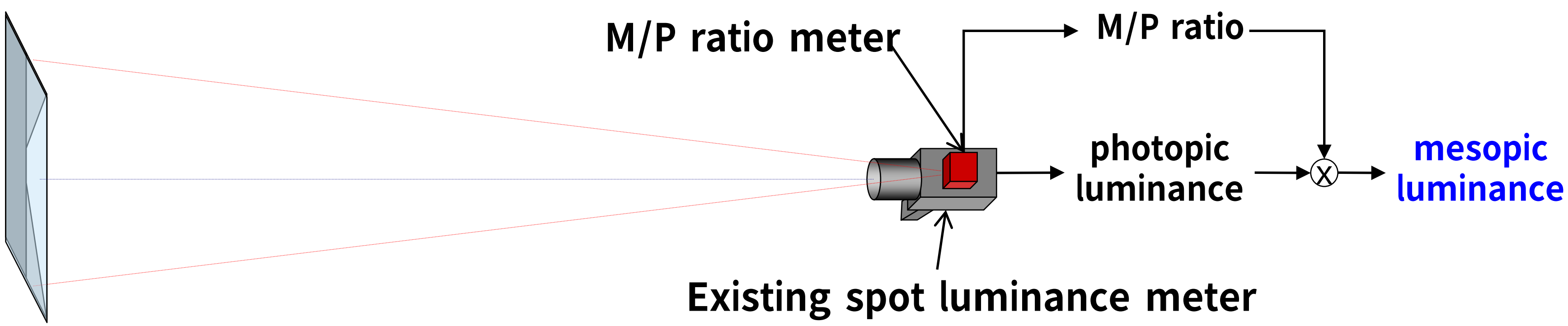


- Local adaptation is dominant – luminance meter type

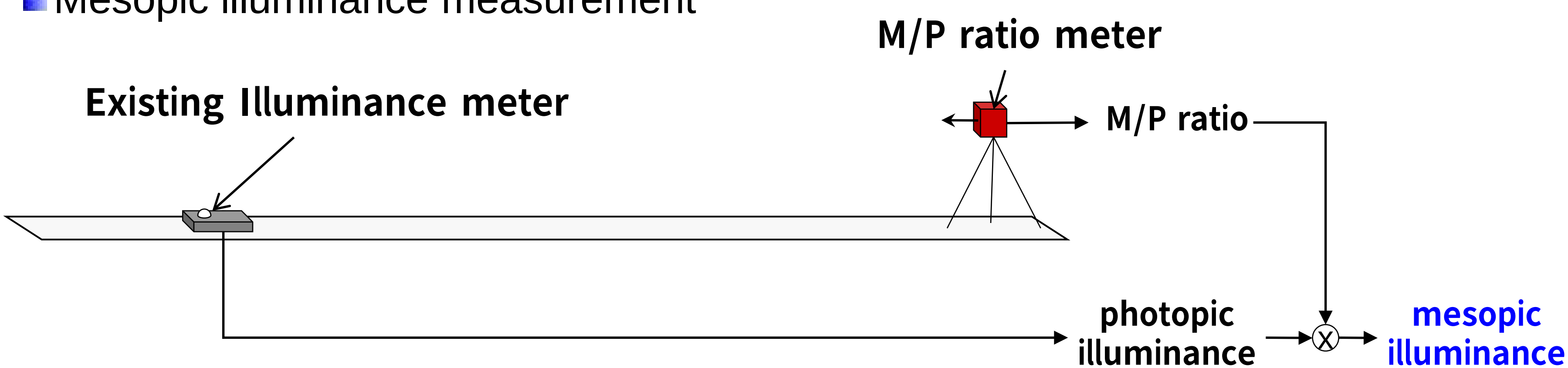


The mesopic luminance/illuminance can be measured by a photopic luminance/illuminance meter combined with a m/p ratio meter

- Mesopic luminance measurement



- Mesopic illuminance measurement



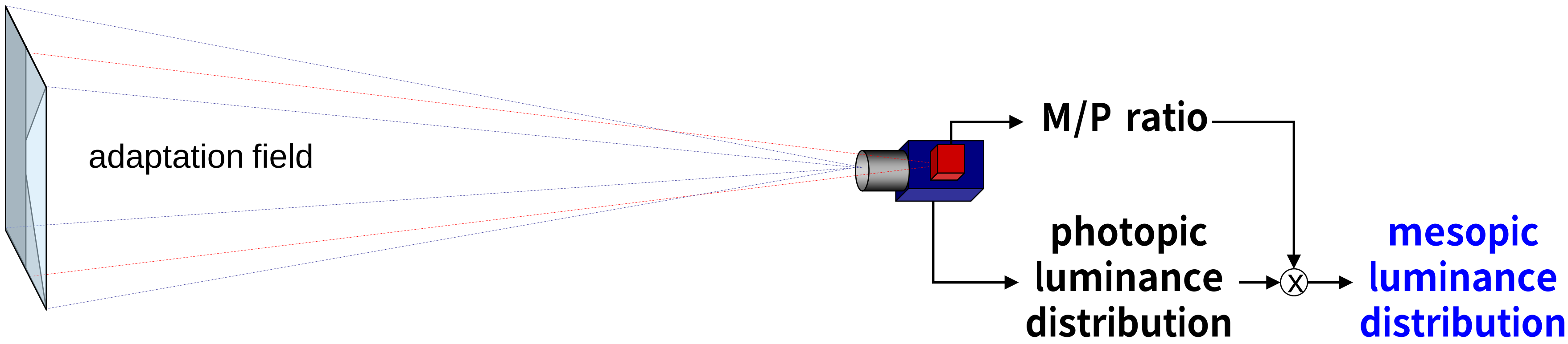
Output quantities: How can we measure mesopic luminance distribution?

The mesopic luminance distribution can be measured by

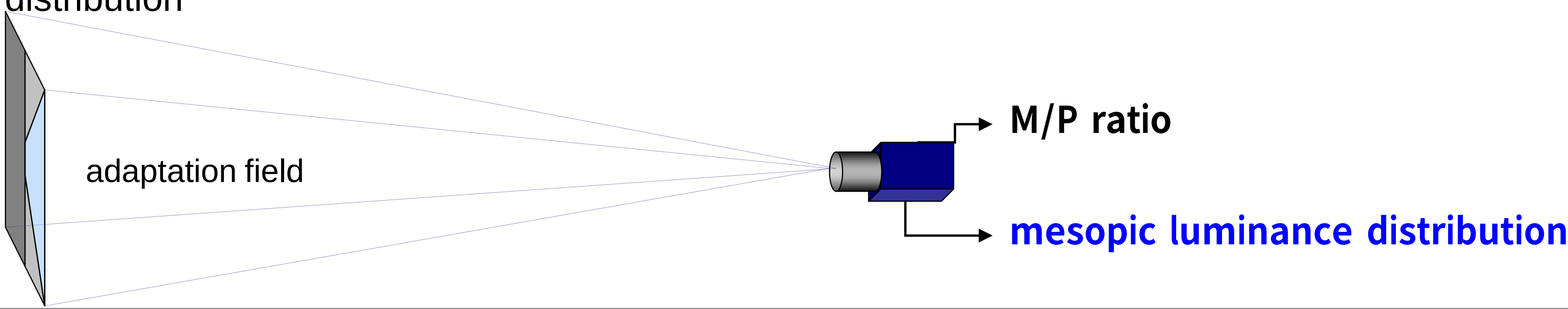
a photopic imaging luminance meter combined with a m/p ratio meter

or a mesopic imaging luminance meter

- Global adaptation is dominant



- Local adaptation is dominant
  - A M/P ratio meter with imaging detector can measure both M/P ratio and mesopic luminance distribution



Output quantities: Expecting error of a M/P ratio meter

The combination of a M/P ratio meter and a photopic luminance meter cause particular error when it measure chromatic scene

M/P ratio meter

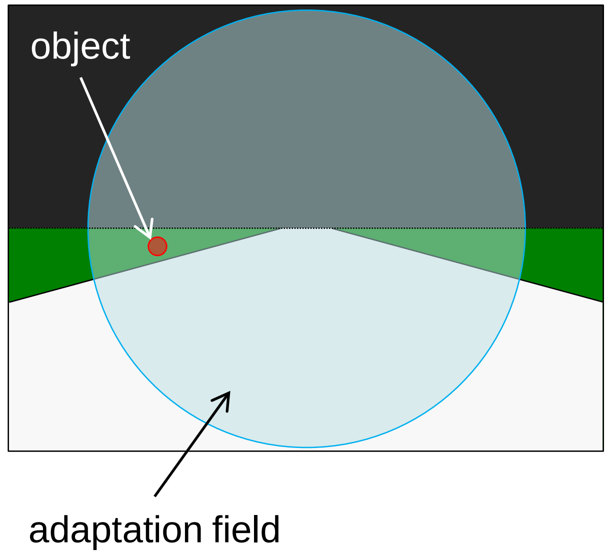
1. Calculate mesopic luminance of adaptation field $L_{mes,a}$

2. Calculate m/p ratio

$$m/p = \frac{L_{mes,a}}{L_{p,a}}$$

3. Calculate mesopic luminance of object $L_{mes,o}$ from $L_{p,o}$ and m/p ratio

$$L_{mes,o} = L_{p,o} \times (m/p)$$



Definition

1. Calculate adaptation field's L_{mes} and m as definition

2. Measure $L_{p,o}$ and $L_{s,o}$ at object

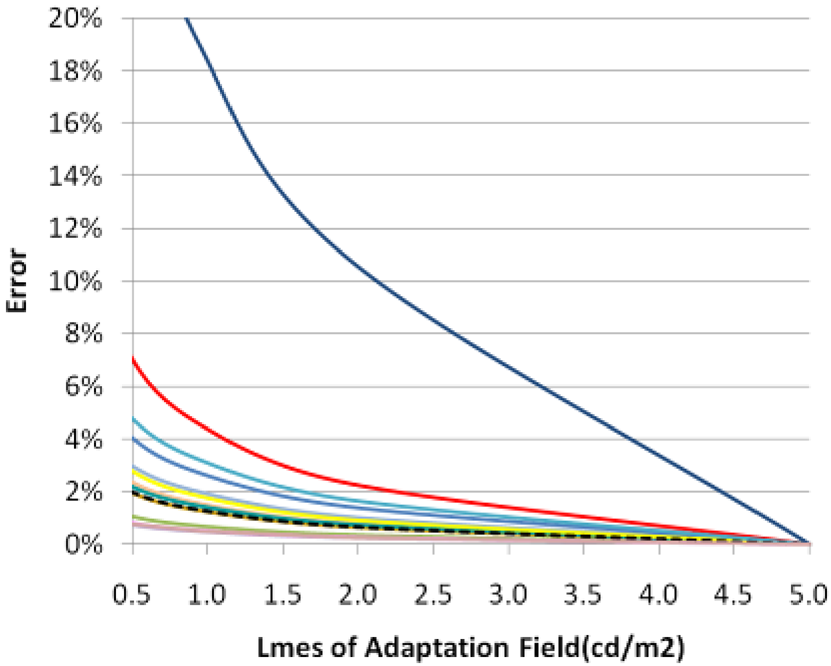
3. Calculate mesopic luminance of object $L_{mes,o}$ from $L_{p,o}$ and $L_{s,o}$

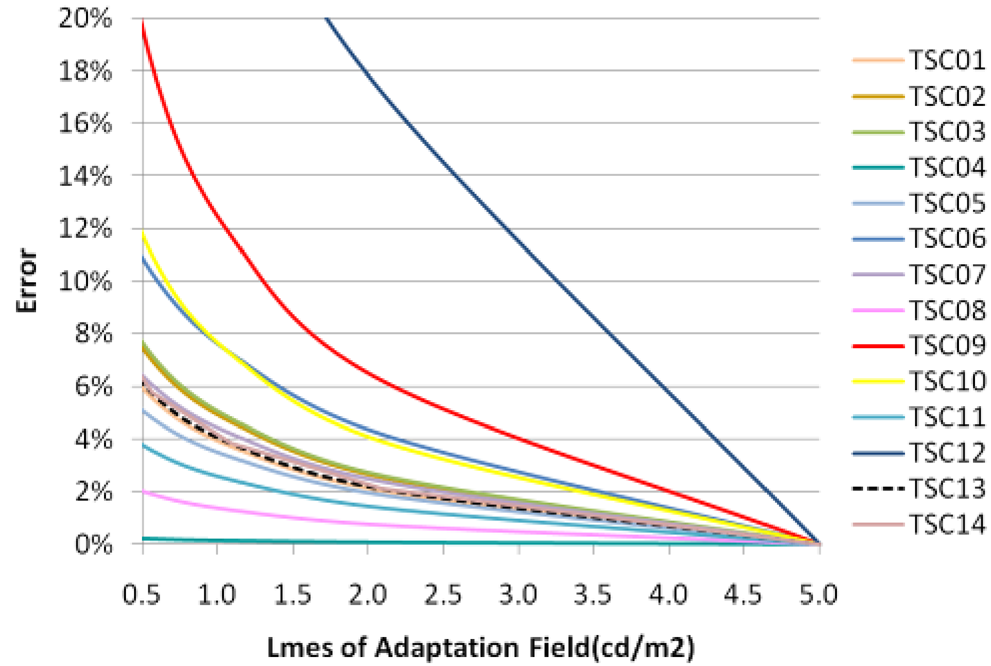
$$L_{mes,o} = \frac{m}{V_{mes}(\lambda_0)M(m)} L_{p,o} + \frac{(1-m)K_m}{V_{mes}(\lambda_0)M(m)K'_m} L_{s,o}$$

Not equal!

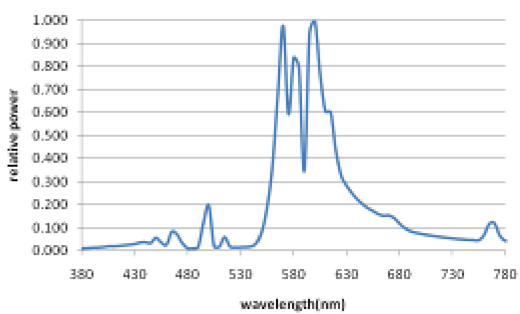
This process assume that the spectral distribution of the object is equal to the adaptation field

High saturation colors cause relatively large error
Midium saturation colors have 6-8% error in practical luminance range

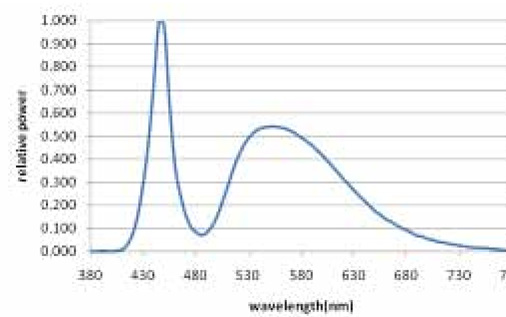




HPS(NH360.L) 2050K

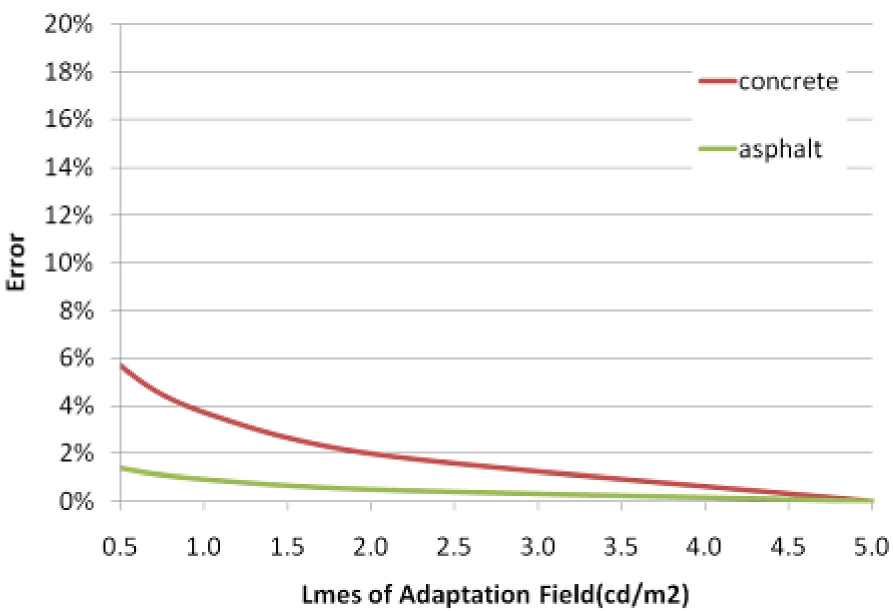


LED(NNN21935)

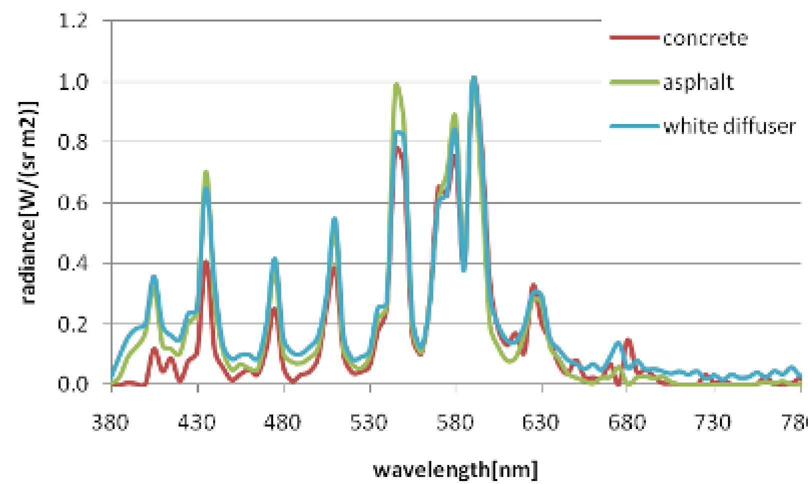


Asphalt surface has less than 2% error
Concrete surface has less than 6% error

- Calculate errors from spectral radiance of road surface lit by MH



Use spectral radiance of a white diffuser put at “concrete” as spectral radiance of the adaptation field



Plan

- determine allowance of uncertainty for mesopic luminance meter to evaluate street lighting
- Make V(λ) / V'(λ) detector / detector array
- Correct evidences whether global or local adaptation is dominant for the peripheral visual task performances
  - If it's not exist, psychophysical experiments are required.
- Develop a calibration method for a M/P ratio meter and mesopic luminance meter including imaging system

Acknowledgement

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Thank you for your attention!