Efficiency of road lighting in the Nordic countries

Draft by Kai Sørensen, DELTA, 25 May 2010

Background and introduction

It is likely that energy saving to road lighting will become an issue in some or all of the Nordic countries. There are several methods to obtain savings:

a. omitting road lighting of particular roads
b. reducing the lighting level in general
c. reducing the lighting level in periods with less traffic
d. improving the efficiency of the road lighting installations.

Only the last-mentioned method is considered in this note. The idea is that a comparison of the efficiency of road lighting installations among the Nordic countries may indicate means of improvement in the individual countries. If for instance one of the countries uses particularly efficient luminaires, this may be exposed and help the other countries to use introduce equally efficient luminaires.

Therefore, the purpose is not to reveal if the road lighting quality differs in the individual countries, only to expose if the energy is used equally well - and eventually to explain differences in terms of the lighting equipment used.

In section 1 it is proposed that a study is based on road lighting of small and medium sized traffic roads only. In section 2, some figures of merit are introduced, while values for some examples of installations are provided in section 3.

1. Limitation of a study to road lighting of small and medium sized traffic roads

It is proposed to consider road lighting of small and medium size traffic roads only, typically with illumination to an average road surface luminance of 0,5 or 0,75 cd/m^2. Such road lighting is assumed to be in accordance with the MEW-series of lighting classes as defined in EN 12301-2 "Road lighting - Part 2: Performance requirements".

For this kind of road lighting, the main quality criteria concern the average of the road surface luminance of the carriageway, while additional criteria include the uniformity of the road surface luminance, illumination of specified areas surrounding the carriageway and glare from the installation. Refer to EN 12301-2 or to national road lighting standards.

NOTE: This means that road lighting of motorways, large traffic roads, road crossings, squares, local roads (domestic roads and some industrial roads), pedestrian crossings, parking lots, paths and so on is not considered – although such road lighting may be included at a later point in time.

2. Figures of merit

2.1 System luminous efficacy of a light source

The luminous efficacy of a light source $\eta_{light\ source}$ is the quotient of the luminous flux emitted by the light source to the power consumed. The unit is lumen per Watt (lm/W).

All discharge lamps need to have ballasts that introduce some additional power consumption. When including this additional power, light sources can be attributed a system luminous efficacy

η_{system}, which is smaller than $\eta_{light\ source}$. Table 1 provides typical values of $\eta_{light\ source}$ and η_{system} for some light sources.

Table 1: Typical luminous efficacy values for some light sources.

Lamps		Luminous efficacy (lm/W)	
		Light source	System
incandescent lamp	100 W	14	14
compact fluorescent lamp	42 W	75	
linear fluorescent tube for low temperatures	65 W	78	
Mercury lamps			
	50 W	40	34
	80 W	50	46
	125 W	54	48
	250 W	57	53
High pressure sodium lamps			
	50	88	72
	70	94	82
	100	105	96
	150	110	94
Compact metal halide lamps			
	35 W	90	65
	70 W	95	74
	150 W	95	86
Some modern lamps		Comparable to high pressure sodium lamps	

2.2 Luminous efficiency of a lighting installation

The luminous efficiency of the lighting installation is defined as:

$\eta_{installation} = \Phi_{minimum}/\Phi_{actual}$

where $\Phi_{minimum}$ is the minimum luminous flux needed in view of the areas to be illuminated and the minimum levels of illumination for those areas

and Φ_{actual} is the nominal luminous flux used by the lighting installation.

The value of $\eta_{installation}$ is calculated in accordance with annex A. The calculated value is affected by:

a. the value of the maintenance factor MF used when designing the installation (enters as a factor)
b. the output ratio of the luminaires (enters as a factor)
c. spill of light outside the areas to be illuminated (reduces the value of $\eta_{installation}$)
d. excess illumination of one or more of the areas to be illuminated (reduces the value of $\eta_{installation}$)
e. The reflection capability of the road surface (reduces or raises the value of $\eta_{installation}$)
f. The capability of the illumination to produce the lighting characteristic used to specify the illumination of the surroundings (reduces or raises the value of $\eta_{installation}$).

The factors a. to d. have the dominating effect and force the value of $\eta_{installation}$ to become less than unity in the general case.

The factor e. reduces or raises the value of $\eta_{installation}$ when the road lighting installation is designed for a road surface with a lower or higher reflection value than normal. A further change of the value of $\eta_{installation}$ may occur depending on the directionality of the illumination.

The factor f. may change the value of $\eta_{installation}$ depending on the directionality of the illumination.

2.3 Total efficacy of a lighting installation

The total efficacy of a lighting installation is defined by:

$\eta_{total} = \Phi_{minimum}/P$

where $\Phi_{minimum}$ is the minimum luminous flux introduced in the previous section

and P is the total power consumed by the installation (light sources and ballasts).

Once the luminous efficacy of the light source and the luminous efficiency of the lighting installation have been calculated, the total efficacy can be obtained as the product ($\eta_{total} = \eta_{system} \times \eta_{installation}$).

3. Examples of lighting installations

Table 2 provides figures of merits for examples of lighting installations.

Table 2: Figures of merit.

	$\eta_{installation}$	η_{system}	η_{total}
Denmark (refer to annex B) [1)]			
Example 1	0,40	98 lm/W	39 lm/W
Example 2	0,41	82 lm/W	34 lm/W
Finland			
Iceland			
Norway			
Sweden			
1) These examples do not show the top performance of the most competitive luminaires, but a performance that is needed in order to take luminaires into consideration at all.			

Annex A: Calculation of the luminous efficiency of a lighting installation $\eta_{installation}$

The carriageway needs to receive a minimum luminous flux of:
$\Phi_{carriageway} = A_{carriageway} \times E_{carriageway}$
where $A_{carriageway}$ is the area of the carriageway (m^2)
and $E_{carriageway}$ is the minimum average illuminance on the carriageway (lx)

The value of $E_{carriageway}$ is calculated by:
$E_{carriageway} = L/Q$
where L is the minimum maintained luminance of the road surface of the carriageway ($cd \cdot m^{-2}$)
and Q is an average luminance coefficient for the road surface ($cd \cdot m^{-2} \cdot lx^{-1}$).

The value L is the one that is requested for the particular lighting installation. The value of Q is not evaluated for the particular lighting installation, but set to a fixed, standard value of 0,07.

The surroundings need to receive a minimum luminous flux of:
$\Phi_{surroundings} = A_{surroundings} \times E_{surroundings}$
where $A_{surroundings}$ is the area of those surroundings that need a specified illumination (m^2)
and $E_{surroundings}$ is the minimum average illuminance on the surroundings (lx)

If the illumination on the surroundings is not specified by means of $E_{surroundings}$ directly, then the value of $E_{surroundings}$ has to be estimated. In case the specification is by means of the average hemispherical illuminance E_{hs}, then $E_{surroundings}$ is obtained by $E_{surroundings} = E_{hs}/0{,}65$.

The value of $\Phi_{minimum}$ is determined as the sum of the values of $\Phi_{carriageway}$ and $\Phi_{surroundings}$.

The value of Φ_{actual} is found as the sum of the nominal luminous flux values of the light sources of the lighting installation. In the case of lighting installations with a uniform cross section of the areas to be illuminated and identical luminaires with a uniform spacing, the values can be calculated for one luminaire spacing (the length of the areas is set to one spacing and Φ_{actual} is set to the nominal luminous flux of a single light source).

Finally, the luminous efficiency of a lighting installation $\eta_{installation}$ is obtained as the ratio of $\Phi_{minimum}$ to Φ_{actual} ($\eta_{installation} = \Phi_{minimum}/\Phi_{actual}$).

Annex B: Road lighting in Denmark

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B.1 General

Road lighting in Denmark is designed according to “Vejregler for vejbelysning”, Vejdirektoratet – Vejregelrådet Marts 1999.

B.2 Relevant lighting classes

Road lighting on traffic roads is mostly designed to the lighting classes L7a or L7b. The requirements are shown in table B.1.

Table B.1: Requirements of lighting classes L7a and L7b.

Road surface luminance and glare limitation	
Dry condition: table N2 with a Qd of 0,078 $cd \cdot m^{-2} \cdot lx^{-1}$	
Average luminance (maintained)	L7a: Minimum 0,75 cd/m^2 L7b: Minimum 0,50 cd/m^2
Overall uniformity	Minimum 0,40
Longitudinal uniformity	Minimum 0,30
Disability glare TI	Maximum 0,15
Wet condition: table W4	
Overall uniformity	Minimum 0,15
Illumination of the surroundings of the carriageway (hemispherical illuminance)	
Average (maintained)	Minimum 2,5 lx
Overall uniformity	Minimum 0,15

The requirements regarding road surface luminance and glare limitation correspond to classes MEW4 and MEW5 of EN 13201-2, while the requirements regarding to illumination of the surroundings to the carriageway correspond to classes A2/A3 (mid between the two).

The requirements for the illumination of the surroundings to the carriageway apply for fields on both sides of the carriageway with a standard width of 3,5 m. Refer to figure B.1

A maintenance factor of 0,85 is generally applied when designing road lighting on traffic roads.

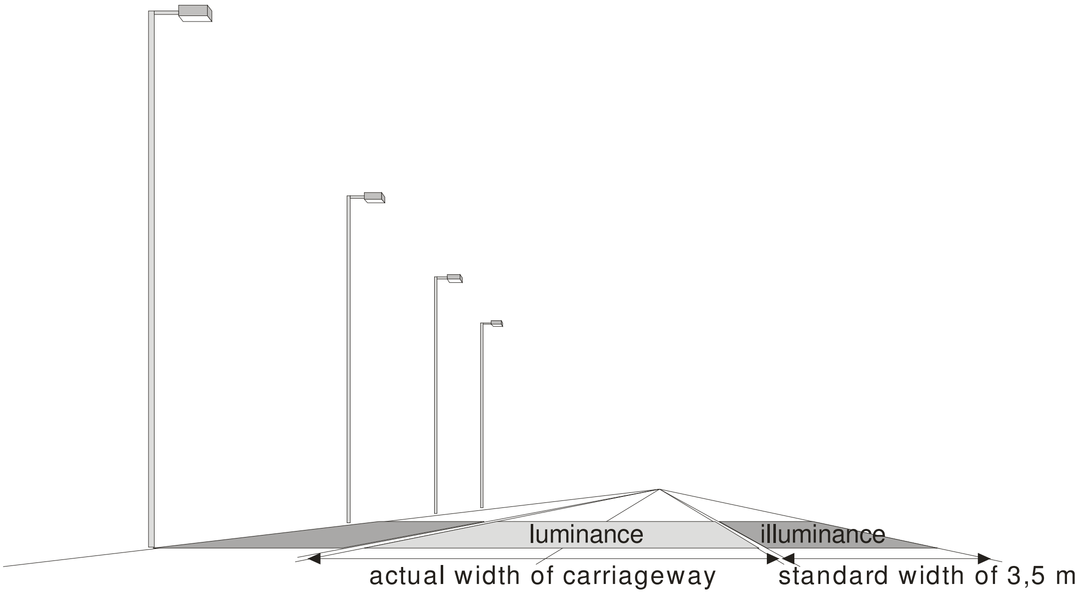

Figure B.1: Fields used to derive values for the luminance of the carriageway and for the illuminance of the surroundings to both sides of the carriageway.

B.3 Other requirements

Mounting heights of luminaires are maximum 8 m for small traffic roads and maximum 10 m for larger traffic roads. Columns are normally 8 or 9 m high. Brackets are not used, except when they are short and a natural part of the design of the columns.

Luminaires used for road lighting of traffic roads must be of class minimum G4, which corresponds to flat glass luminaires, and they must be mounted without tilt or with a tilt of maximum 3°.

In view of the low mounting heights and the use of table W4 for the wet condition, the luminaires are used with a setting that provides a larger toe-in of the beams than for most other road lighting traditions.

B.4 Typical installations

Figure B.2 shows a typical lighting installation for lighting class L7a. The light source is a tubular high pressure sodium lamps of 100 W with a luminous output of 10.700 lm.

Figure B.3 shows a typical lighting installation for lighting class L7b. The light source is of the same type as for the example in figure A.2, but of 70 W and with a luminous output of 6.600 lm.

The two typical lighting installations are called examples 1 and 2 in the following. They have been copied form a note “Armaturernes evne til at opfylde kravene til statens veje”, Rev. 2, 18.01.2010, issued by ÅF - Hansen & Henneberg. The examples do not show the top performance of the most competitive luminaires, but a performance that is needed in order to take luminaires into consideration at all.

NOTE: ÅF - Hansen & Henneberg is advisor to the Danish Road Directorate in matters of road lighting and work also for other road administrations in Denmark and some of the Nordic countries.

Figures of merit are given in tables B.2 and B.3 for the two examples of lighting installations.

Table B.2: Values of figures of merit for example 1.

	Spacing	Width	Area	Minimum illuminance	Luminous flux
Carriageway	38 m	8 m	304 m^2	10,7 lx	3253 lm
Surroundings		2×3,5 m	266 m^2	3,85 lx	1024 lm
$\Phi_{minimum}$	(sum for carriageway and surroundings)				4277 lm
Φ_{actual}	(luminous flux for one 100 W lamp)				10700 lm
					Results
$\eta_{installation}$	$(\Phi_{minimum}/\Phi_{actual})$				0,40
η_{system}	(luminous flux/power of lamp and ballast)				98 lm/W
η_{total}	$(\eta_{system} \times \eta_{installation})$				39 lm/W

Table B.3: Values of figures of merit for example 2.

	Spacing	Width	Area	Minimum illuminance	Luminous flux
Carriageway	35 m	7 m	245 m^2	7,14 lx	1749 lm
Surroundings		2×3,5 m	245 m^2	3,85 lx	943 lm
$\Phi_{minimum}$	(sum for carriageway and surroundings)				2692 lm
Φ_{actual}	(luminous flux for one 100 W lamp)				6600 lm
$\eta_{installation}$	$(\Phi_{minimum}/\Phi_{actual})$				0,41
η_{system}	(luminous flux/power of lamp and ballast)				82 lm/W
η_{total}	$(\eta_{system} \times \eta_{installation})$				34 lm/W

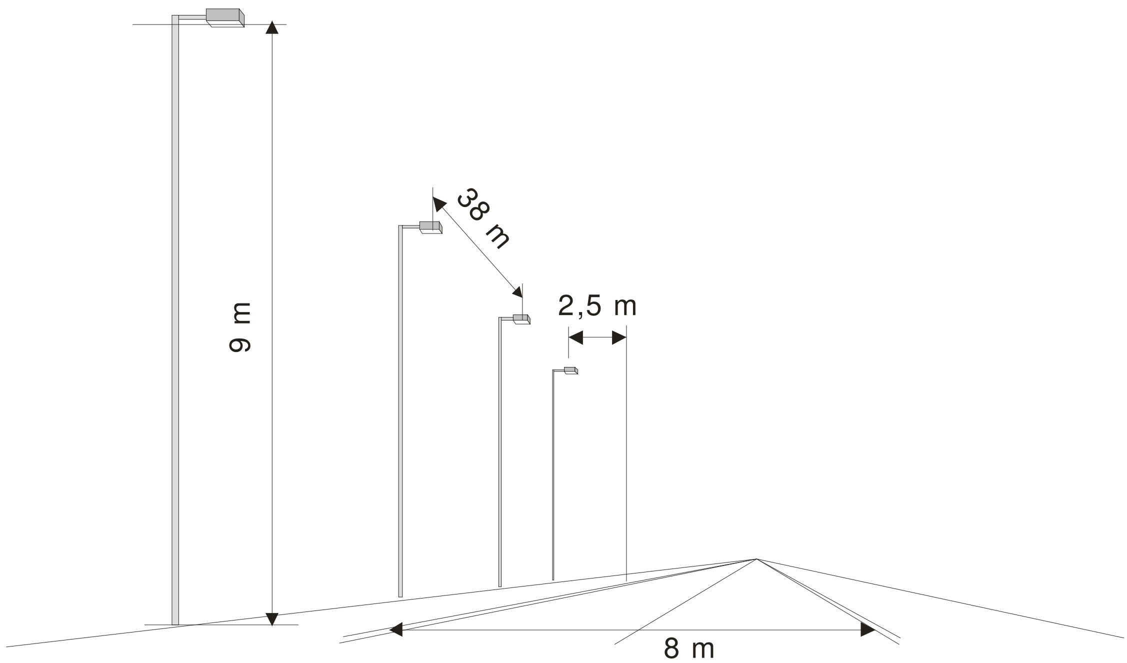

Figure B.2: Typical installation for lighting class L7a.

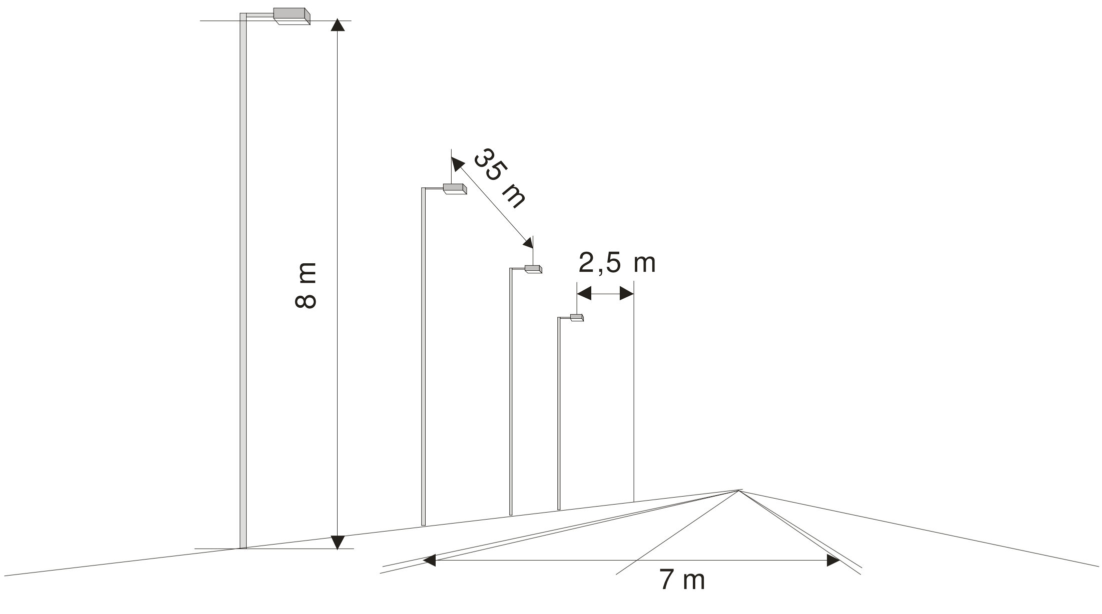

Figure B.3: Typical installation for lighting class L7b.