LED – EFFICIENCY ASPECTS

\[
\begin{array}{ccc}
\text{Im/W} & \% \\
\text{cd/m}^2 / \text{W/m}^2 & \text{Im/LED}
\end{array}
\]
LED Streetlight Luminaire, Cobrahead M-400 Housing
Better Visibility • Reduced Light Pollution • Consumes Only 20 Watts Power
Suitable for Replacing 70-100Watt HPS & MH Streetlights

• Huge Cost Saving Benefit – up to 85% reduction in electricity costs.
• High Luminous Efficiency – output of 150 lumens per watt, the 38 watt LED lamp can replace a
400 watt traditional sodium lamp.

10x
45%

LEDs – The magic solution???
The Use of LEDs in Public Lighting

- System efficacy - LED efficacy
- Luminaire comparison
- Consideration of lumen depreciation
- Photopic/scotopic approach
- Conclusion
Efficiency or Efficacy?

Efficacy:

Input and output units differ:

- Lumen output / power input \( \text{Im/W} \)
- Average luminance / power input/m\(^2\) \( \text{cd/m}^2/\text{W/m}^2 \)

Efficiency:

Input and output units are the same:

- output power / input power \( \% \)
- lumen emitted by the luminaire / lumen emitted by the LEDs \( \% \)
LED System Efficacy

LED system efficacy =

LED efficacy $\times$ driver efficiency $\times$ optical efficiency $\times$ Thermal efficiency
LED Luminous Efficacy compared to other light sources

- 2009: ~130 lm/W
- 2012: ~150 lm/W
LED – Luminous Efficacy

Driver efficiency

220/230 V ~

AC/DC Power Supply

24/48V

Current Source

350 mA

LEDs + PCBs

85-90 %

> 90 %

90-95 %

~ 80 %

= 72-86 %

EFFICIENCY
Optical efficiency of TIR optics: 
85% - 90%

Additional cover glass
+ ~ 8% losses due to Fresnel reflection
LED efficacies are specified at a junction temperature $T_j = 25 \, ^\circ\text{C}$

Realistic condition: $T_j = 70 \, ^\circ\text{C} \Rightarrow \text{Efficacy} \sim 90 \%$
LED Efficacy

LED system efficacy =

LED efficacy x driver efficiency x optical efficiency x thermal efficiency

\[
100 \text{ lm/W} \times 90\% \times 90\% \times 95\%
\]

= 77 \text{ lm/W available (85 lm/W ex driver losses)}
Efficacy of warm white LEDs

Reduction of luminous efficacy (~ -20 % to 30 %)
Utilisation coefficient

**HID**
100 lm/W

50% utilization efficiency

Effective: 50 lm/W

**White LED**
80 lm/W

70% utilization efficiency

Effective: 56 lm/W
Increase the current → Reduce the # of LEDs?

50 LEDs, 350 mA
Warm white
75 lm/W @ 25 °C

\[ T_j = 65^\circ\text{C} \rightarrow 92\% \rightarrow 69\text{ lm/W} \]

30 LEDs, 700 mA
Warm white, 75 lm/W

\[ T_j \approx 80^\circ\text{C} \rightarrow 88\% \rightarrow 66\text{ lm/W} \]

700 mA: 100% → 82% → 54 lm/W
Increase the current → Reduce the # of LEDs?

50 LEDs, 350 mA
Warm white
69 lm/W @ 65 °C

56 W, 4200 lm

30 LEDs, 700 mA
Warm white,
54 lm/W @ 80 °C

74 W, 4000 lm

Lifetime:
110000 h → 70000 h
Global luminaire efficacy comparisons

Hypothesis:
Road configuration and photometric constraints

Target:
Luminance = 1 cd/m²
Lighting efficiency
Comparison LEDs vs. CosmoPolis and Metal Halide (CDM-T)

CITEA+CDM-T  FURYO+CosmoPolis  PERLA+LED
## Photometric comparison, target luminance 1 cd/m²

<table>
<thead>
<tr>
<th>Lamp</th>
<th>CCT</th>
<th>Total Power</th>
<th>Pole distance</th>
<th>Total uniformity $U_0$</th>
<th>Longitudinal uniformity $U_l$</th>
<th>Power/ length unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITEA, Metal Halide CDM-T 70 W</td>
<td>4200 K</td>
<td>77 W</td>
<td>13 m</td>
<td>59 %</td>
<td>88 %</td>
<td>5,9 W/m</td>
</tr>
<tr>
<td>FURYO1, CosmoPolis 60 W</td>
<td>2750 K</td>
<td>66 W</td>
<td>18 m</td>
<td>60 %</td>
<td>76 %</td>
<td>3,7 W/m</td>
</tr>
<tr>
<td>PERLA, 64 LEDs warm white (87 lm)</td>
<td>3500 K</td>
<td>79 W</td>
<td>14,5 m</td>
<td>64 %</td>
<td>77 %</td>
<td>5,3 W/m</td>
</tr>
<tr>
<td>PERLA, 64 LEDs cool white (107 lm)</td>
<td>6000 K</td>
<td>79 W</td>
<td>18 m</td>
<td>60 %</td>
<td>73 %</td>
<td>4.4 W/m</td>
</tr>
</tbody>
</table>
### Global luminaire efficacy comparisons

Configuration optimised for all luminaires for $L_{av} = 1 \text{ cd/m}^2$

<table>
<thead>
<tr>
<th>Luminaire / Lamp</th>
<th>CCT °K</th>
<th>Total power W</th>
<th>Pole distance m</th>
<th>Power per meter of length W/m</th>
<th>Luminance uniformities</th>
<th>Luminaire power efficacy W/ cd/m²</th>
<th>Global luminaire efficacy Cd/m² / W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITEA, Metal Halide CDM-T 70 W</td>
<td>4200</td>
<td>77</td>
<td>13</td>
<td>5.92</td>
<td>59</td>
<td>88</td>
<td>77</td>
</tr>
<tr>
<td>FURYO1, CosmoPolis 60 W</td>
<td>2750</td>
<td>66</td>
<td>18</td>
<td>3.67</td>
<td>60</td>
<td>76</td>
<td>66</td>
</tr>
<tr>
<td>PERLA, 64 LED warm white (87 lm/LED)</td>
<td>3500</td>
<td>79</td>
<td>14.5</td>
<td>5.45</td>
<td>64</td>
<td>77</td>
<td>79</td>
</tr>
<tr>
<td>PERLA, 64 LED cool white (107 lm/LED)</td>
<td>6000</td>
<td>79</td>
<td>18</td>
<td>4.39</td>
<td>60</td>
<td>73</td>
<td>79</td>
</tr>
</tbody>
</table>

*U₀ %, U₁ %*
Hypothesis: Road configuration and photometric constraints

Target: Same configuration for all luminaires and optimised for P186
## Global luminaire efficacy comparisons

### Same configuration for all luminaires and optimised for P186

<table>
<thead>
<tr>
<th>Luminaire / Lamp</th>
<th>Luminance</th>
<th>Luminaire efficacy</th>
<th>Glare TI %</th>
<th>Utilis. factor K %</th>
<th>Total power W</th>
<th>Luminaire power efficacy W/ cd/m²</th>
<th>Global luminaire efficacy cd/m² / W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>P186 96 LED 115W (80 lm/LED)</td>
<td>1.22/1.38</td>
<td>14.0/12.4</td>
<td>14.8</td>
<td>67</td>
<td>115</td>
<td>94</td>
<td>2.04</td>
</tr>
<tr>
<td>ONYX SON-T 100 W</td>
<td>0.99/1.09</td>
<td>17.0/15.6</td>
<td>10.9</td>
<td>39.5</td>
<td>110</td>
<td>111</td>
<td>1.73</td>
</tr>
<tr>
<td>IPSO SON-T 70 W</td>
<td>0.80/0.89</td>
<td>15.5/13.9</td>
<td>12.7</td>
<td>45</td>
<td>77</td>
<td>96</td>
<td>1.99</td>
</tr>
<tr>
<td>FURYO2 Cosmo 90W</td>
<td>1.40/1.61</td>
<td>14.0/12.1</td>
<td>13.8</td>
<td>43</td>
<td>100</td>
<td>71</td>
<td>2.68</td>
</tr>
</tbody>
</table>
## Street Lighting – HID vs. LED Efficacy

**HPS 250 W – LED equivalent**
*(no consideration of the lumen depreciation)*

<table>
<thead>
<tr>
<th></th>
<th>HPS 250 W (128 lm/W)</th>
<th>LED (100 lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminaire power</td>
<td>285 W</td>
<td>222 W 321 W</td>
</tr>
<tr>
<td></td>
<td></td>
<td>193 / 279 LEDs</td>
</tr>
<tr>
<td>Lamp power</td>
<td>250 W</td>
<td>202 W 289 W</td>
</tr>
<tr>
<td>Lumen (lamp)</td>
<td>32000</td>
<td>20200 28900</td>
</tr>
<tr>
<td>Efficiency (luminaire)</td>
<td>77 %</td>
<td>80 %</td>
</tr>
<tr>
<td>Lumen luminaire</td>
<td>24600</td>
<td>16150 23100</td>
</tr>
<tr>
<td>Utilization factor k</td>
<td>43 %</td>
<td>70 %</td>
</tr>
<tr>
<td>(street lighting)</td>
<td>70 %</td>
<td>80 %</td>
</tr>
<tr>
<td>Lumen on the road</td>
<td>11300 18500</td>
<td>11300 18500</td>
</tr>
</tbody>
</table>

The comparison of efficacies also depends on the application.
# Street Lighting – HID vs. LED Efficacy

## Metal Halide 250 W – LED equivalent (no consideration of the lumen depreciation)

<table>
<thead>
<tr>
<th></th>
<th>MH 250 W (92 lm/W)</th>
<th>LED (91 lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminaire power</td>
<td>285 W</td>
<td>166 W 236 W</td>
</tr>
<tr>
<td>Lamp power</td>
<td>250 W</td>
<td>150 W 213 W</td>
</tr>
<tr>
<td>Lumen (lamp)</td>
<td>23000</td>
<td>13600 19400</td>
</tr>
<tr>
<td>Efficiency (luminaire)</td>
<td>77 %</td>
<td>80 %</td>
</tr>
<tr>
<td>Lumen luminaire</td>
<td>17700</td>
<td>10900 15500</td>
</tr>
<tr>
<td>Utilization factor k (street lighting) (Area lighting)</td>
<td>43 % 70 %</td>
<td>70 % 80 %</td>
</tr>
<tr>
<td>Lumen on the road</td>
<td>7600 12400</td>
<td>7600 12400</td>
</tr>
</tbody>
</table>
LED → high investment per photon

LED vs. HPS - Lamp cost depending on the required flux

Most efficient and economic LED solution:
Replacement of low power HID lamps
Photopic/Mesopic/Scotopic View

Scotopic view: \( L < 0.01 \text{ cd/m}^2 \) (rods, peripheral vision)
Mesopic view: \( < 0.01 \text{ cd/m}^2 < L < 10 \text{ cd/m}^2 \) (rods+cones)
Photopic view: \( L > 10 \text{ cd/m}^2 \) (cones, foveal vision)

Street lighting
Compared to HPS lamps the LED efficacy is increasing under mesopic conditions.

Mesopic sensitivity is not yet integrated into international lighting standards!

+++ LEDs provide white light!!! +++
Scotopic/Photopic Approach

Scotopic/Photopic ratio

S/P: Ratio of *scotopic* and *photopic* sensitivity

S/P depends on the light source, favorable for white light

S/P ratio:
- High Pressure Sodium: ~0.63
- Metal Halide: ~1.54
- Cool white LED: ~2.04

Mesopic view using LEDs (6200 K):

Perception of contrast +

Perception of brightness increased by max. 16% compared to a HPS source
Scotopic/Photopic Approach

Scotopic/Photopic ratio

S/P: Ratio of scotopic and photopic sensitivity

S/P depends on the light source, favorable for white light

S/P ratio:
High Pressure Sodium: \(~0.63\)
Metal Halide: \(~1.54\)
Cool white LED: \(~2.04\)

<table>
<thead>
<tr>
<th>Source</th>
<th>Luminaire Wattage</th>
<th>Photopic lumens (luminaire)</th>
<th>Scotopic lumens (luminaire)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS 250 W</td>
<td>280</td>
<td>19000</td>
<td>12000</td>
</tr>
<tr>
<td>240 LEDs</td>
<td>310</td>
<td>19400</td>
<td>39600</td>
</tr>
<tr>
<td>80 LEDs</td>
<td>104</td>
<td>6500</td>
<td>13200</td>
</tr>
</tbody>
</table>

Non-standardised scotopic approach
System efficacy is the crucial indicator

Reducing the quantity of LEDs and increasing the current may reduce the cost of a luminaire but compromises the system efficacy

$cd/m^2 / W/m^2$ is a universal indicator for the luminaire efficacy in a luminance based road lighting configuration

Beware of scotopic comparisons between HID lamps and LEDs