Power Density Targets for Efficient Lighting of Interior Task Areas

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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
- \( \Phi_{TA}^{fin} \): maintained luminous flux on TA (lumen)
- \( \Phi_{TA}^{fin} = A_{TA} \cdot \overline{E}_{TA}^{fin} \)
  - \( A_{TA} \): Task Area (m\(^2\))
  - \( \overline{E}_{TA}^{fin} \): 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 à 2.5 (W/m².100 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
• 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
$NPD = \frac{P_{sys}}{\Phi_{fin}}$

$LOR = \frac{\Phi_{ini}}{\Phi_{ini}^{lum}}$

$\Phi_{TA}^{fin} = A_{TA} \cdot E_{TA}^{fin}$

efficiency of the luminaire (Light Output Ratio)
efficiency of directing the luminous flux to the task area: utilance (LDF, spacing, room reflectance)
efficiency of maintaining
the initial luminous flux:
maintenance factor

\[ NPD = \frac{P_{\text{sys}}}{\Phi_{TA}^{\text{fin}}} \]

\[ \Phi_{TA}^{\text{fin}} = A_{TA} \cdot E_{TA}^{\text{fin}} \]

\[ MF = \frac{\Phi_{TA}^{\text{fin}}}{\Phi_{TA}^{\text{ini}}} \]
Combining efficiencies

Maximum value

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

Minimal values:
Selecting the best?
Eliminating the worst?
Proposal:

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

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

$$\text{LOR} > 0.75$$

$$\text{MF} > 0.75$$

$$U > ???$$
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

$$K = \frac{\text{horizontal area}}{\text{vertical area}} = \frac{l.w}{h.(l + w)}$$
Luminous flux on total room area:

\[ \Phi_{lum}^{ini} + <\rho> \cdot \Phi_{lum}^{ini} + <\rho>^2 \Phi_{lum}^{ini} + \ldots \]

\[ = \frac{\Phi_{lum}^{ini}}{1 - <\rho>} 2 \cdot \Phi_{lum}^{ini} \quad \text{with} \quad <\rho> \geq 0.5 \]
Check:
room: 6x6x3

<table>
<thead>
<tr>
<th></th>
<th>A(m²)</th>
<th>$\bar{E}$ (lux)</th>
<th>$\Phi_{ini}^{lum}$ (lm)</th>
<th>$\bar{E}$ (lux)</th>
<th>$\Phi_{ini}^{lum}$ (lm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>36</td>
<td>103</td>
<td>3 708</td>
<td>76</td>
<td>2 736</td>
</tr>
<tr>
<td>Walls</td>
<td>72</td>
<td>146</td>
<td>10 530</td>
<td>128</td>
<td>9 216</td>
</tr>
<tr>
<td>Floor</td>
<td>36</td>
<td>237</td>
<td>8 532</td>
<td>231</td>
<td>8 316</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>22 770</td>
<td>20 268</td>
</tr>
</tbody>
</table>

$< \rho > = 0.5$ could be too optimistic for downlighters

$\rho_{TA} = 0.5$
The luminous flux on total room area can also written as

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

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

$$\bar{E}_{nTA}$$ 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:

\[ \eta_{\text{gear}} > 0.85 \]
\[ \eta_{\text{lamp}} > 70\text{lm}/\text{W} \]
\[ LOR > 0.75 \]
\[ MF > 0.75 \]

\[ U > \frac{2}{1 + 0.5 \frac{A_{nTA}}{A_{TA}}} \]
Target value

\[ NPD \left( \frac{W}{m^2 \cdot 100\text{lux}} \right) < (1.5 + 0.75 \frac{A_{nTA}}{A_{TA}}) \]

Task area!
(Non-)Task area

Edge zone included in task area (EN12464)
Preliminary tests
Test 1: standard task area

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

\[ NPD < (2.25 + \frac{1.5}{K}) \]
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

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

$A_{nTA} = 135$

$U > 0.24$

$NPD < 12.8 \text{ W/m}^2 \cdot 100 \text{lux}$ or maximum $115 \text{ W/100 lux}$
Test 2: software calculations

Three T5 lamps, 24 W, above desk

\[ P_{sys} = 88 \, \text{W} \]

\[ U = 0.71 \ggg 0.24 \]

\[ \bar{E}_{TA}^{ini} = 385 \, \text{lux} \]

\[ \bar{E}_{nTA}^{ini} = 40 \, \text{lux} \]

\[ \text{NPD} = \frac{88 \, \text{W}}{9 \, \text{m}^2 \cdot (2.9)} = 3.4 \ll 12.8 \, (\text{target}) \]
Test 3: software calculations

Three T5 lamps, 24 W, corner
Psyst = 88 W
U= 0.085 << 0.24

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

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

\[
\text{NPD} = \frac{88W}{9m^2 \cdot (0.35)} = 28 >> 12.8
\]
Test 3
Conclusions

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

• 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!