

Power Density Targets for Efficient Lighting of Interior Task Areas

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To be published LR&T 2007

april 2007

Laboratorium voor Lichttechnologie



Normalized Power Density NPD

$$NPD = \frac{P_{sys}}{\Phi_{TA}^{fin}} \quad [W / m^2 \cdot 100lux = W / 100lm]$$

P_{sys} : installed power for lighting

Φ_{TA}^{fin} : maintained luminous flux on TA (*lumen*)

$$\Phi_{TA}^{fin} = A_{TA} \cdot \bar{E}_{TA}^{fin}$$

A_{TA} : Task Area (m^2)
 \bar{E}_{TA}^{fin} : maintained mean illuminance (*lux*)

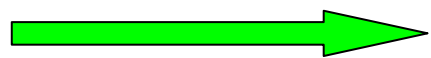
NPD

- A measure of the efficiency to illuminate a specific task area
- It is not a measure of energy consumption, which depends on illumination levels, switch-on time, dimming, . . .

Actual criterium

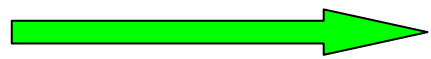
$NPD < 2.0 \text{ à } 2.5 \text{ (W/m}^2 \cdot 100 \text{ lux)}$

1. Based on best practice



Theoretical basis?

2. Standard task area: floor (edge zone in-or excluded)



Non-standard task areas

EN 12464

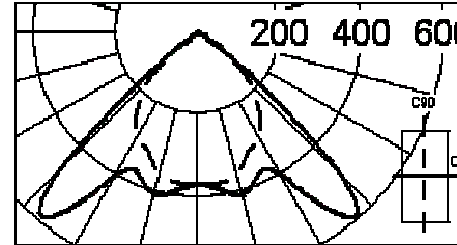
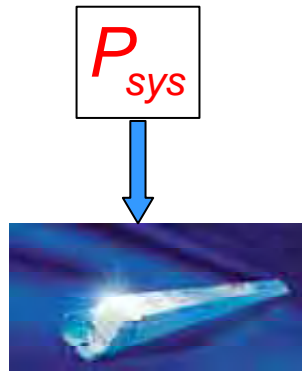
shops, classrooms, musea?

Purpose:

determine a target NPD value

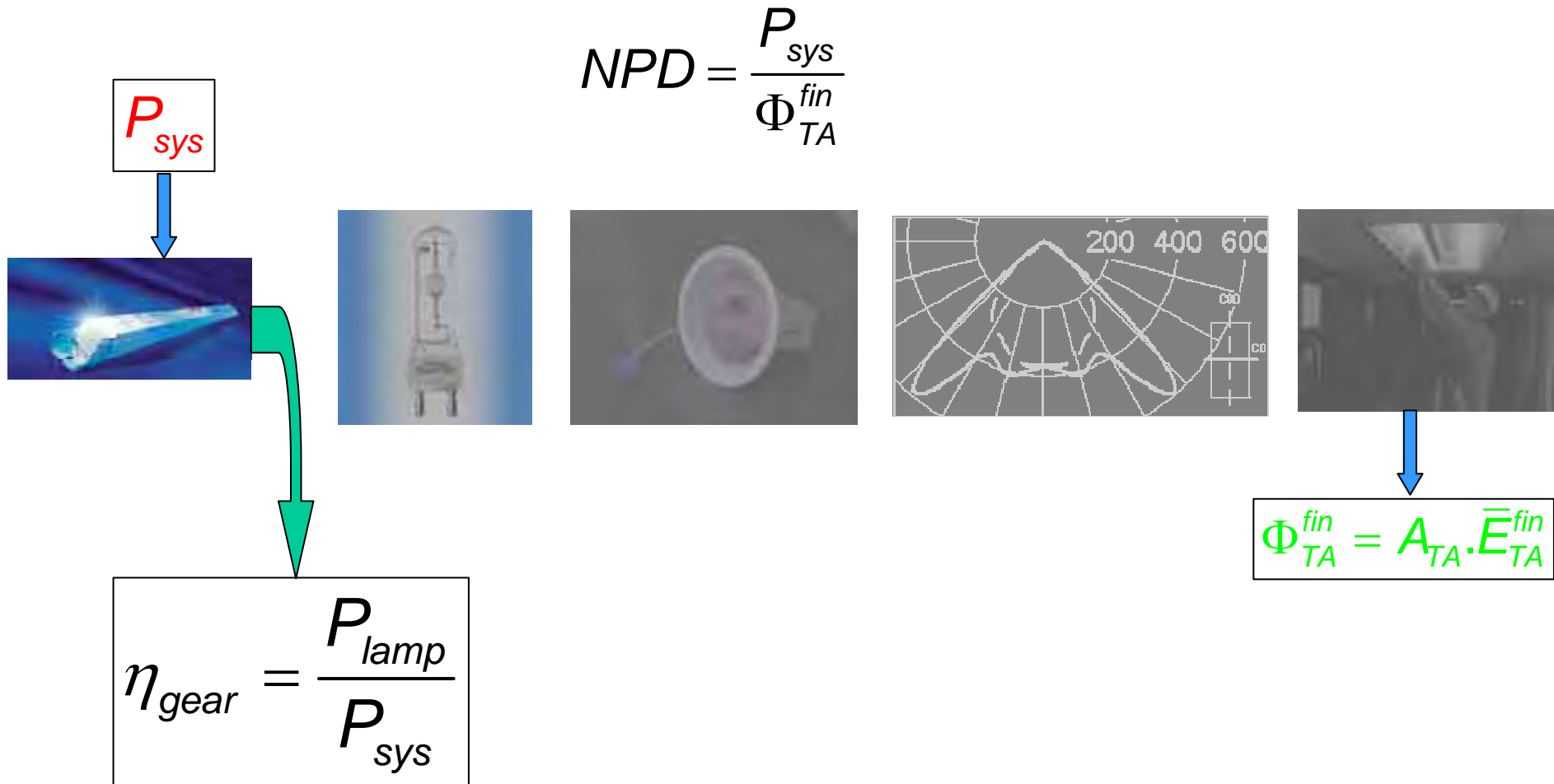
- lighting task as a starting point
- allowing arbitrary task areas;
- valid for a wide range of applications like offices, shops, work areas, classrooms;
- simple and easy-to-use while being accurate and reproducible;
- independent of a specific light calculation software and related input and output parameters;
- visual comfort requirements are included

$$NPD = \frac{P_{sys}}{\Phi_{TA}^{fin}}$$

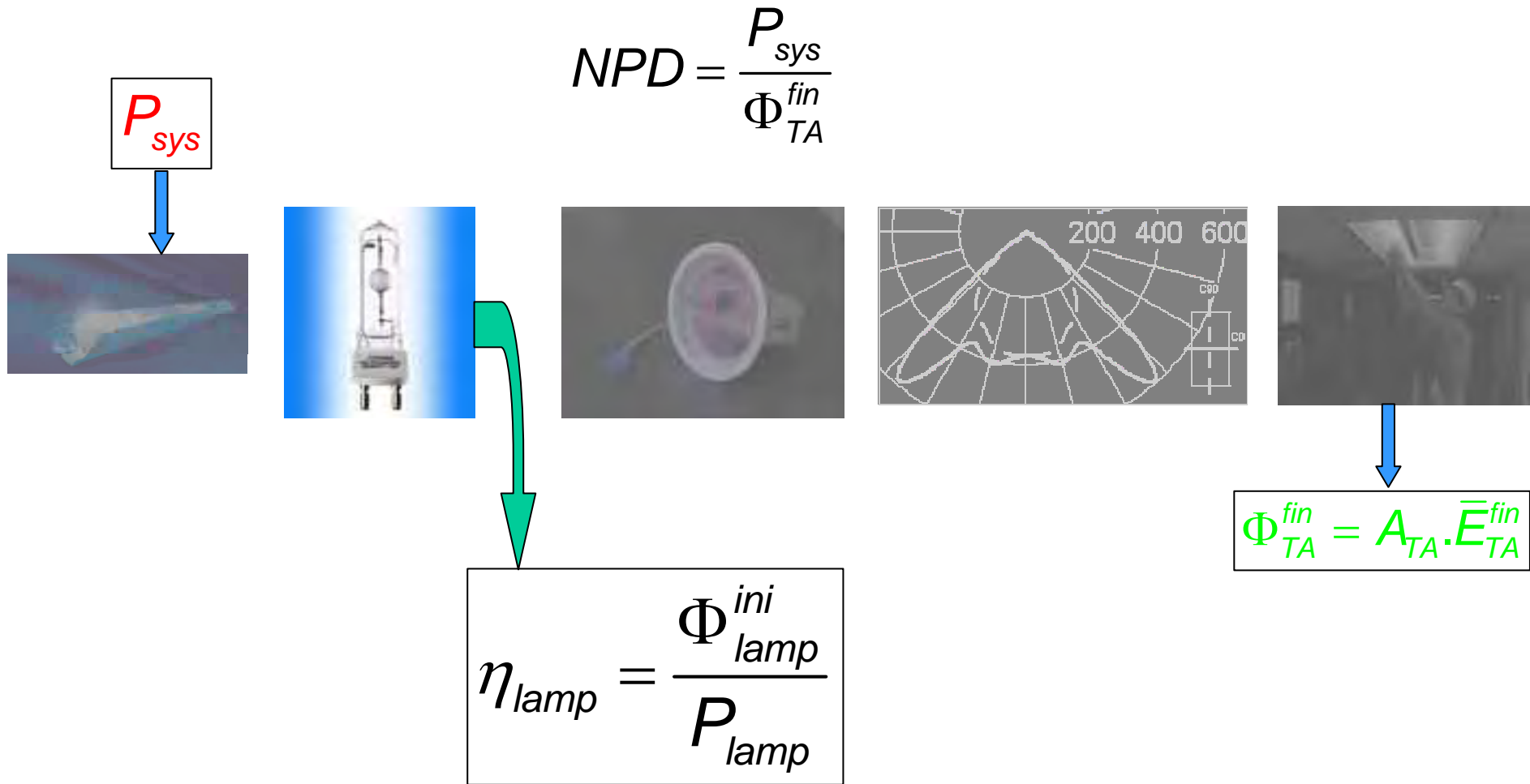


$$\Phi_{TA}^{fin} = A_{TA} \cdot \bar{E}_{TA}^{fin}$$

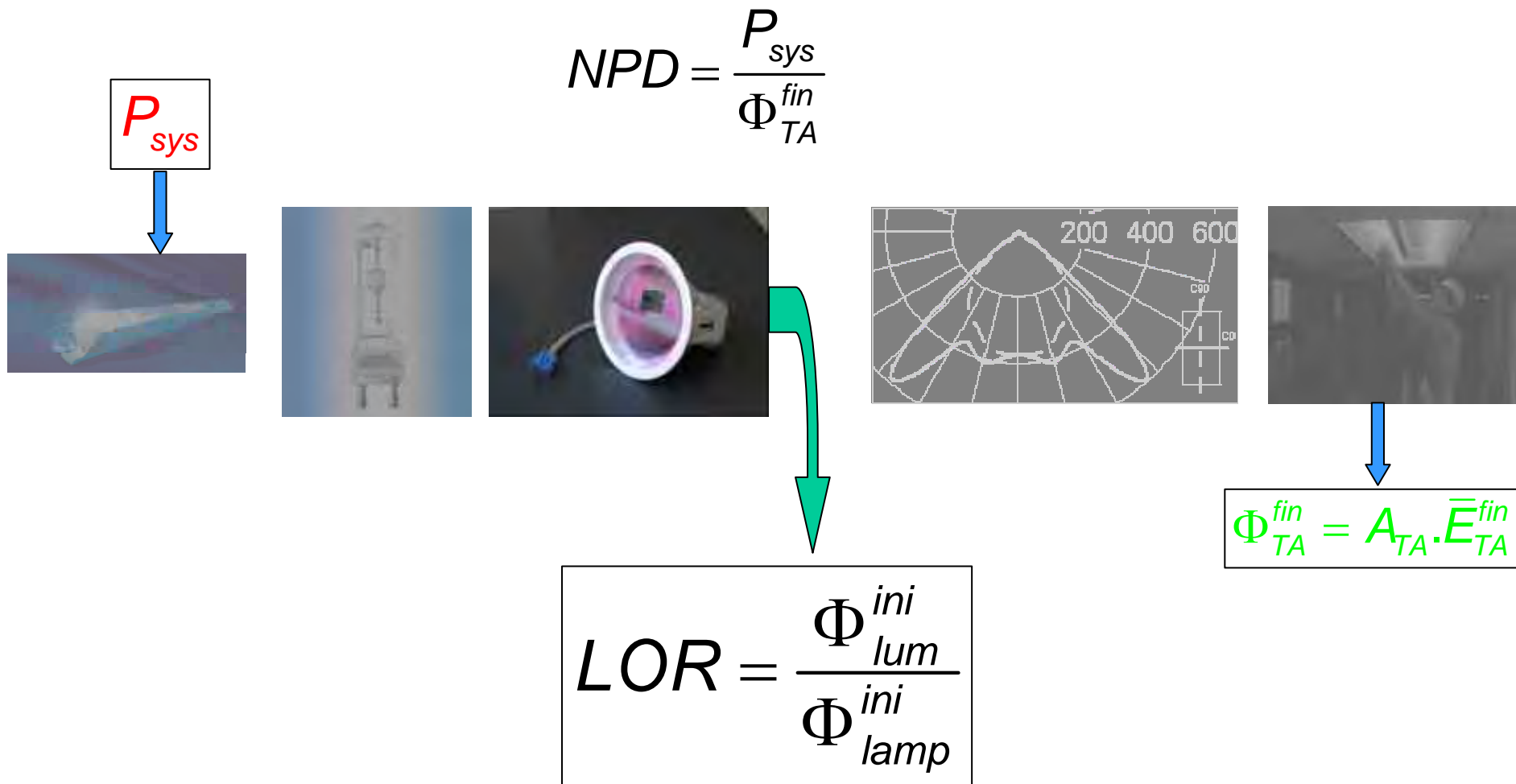
- efficiency to power the light source
- efficiency of converting electrical power to light
- efficiency of the luminaire
- efficiency of directing the luminous flux to the task area
- efficiency of maintaining the initial luminous flux.



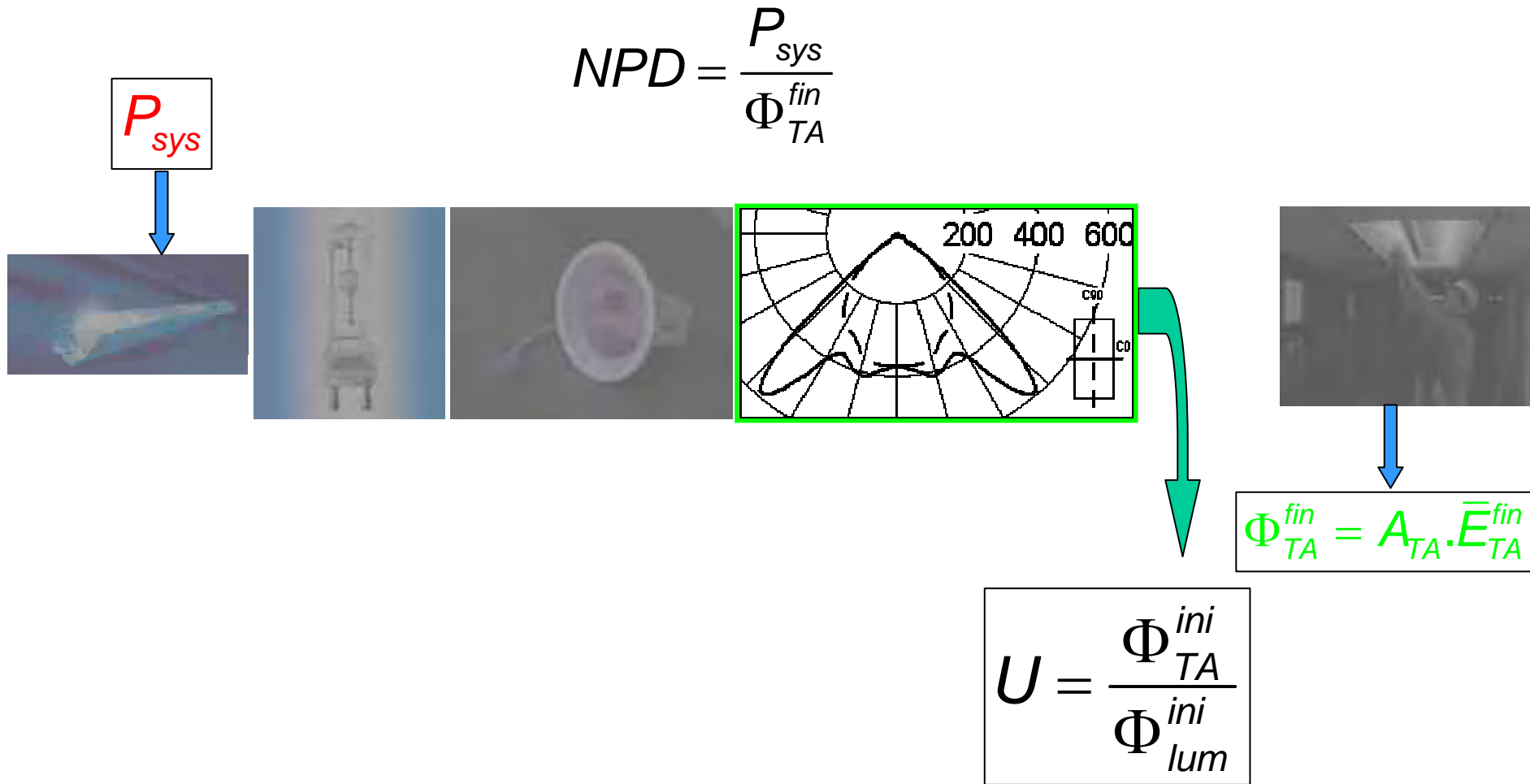
efficiency to power the light source



efficiency of converting electrical power to light

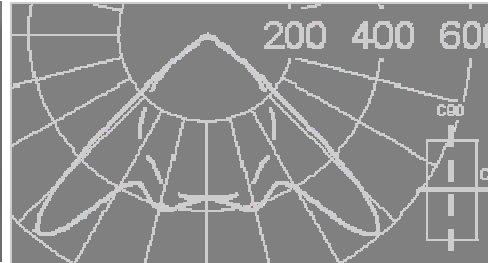
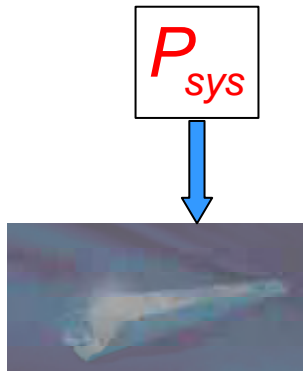


efficiency of the luminaire (Light Output Ratio)



efficiency of directing the luminous flux to the task area:
 utilance (LDF, spacing, room reflectance)

$$NPD = \frac{P_{sys}}{\Phi_{TA}^{fin}}$$



$$\Phi_{TA}^{fin} = A_{TA} \cdot \bar{E}_{TA}^{fin}$$

efficiency of maintaining
the initial luminous flux:
maintenance factor

$$MF = \frac{\Phi_{TA}^{fin}}{\Phi_{TA}^{ini}}$$

Combining efficiencies

Maximum value

$$NPD = \frac{P_{\text{sys}}}{\Phi_{TA}^{\text{fin}}} = \frac{100}{MF \cdot U \cdot LOR \cdot \eta_{\text{lamp}} \cdot \eta_{\text{gear}}}$$

Minimal values:
Selecting the best?
Eliminating the worst?

Proposal:

$$\eta_{\text{gear}} > 0.85$$

$$\eta_{\text{lamp}} > 70 \text{ lm/W}$$

$$LOR > 0.75$$

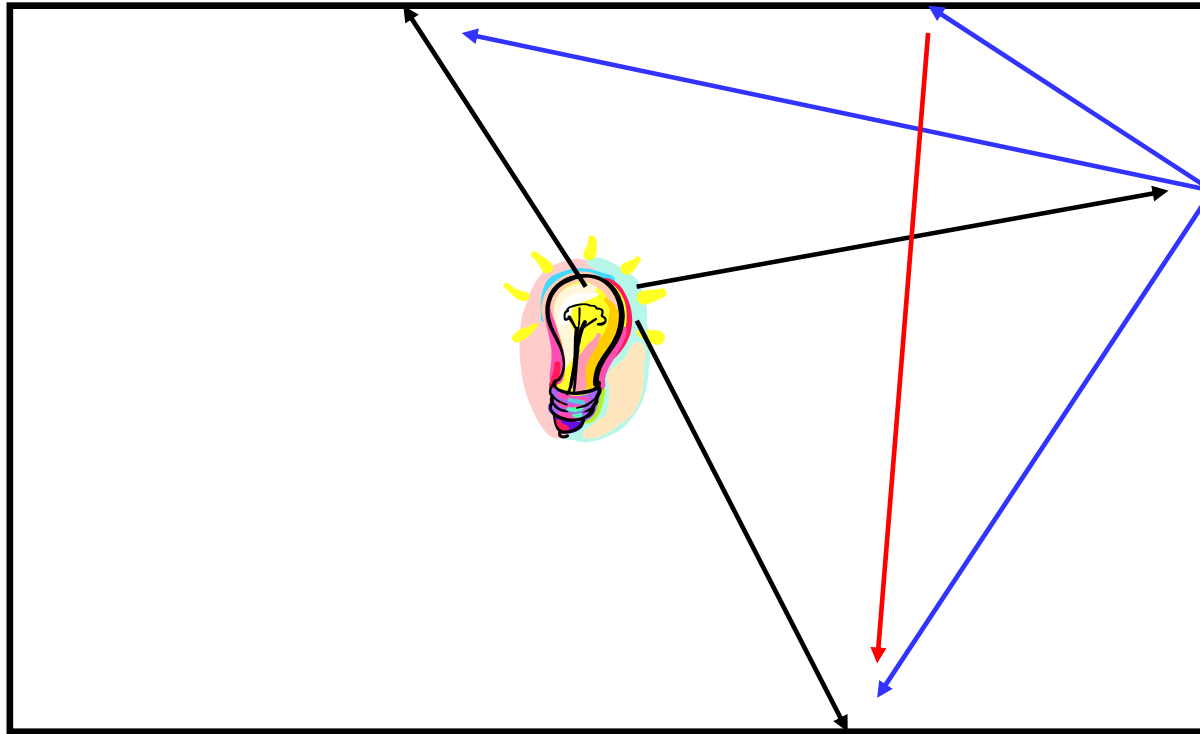
$$MF > 0.75$$

$$U > ???$$

Target value for utilance

Different methods (ray-tracing, point-by-point, flux transfer) with room reflectance and room index K as parameter and . . . standard task area

$$K = \frac{\text{horizontal area}}{\text{vertical area}} = \frac{l \cdot w}{h \cdot (l + w)}$$



Luminous flux on total room area:

$$\Phi_{lum}^{ini} + \langle \rho \rangle \cdot \Phi_{lum}^{ini} + \langle \rho \rangle^2 \Phi_{lum}^{ini} + \dots$$

$$= \frac{\Phi_{lum}^{ini}}{1 - \langle \rho \rangle} \approx 2 \cdot \Phi_{lum}^{ini} \quad \text{with } \langle \rho \rangle = 0.5$$

Check: room: 6x6x3

| $\Phi_{lum}^{ini} = 11\,442\text{ lm}$ | | $\rho = 0.5/0.5/0.5$ | | $\rho = 0.7/0.5/0.3$ | |
|----------------------------------------|--------------------|----------------------|-------------------|----------------------|-------------------|
| | A(m ²) | \bar{E} (lux) | Φ^{ini} (lm) | \bar{E} (lux) | Φ^{ini} (lm) |
| Ceiling | 36 | 103 | 3 708 | 76 | 2 736 |
| Walls | 72 | 146 | 10 530 | 128 | 9 216 |
| Floor | 36 | 237 | 8 532 | 231 | 8 316 |
| Total | | | 22 770 | | 20 268 |

$\langle \rho \rangle = 0.5$ could be too optimistic for downlighters

$$\rho_{TA} = 0.5$$

The luminous flux on total room area
can also be written as

$$2 \cdot \Phi_{lum}^{ini} = A_{TA} \cdot \bar{E}_{TA} + A_{nTA} \cdot \bar{E}_{nTA}$$

$$U = \frac{2}{1 + \frac{\bar{E}_{nTA}}{\bar{E}_{TA}} \cdot \frac{A_{nTA}}{A_{TA}}}$$

\bar{E}_{nTA} high: U will be low, low efficiency

\bar{E}_{nTA} low: U will be high, low lighting comfort

$$\bar{E}_{nTA} < 0.5 \bar{E}_{TA}$$

CIBSE, Luminance criteria

$$\frac{L}{E} = \frac{\rho}{\pi}$$

$$L_{ceiling} = 0.7 L_{TA}$$

$$L_{wall} = 0.5 L_{TA}$$

$$L_{floor} = 0.2 L_{TA}$$

$$U > \frac{2}{1 + 0.5 \frac{A_{nTA}}{A_{TA}}}$$

Proposal:

$$\eta_{\text{gear}} > 0.85$$

$$\eta_{\text{lamp}} > 70 \text{ lm/W}$$

$$LOR > 0.75$$

$$MF > 0.75$$

$$U > \frac{2}{1 + 0.5 \frac{A_{nTA}}{A_{TA}}}$$

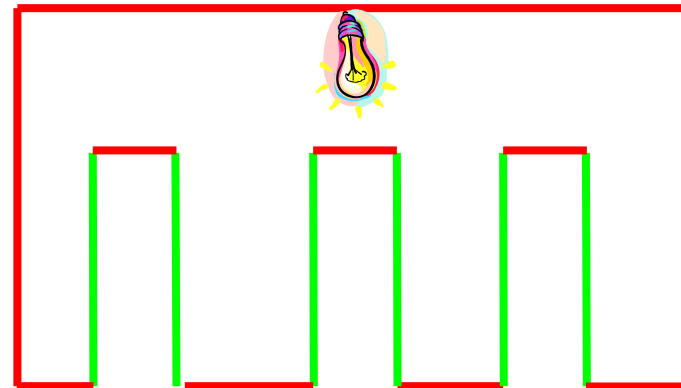
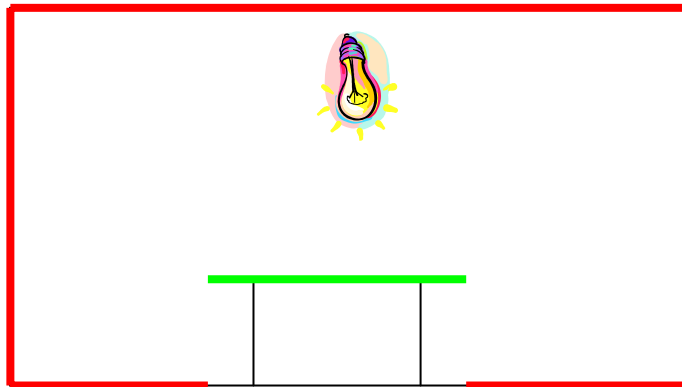
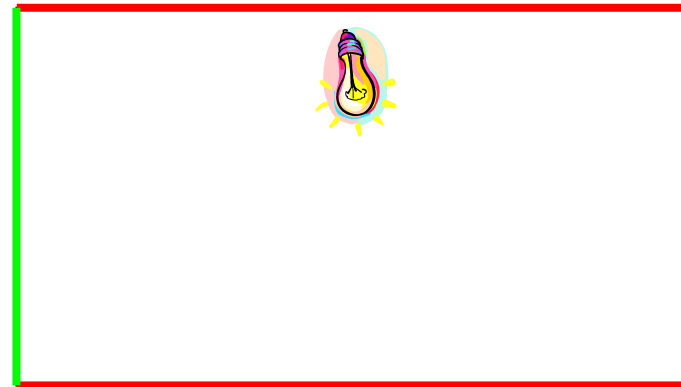
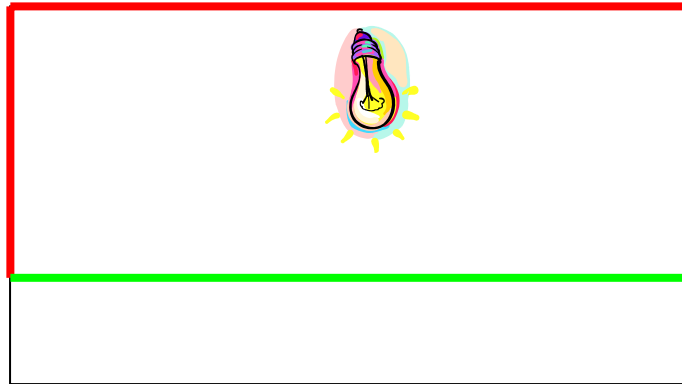
Target value

$$NPD(W / m^2 \cdot 100lux) < (1.5 + 0.75 \frac{A_{nTA}}{A_{TA}})$$

Task area!

(Non-)Task area

Edge zone included in task area (EN12464)



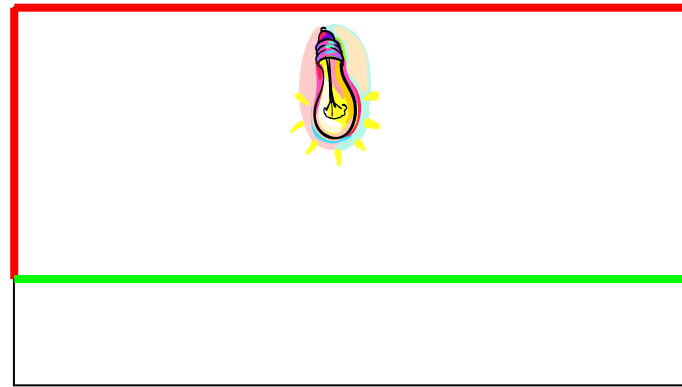
Preliminary tests

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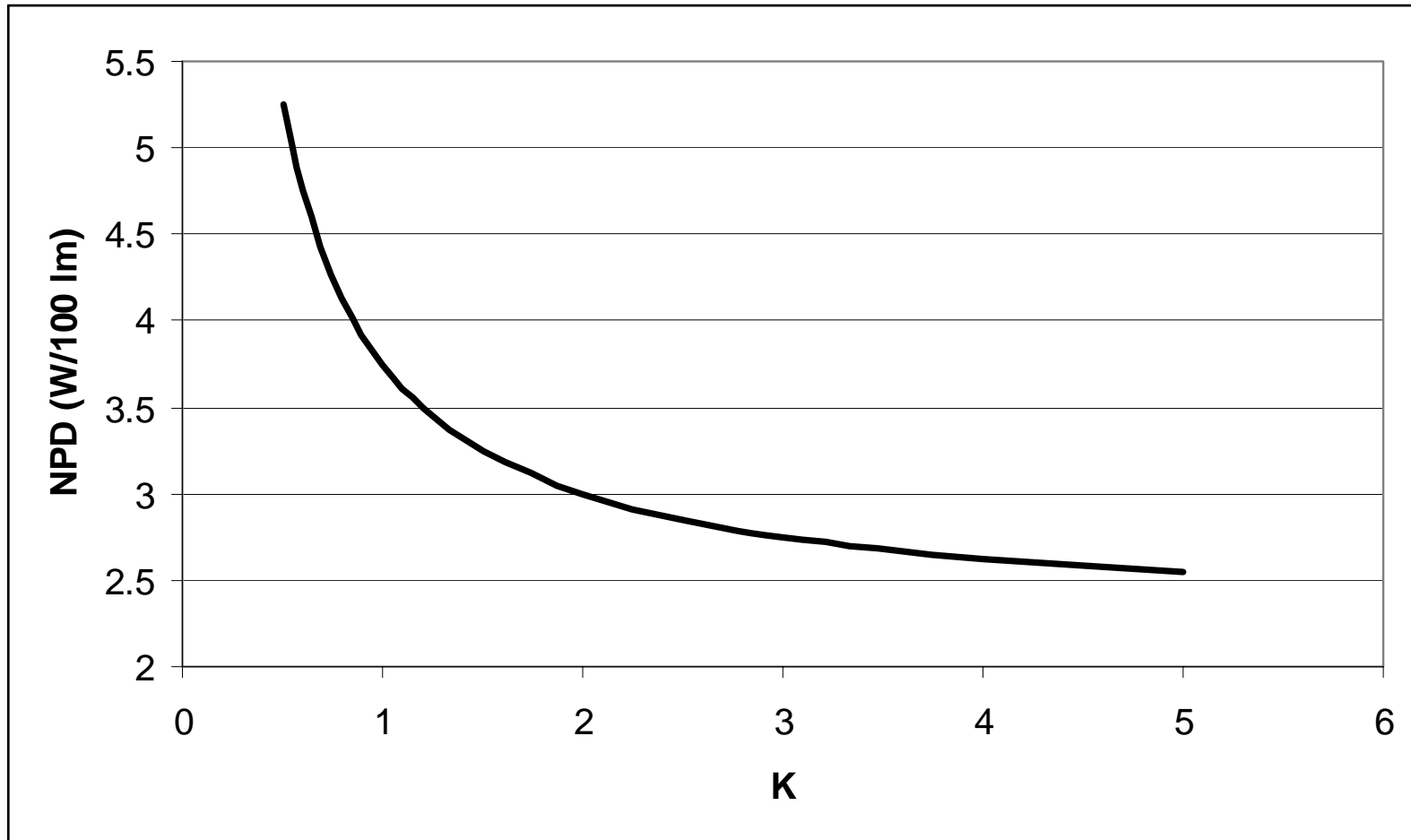


Test 1: standard task area



$$\frac{A_{nTA}}{A_{TA}} = 1 + \frac{2}{K}$$

$$NPD < \left(2.25 + \frac{1.5}{K} \right)$$



The formula offers theoretical basis for actual targets with standard task area!

Test 1: standard task area

Large landscape
office (30x30x3)

- $K=5$
- $U > 1.18$
- $NPD < 2.55W/m^2.100lux$



Test 1: standard task area

Indoor sport (44x23x8m)

- $K = 1.888$
- $U > 0.99$
- $NPD < 3 \text{ W/m}^2 \cdot 100\text{lux}$



Test 2: non-standard task area

Room: 6x6x3

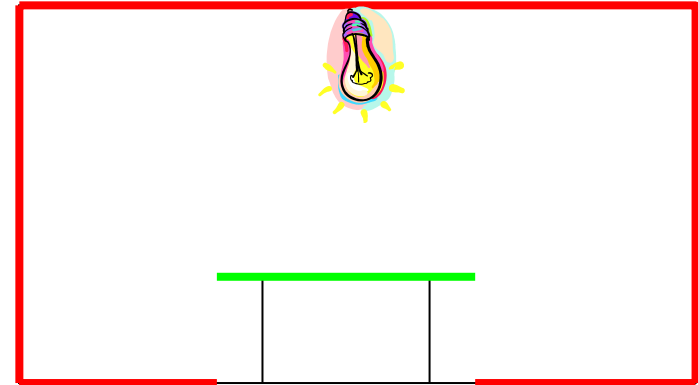
Desk: 2x2

$$A_{TA} = 3 \times 3 = 9$$

$$A_{nTA} = 135$$

$$U > 0.24$$

NPD < 12.8 W/m².100lux or maximum 115W/100 lux



Test 2: software calculations

Three T5 lamps, 24 W, above desk

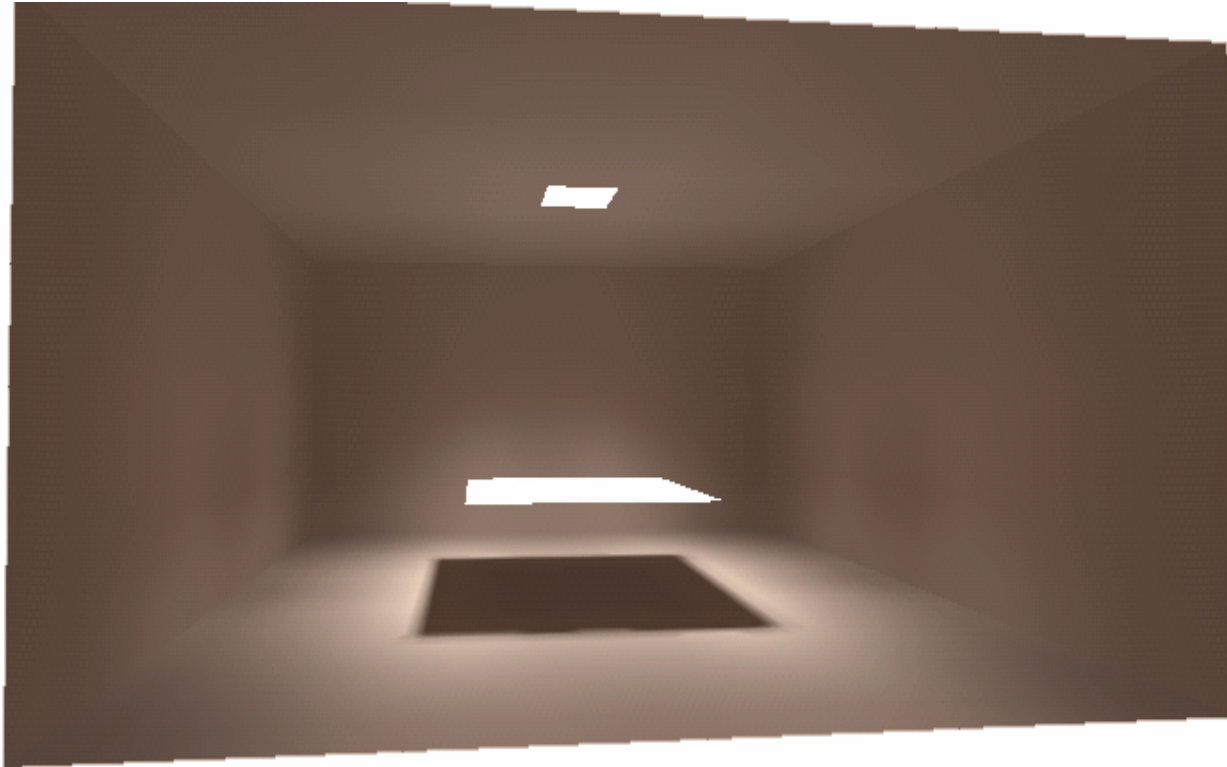
$P_{\text{sys}} = 88 \text{ W}$

$$U = 0.71 \gg \gg 0.24 \quad \bar{E}_{TA}^{ini} = 385 \text{ lux}$$

$$\bar{E}_{nTA}^{ini} = 40 \text{ lux!!!!}$$

$$\text{NPD} = \frac{88 \text{ W}}{9 \text{ m}^2 \cdot (2.9)} = 3.4 \ll 12.8 \text{ (target)}$$

Test 2



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Test 3: software calculations

Three T5 lamps, 24 W, corner

$P_{\text{sys}} = 88 \text{ W}$

$U = 0.085 \lll 0.24$

$$\bar{E}_{TA}^{ini} = 46 \text{ lux!!!!}$$

$$\bar{E}_{nTA}^{ini} = 131 \text{ lux!!!!}$$

$$\text{NPD} = \frac{88 \text{ W}}{9 \text{ m}^2 \cdot (0.35)} = 28 \gg 12.8$$

Test 3



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Conclusions

$$NPD(W / m^2 \cdot 100lux) < (1.5 + 0.75 \frac{A_{nTA}}{A_{TA}})$$

- Easy, independent of software calculations
- In accordance with actual criterium for standard task areas
- Non – standard task areas: needs further testing
- Fine tuning for target values is possible

Thank you!