Lighting

Efficiency and Efficacy of Road Lighting

Nordisk Møde for Forbedret Vejudstyr

Nordisk Møde for Forbedret Vejudstyr

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of Road Lighting

Efficiency and efficacy of road lighting in the Nordic countries

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Content

1. Introduction

Energy savings for road lighting must be considered in many future projects and there are a number of methods that can be applied to obtain energy savings. These are listed in the note, *Efficiency of road lighting in the Nordic countries* [1]:

The methods are:
1. Omitting road lighting on particular roads.
2. Reducing the lighting level in general.
3. Reducing the lighting level in periods of reduced traffic intensity.
4. Improving the efficiency of the road lighting installations.

The note [1] suggests a study of road lighting installations in the Nordic countries and a comparison of the efficiency of the road lighting installations thus addressing item 4 in the list above.
The objective of this investigation is an evaluation of the method for calculation of the efficiency and efficacy through a comparison of the efficiency of the road lighting installations in four Nordic countries: Denmark, Finland, Norway and Sweden.

The method facilitates comparison of the efficiency across different requirements and installation geometries.

2. Method

As there are a large variety of road types a limitation is set for the study. Only small and medium size traffic roads are considered. A small traffic road is assumed to have an, which constitutes to average road surface luminance levels of 0.5 to 1.5 cd/m^2. Other types of roads, i.e. motorways, large traffic roads, crossings, squares, local roads etc. are not considered in this study.

Collection of information/data for the installations was conducted by contacting the road directorates in the four countries asking them to supply information on typical installation parameters for small and medium traffic roads.

The regulations for road lighting were also delivered if it was not available on the internet site of the road directorate.

From [1] the calculation model was implemented in an Excel-spread sheet and the different figures of merit were used to calculate the luminous efficiency of the lighting installation.

The regulations for road lighting of the different countries constitute the basis for selection of the lighting class for a particular road. How the selection of a lighting class for a particular road is conducted, is different in all four countries. They are in essence based on the parameters listed in EN 13201-1. The specific levels for each lighting class does somewhat follow EN 13201-2 – in some cases with alterations to uniformity, glare restrictions and some are divided into even finer groups.

For all four countries the MEW classes are used on traffic roads. There are though differences in the use of longitudinal uniformity and in the requirements for areas adjacent to the carriageway. Restrictions of disability glare is also different. These differences will be addressed in section 4.

In addition to a comparison of the efficiency and efficacy a comparison of the costs for equipment – luminaires and poles – per km and the energy consumption – luminaire and ballast - per km are included.
The cost of equipment is an estimation based on list prices from suppliers and manufacturers of luminaires and columns. Power line cables and manual labour is not included.

Applying the method one considers the illuminated areas in a cross section of the road within one luminaire spacing. In the case of a single side installation this can be considered as illuminated by the flux in one luminaire. In other cases the flux of two or more luminaires must be considered as providing the illumination of the areas within one spacing.

All the areas covered by requirements (of the lighting class) should be counted in, because our interest is to know how efficient the installation is to provide the lighting it is designed for.

3. Efficiency of road lighting

The efficiency of a road lighting installation is defined as the ratio of the minimum needed luminous flux to the actual installed luminous flux [1]:

$$\eta_{\text{installation}} = \frac{\Phi_{\text{minimum}}}{\Phi_{\text{actual}}}$$

where Φ_{minimum} is the minimum luminous flux needed to provide the minimum lighting levels required for the specified areas

and Φ_{actual} is the luminous flux actually used by the lighting installation for the illumination of the same areas.

The $\eta_{\text{installation}}$ shows the fraction of the luminous flux used to provide the illumination required by, for instance, the lighting class. It is the joint efficiency of the luminaire optics, the luminaire light distribution, the road surface reflection and the geometrical arrangement of the luminaire position towards the areas to be illuminated. It is useful to know this efficiency independently of the efficacy of the light source and its control gear, because it reveals how well the installation is designed to fit to the requirements in terms of exploiting the luminous flux.

It is though, interesting to look at the total efficacy of the installation, i.e. the ratio of the minimum needed luminous flux to the total power consumption [1]:

$$\eta_{\text{total}} = \frac{\Phi_{\text{minimum}}}{P_{\text{lamp}} + P_{\text{ballast}}} = \frac{\Phi_{\text{minimum}}}{P}$$

where Φ_{minimum} is as defined above and $P = P_{lamp} + P_{ballast}$ is the total power consumed by the light source and ballast. It is an important figure of merit to take into account as well as it gives insight to how effective the chosen luminaires and light sources are to the task at hand.

The total efficacy of a lighting installation is given by the product of the efficiency of the installation, $\eta_{installation}$, and the efficiency of the system, η_{system}:

$$\eta_{\text{total}} = \eta_{\text{system}} \times \eta_{\text{installation}}$$

where η_{system} is the lamp efficacy including control gear losses and defined as the ratio between the luminous flux from the light source and the total power consumption:

$$\eta_{\text{system}} = \frac{\Phi_{\text{actual}}}{P_{\text{lamp}} + P_{\text{ballast}}} = \frac{\Phi_{\text{actual}}}{P}$$

The unit for the joint efficacy of the installation and for the system is lumen per Watt (lm/W). The efficiency does by definition not have a unit.

The η_{total} comprises the joint efficacy of the actual lamp, the luminaire, the control gear, the lighting geometry and the road surface reflection to meet the requirements of the lighting class.[1]

3.1 Calculation of the luminous efficiency and efficacy of a lighting installation

As defined in [1] the calculation of the luminous efficiency is calculated using

- The minimum required luminous flux for the carriageway, $\Phi_{carriageway}$ (lm)
- The minimum required luminous flux for the surroundings, $\Phi_{surroundings}$ (lm)
- The actual luminous flux of the lighting installation, Φ_{actual} (lm)
- The area of the carriageway, $A_{carriageway}$ (m^2)
- The minimum required average illuminance on the carriageway, $E_{carriageway}$ (lx)
- The area of the surroundings, $A_{surroundings}$ (m^2)
- The minimum required average illuminance of the surroundings, $E_{surroundings}$ (lx)

The minimum required luminous flux to provide the illuminance, E, is defined as:

$$\Phi_{\text{minimum}} = \text{A} \times \text{E}$$

This is sufficient for areas where the requirement is based on the horizontal illuminance, as in the CE- and S-lighting classes.

For areas applying other requirement parameters the requirement has to be converted into a corresponding horizontal illuminance.

[1] The terms for describing the efficiency and efficacy used in this report are identical to the terms used in [1]. In Annex C in [9] similar, but different, terms are used. The concepts covered by the terms are the same.

The required luminance of the carriageway is converted into the illuminance on the carriageway, $E_{carriageway}$, is calculated by

$$E_{carriageway} = \frac{L}{Q}$$

where L is the required luminance of the road surface of the carriageway (cd/m^2), and Q is an average luminance coefficient of the road surface (cd/m^2/lx).

The value of L is the required luminance in the lighting class for the specific road. The value of Q is a fixed, standard value of 0.07. Fixing the average luminance coefficient at 0.07 cm/m^2/lx is based on the arguments described in [2]: Looking through the reflection table covering N1-N4, R1-R4, C1 and C2 the most common value of Q0 is 0.07 cd/m^2/lx.

The flux required for the carriageway is then:

$$\Phi_{carriageway} = A_{carriageway} \times E_{carriageway}$$

For the surroundings, i.e. the area adjacent to the carriageway, the value of the illumination can be specified directly as

$$E_{surroundings}$$

If the requirement for the adjacent area is based on the horizontal illuminance.

If the specification is given by means of the average hemispherical illumination, E_{hs}, the value of $E_{surroundings}$ is estimated as:

$$E_{surrounding}= \frac{E_{hs}}{0.65}$$

For the case that the area adjacent to the carriageway is defined as SR, surround ratio, the $E_{surroundings}$ is ½ of the illuminance of the nearby carriageway:

$$E_{surroundings}= \frac{E_{carriageway}}{2} = \frac{L}{2 \times 0.07}$$

If this is not the case, it must be estimated otherwise.

The minimum luminous flux needed is then the sum of the flux from the carriage-way and the surroundings:

$$\phi_{minimum} = \phi_{carriageway} + \phi_{surroundings}$$

The actual luminous flux, Φ_{actual}, is the sum of the luminous flux values of the light sources in the lighting installation. If the road and the lighting installation have uniform cross section of the areas illuminated with identical luminaires, the value can be calculated for the average luminaire spacing. That is, the length of the area is set to the pole spacing (on one side) and Φ_{actual} is set to the nominal luminous flux of the light sources per spacing, i.e. for single sided installations normally one single light source.

The efficiency of a lighting installation is then the ratio of Φ_{minimum} to Φ_{actual}:

$$\eta_{\mathrm{installation}} = \frac{\Phi_{\mathrm{minimum}}}{\Phi_{\mathrm{actual}}}$$

The efficacy of the lighting installation is calculated as described in the section above.

3.2 Calculation of energy consumption per km

Calculation of energy consumption per km of a lighting installation is calculated as the product of the total power, $P_{KM} = P_{lamp} + P_{ballast}$, and the number of energy consuming units per km:

$$P_{KM} = P_{total} \times \frac{1000\ \mathrm{m}}{D_{poles}}$$

where $P_{total} = P_{lamp} + P_{ballast}$ and D_{poles} = distance between light points.

4. Lighting classes in the Nordic countries

As indicated above each country has its own implementation of EN 13201-2:2003. This paragraph will cover how they are implemented for the traffic road in question. A complete coverage of implementation on all the road and lighting classes is considered to lie outside the scope of this report.

Lighting class

In general the Nordic countries have implemented the MEW-classes listed in EN 13201-2:2003 as it is. Denmark has used an option all ways to have a requirement for the area adjacent to the carriageway and the size of the area is defined as 3.5 meter. EN 13201-2:2003 specifies the surround ratio as the standard option when there is no other traffic area with its own requirement. Further Denmark has tighter restrictions on disability glare than the standard.

The following table includes the deviations in performance requirements.

All text in **bold** differs from EN 13201-2:2003

DENMARK

EN 13201-2:2003 class name		Luminance of the road surface of the carriageway for the dry and wet road surface condition				Disability glare	Lighting of surroundings
		Dry conditions			Wet		
		$\bar{L}$ in cd/m² [minimum]	U_0 [minimum]	U_l [minimum]	U_0 [minimum]	*TI* in %	Strip of 3,5 meter adjacent to carriageway[2]
Motorway	MEW 1	2.00	0.4	0.6	0.15	**6.1**	**5.0 lx**
	MEW 2	1.50	0.4	0.6	0.15	**6.5**	**5.0 lx**
	MEW 3	1.00	0.4	0.6	0.15	**6.8**	**2.5 lx**
Traffic road	MEW 1	2.00	0.4	**0.3**	0.15	**6.1**	**5.0 lx**
	MEW 2	1.50	0.4	**0.3**	0.15	**6.5**	**5.0 lx**
	MEW 3	1.00	0.4	**0.3**	0.15	**6.8**	**2.5 lx**
	MEW 4	0.75	0.4	**0.3**	0.15	**7.0**	**2.5 lx**
	MEW 5	0.50	**0.4**	**0.3**	0.15	**7.0**	**2.5 lx**

E - class name	Hemispherical illuminance	
	$\bar{E}$ in lx [minimum]	Uniformity
E1	5	0.15
E2	2.5	0.15
E3	1	0.15
E4	-	-

The E-class applies to areas adjacent to carriageways, local roads, paths, parking lots etc. It is similar to the A-class in EN 13201-2:2003.

FINLAND

EN 13201-2:2003 class name	Luminance of the road surface of the carriageway for the dry and wet road surface condition				Disability glare	Lighting of surroundings
	Dry conditions			Wet		
	$\bar{L}$ in cd/m² [minimum]	U_0 [minimum]	U_l [minimum]	U_0 [minimum]	*TI* in %	SR [minimum]
MEW 1	2,00	0.4	0.6	0.15	10	0.5
MEW 2	1.50	0.4	0.6	0.15	10	0.5
MEW 3	1.00	0.4	0.6	0.15	15	0.5
MEW 3	1.00	0.4	**0.4**	0.15	15	0.5
MEW 4	0.75	0.4	**0.4**	0.15	15	0.5
MEW 5	0.50	**0.4**	**0.4**	0.15	15	0.5

[2] Measured as minimum average hemispherical illuminance, $\bar{E}_{hs}$, which is similar to the A-series lighting class from EN 13201-2.

EN 13201-2:2003 class name	**Horizontal illuminance**	
	$\bar{E}$ in lx [minimum]	$E_{minimum}$ in lx [maintained]
S1	15	5
S2	10	3
S3	7.5	1.5
S4	5	1
S4	3	0.6
S6	2	0.6

NORWAY

EN 13201-2:2003 class name	**Luminance of the road surface of the carriage-way for the dry and wet road surface condition**				**Disability glare**	**Lighting of surroundings**
	Dry conditions			Wet		
	$\bar{L}$ in cd/m² [minimum]	U_0 [mini-mum]	U_l [mini-mum]	$\mathbf{U_0}$* [mini-mum]	*TI* in %	SR [minimum]
MEW 1	2.00	0.40	0.6	0.15	10▲	0.5
MEW 2	1.50	0.40	0.6	0.15	10▲	0.5
MEW 3	1.00	0.40	0.6	0.15	15▲	0.5
MEW 4	0.75	0.40	-	0.15	15	0.5
MEW 5	0.50	0.35	-	0.15	15	0.5

* The requirement is under the assumption of the use of surface type W4. If W3 is used instead the requirement is $U_0 \geq 0.20$.
▲ In regular dark surroundings ⅔ of the TI-value should not be exceeded.

EN 13201-2:2003 class name	**Horizontal illuminance**	
	$\bar{E}$ in lx [minimum]	$E_{minimum}$ in lx [maintained]
S1	15	5
S2	10	3
S3	7.5	1.5
S4	5	1
S4	3	0.6
S6	2	0.6

SWEDEN

EN 13201-2:2003 class name	**Luminance of the road surface of the carriage-way for the dry and wet road surface condition**				**Disability glare**	**Lighting of surroundings**
	Dry conditions			Wet		
	$\bar{L}$ in cd/m² [minimum]	U_0 [mini-mum]	U_l [mini-mum]	U_0* [mini-mum]	*TI* in %	SR [minimum]
MEW 1	2.00	0.40	0.6	0.15	10	0.5
MEW 2	1.50	0.40	0.6	0.15	10	0.5
MEW 3	1.00	0.40	0.6	0.15	15	0.5
MEW 4	0.75	0.40	-	0.15	15	0.5
MEW 5	0.50	**0.40**	-	0.15	15	0.5

EN 13201-2:2003 class name	Horizontal illuminance	
	$\overline{E}$ in lx [minimum]	$E_{minimum}$ in lx [maintained]
S1	15	5
S2	10	3
S3	7.5	1.5
S4	5	1
S4	3	0.6
S6	2	0.6

Selection of lighting class

In all the four countries the selection of lighting class is determined by the type of road, the type of traffic that it supports the geometry of the carriageway and on the speed limit on the carriageway.

In Denmark selection of lighting class is based on the geometry of the road (the number of lanes), on the width of a central median if present, and on the type of traffic, i.e. are there pedestrian and/or cyclists on the carriageway or do they have their own traffic area.

The Finnish regulations are similar to the Danish regulation in the sense that it states that the selection of lighting class is based on the speed limit and on whether or not cyclist and pedestrians are present on the carriageway.

In Norway and Sweden the lighting class is determined by the annual average daily traffic (AADT) and on the geometry of the road.

5. Data

5.1 Standard installation properties

In order to compare the installed road lighting equipment a request on a standard installation on two types of traffic roads was issued to the department of operation at the road directorates in Denmark, Finland, Norway and Sweden. The two types of road were a small and a medium size traffic road.
A small size road is characterised as a road with a speed limit of approximately 50 km/h having one carriageway in each direction. The traffic load is up to 12,000 (measured as AADT).
A medium size road is characterised as a road with a speed limit of approximately 70 km/h. The traffic load is 12,000 or higher (measured as AADT).

It is further more assumed that both the small and medium size roads have a bicycle path and pedestrian areas on each side of the carriageway, thus the surroundings are the two bicycle path and pedestrian area.

As there are different traditions and principles of setting up requirements and solutions, the data have different structures depending on which country they were received from. For both types of road the following parameters are listed:

- Pole spacing
- Light point height
- Width of carriageway
- Width of surroundings
- Luminaire power consumption (lamp and ballast)
- Lighting class including carriageway and surroundings.

Data from the four countries are as follows:

DENMARK

The data used in this table are found in [1] and in the document *Template for evaluation of luminaires* [3] where they represents typical figures of merit for road lighting installations in Denmark used by the Danish Road Directorate.

Type of road	Pole spacing	Light point height	Width of carriageway	Width of surroundings	Luminaire power con-sumption	Lighting class
Small	35 m	8.0 m	7.0 m	2 × 3.5 m	79 W	MEW 5 + E2
Medium	38 m	9.0 m	8.0 m	2 × 3.5 m	109 W	MEW 4 + E2

The r-table used to achieve these figures is:

r-table		Q_0	Q_d
Dry	N2 (DK)	0.090 cd/m^2/lx	0.078 cd/m^2/lx
Wet	W4 (DK)	-	-

The geometry of roads are in both situations single carriageways with a bicycle path and pedestrian area on each side of the carriageway.

FINLAND

The data used in the table below is a compilation from the report *Maanteillä käytettävät valaisimet (On the roads used for lighting)* [4] which were received from Pentti Hautala from Sito Oy. The report documents different solutions for road lighting installations on four different road geometries as to light point height and with different requirements as to the lighting class.

Figures of merit representing a typical solution have been compiled from the data in this report as shown in Appendix C.

The pole spacings are averages for each light point height. As seen in Appendix C the standard deviation of pole spacings are low, so the average pole spacing can be regarded as typical.

With a road of similar geometry then according to [4] the lighting class used for a small traffic road is AL4b (MEW4). For a medium traffic road the lighting class used is AL3 (MEW3, with longitudinal uniformity of 0.6).

From [4] and [5] it is given that an installation which fulfils lighting class AL3 is a double row installation, that is, one luminaire for one direction. For an installation which fulfils lighting class AL4b a single row installation is used.

Type of road	Pole spacing	Light point height	Width of carriageway	Width of surroundings	Luminaire power consumption	Lighting class
Small	50.6 m	10.0 m	7.0 m	2 × 3.5 m	150 W	MEW 4 + S6
Medium	54.7 m	12.0 m	2 × 7.5 m*	2×3.5 m + 2×3.25 m*	250 W	MEW 3 + S4
	65.6 m	15.0 m	2 × 7.5 m*	2×3.5 m + 2×3.25 m*	250 W	MEW 3 + S4

*) The medium roads have a central median of 6.5 m regarded as a part of the surroundings.

The r-table used to achieve these figures is:

r-table		Q_0	Q_d
Dry	R2	0.070 cd/m^2/lx	0.057 cd/m^2/lx
Wet	W3	-	-

The geometry of roads is a single carriageway for the small traffic road, and a dual carriageway for the medium traffic road. It is assumed that there is a bicycle path and pedestrian area on each side of the carriageway for both types of road.

NORWAY
Data regarding typical light sources and pole spacing was received from Per Ole Warvik, Statens Veivesen, and the Håndbok 264 [6] was used to determine width of carriageway and surroundings.

Type of road	Pole spacing	Light point height	Width of carriageway	Width of surroundings	Luminaire power consumption	Lighting class
Small	22.5 m	6.0 m	7.0 m	2 × 3.5 m	100 W	MEW 3 + S4
	32.5 m	8.0 m	7.0 m	2 × 3.5 m	150 W	MEW 3 + S4
Medium	40.0 m	10.0 m	8.5 m	2 × 3.5 m	250 W	MEW 2 + S2

The r-table used to achieve these figures is:

r-table		Q_0	Q_d
Dry	C2	0.070 cd/m^2/lx	0.054 cd/m^2/lx
Wet	W3	-	-

The geometry of roads is in both situations single carriageways with a bicycle path and pedestrian area on each side of the carriageway.

SWEDEN
All data on typical light sources, pole heights and spacing were delivered by Petter Hafdell, Trafikverket. The width of carriageway and surroundings was determined using [7].

Type of road	Pole spacing	Light point height	Width of carriageway	Width of surroundings	Luminaire power consumption	Lighting class
Small	30 m	8.0 m	7.0 m	2 × 3.5 m	150 W	MEW 5 + S2
Medium	35 m	10.0 m	2 × 7.5 m	2 × 3.5 m	100 W	MEW 4 + S2

The r-table assumed used to achieve these figures is:

Type of road	r-table		Q_0	Q_d
Small	Dry	N1[1]	0.100 cd/m2/lx	0.090 cd/m2/lx
	Wet	W3	-	-
Medium	Dry	N2[1]	0.080 cd/m^2/lx	0.070 cd/m^2/lx
	Wet	W3	-	-

The geometry of roads is a single carriageway for the small traffic road, and a dual carriageway for the medium traffic road. It is assumed that there is a bicycle path and pedestrian area on each side of the carriageway for both types of road.

5.2 Product data

Light sources

Data on the light source, light flux and energy consumption is based on Philips SON-T light sources. The properties of light sources from other manufactures are almost identical with regards to the luminous flux.

LUMINOUS FLUX	
Wattage	Philips SON-T
70 W	6,600 lm
100 W	10,700 lm
150 W	18,000 lm
250 W	33,300 lm

[1] Values for N1 and N2 are listed in [7]

Luminaires and poles

For comparison of installation costs the data is based on list prices from DanIntra regarding poles and Philips' Copenhagen regarding luminaire.

POLES DanIntra – passive safe steel pole	
Height	Price
6 m	€ 700
8 m	€ 790
9 m	€ 845
10 m	€ 990
12 m	€ 1,320
15 m	€ 1,685

LUMINAIRES Philips Copenhagen	
Wattage	Price
70 W	€ 425
100 W	€ 540
150 W	€ 540
250 W	€ 725

The 15 m pole is not a passive safe steel pole in contrast to the others.

6. Comparison

6.1 Efficiency and efficacy

The luminous efficiency of the installations is calculated based on the principles described in section 3.1 and the data listed in the previous section are used for this calculation. Detailed calculations can be found in Appendix A. The figures below show the result of the calculations.

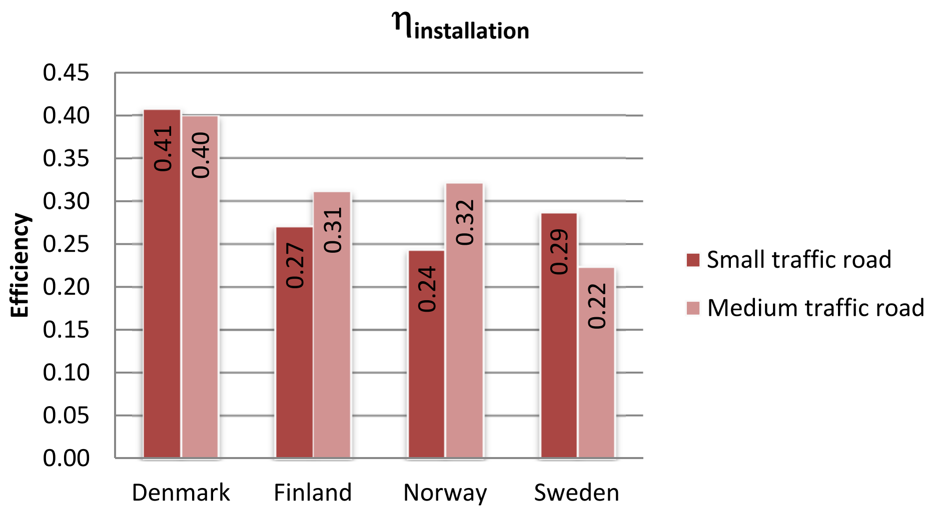

Figure 6.1 Installation efficiency of typical road lighting installations in four Nordic countries.

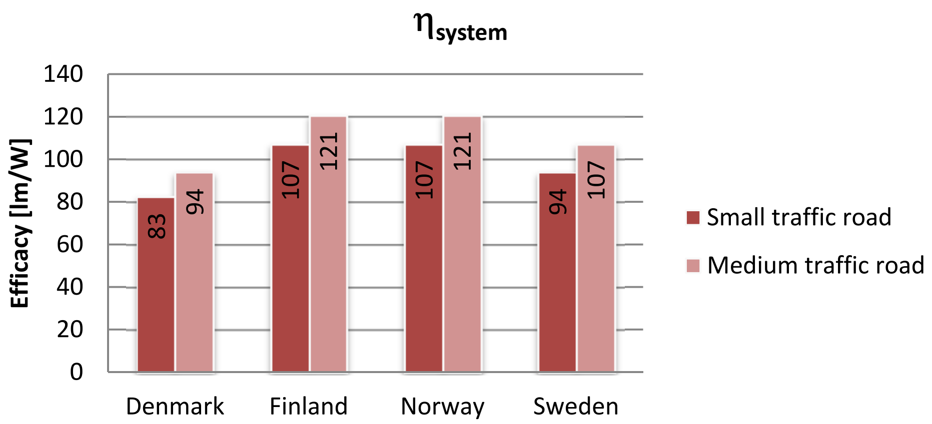

Figure 6.2 System efficacy [lm/W] of typical road lighting installations in four Nordic countries.

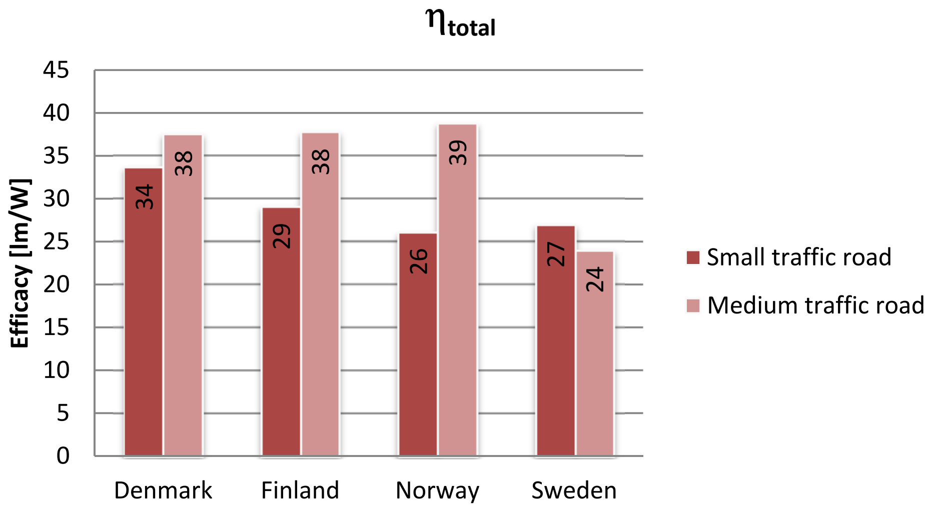

Figure 6.3 Total efficacy of typical road lighting installations in four Nordic countries.

6.2 Costs of lighting equipment

The cost of luminaires and poles per km is calculated by using the information on the pole spacing given in section 5.1 and the information on the list price of poles and luminaires given in section 5.2.
The comparison does not include manual labour work for the installation, power line cable or road cupboards.

The figure below lists the results of the calculations

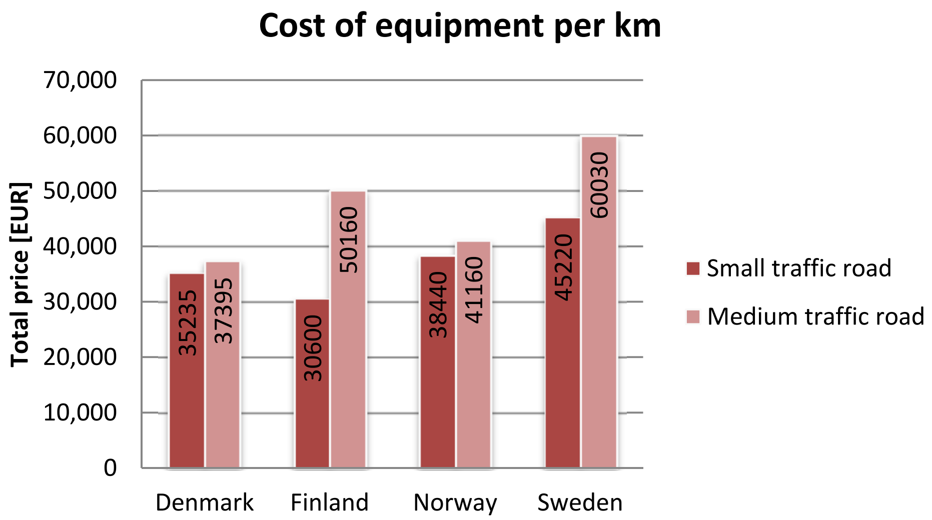

Figure 6.4 Costs of poles and luminaires per km.

6.3 Energy consumption per km

The total energy consumption per km is calculated by using the information on the pole spacing and energy consumption of each light point given in section 5.1.

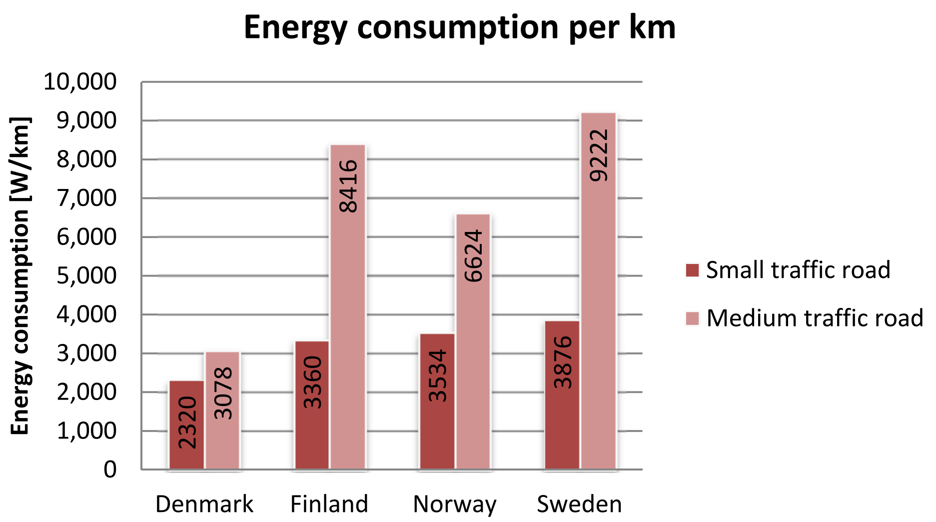

Figure 6.5 Costs of poles and luminaires per km.

7. Discussion

In section 6.1 the results from the calculations of the efficacy and efficiency of the road lighting installations are presented in Figure 6.1, 6.2 and 6.3.

The comparison of efficiency and efficacy is based only on the technical data. It does not take into account the national and cultural preferences that might exist in each of the four countries.

The efficiencies and efficacies do not differ much from each other even though the requirements, the road geometries and the selected solutions are different from each other. Generally the lighting installations on medium traffic roads tend to be a little more efficient than lighting installations on small traffic roads.

The main differences are seen in the efficiency, $\eta_{installation}$, and the system efficacy, η_{system}. So the differences in $\eta_{installation}$ and η_{system} tend balance each other in total efficacy.

7.1 The efficiency of the installations

As illustrated in Figure 6.1 the figures do not differ greatly. What can be found is that the installations in Denmark have the most efficient use of the chosen light source for fulfilment of the required lighting class.

A possible explanation for this is the use of a tarmac with a high ratio of light aggregates. This is seen in the high luminance coefficient, Q_0. The combination of a high Q_0, efficient light distributions and adjustment of the light point height to the area result in a high efficiency (just as expected).

It should be noted that the geometries in the Finnish and Swedish lighting installations on medium traffic roads are based on “double sided” installations. These types of installation will benefit from the combined luminous flux from the two luminaires reducing the needed power to fulfil the required lighting class.

The low efficiency of the Swedish installation on medium roads may have a number of reasons, which requires further analysis to explain. It does however lie outside the scope of this report.

7.2 The efficacy of the installations

η_{system}

Both on small and medium traffic roads the Finnish and the Norwegian lamp systems are the most efficient. This is caused by the fact that the high wattage lamps, 150 W – 400 W (HPS and metal halide), are more efficient compared to the low wattage lamps – 50 W – 100 W (HPS and metal halide). In Denmark it is customary to use 70 W and 100 W lamps for lighting small and medium traffic roads. Their efficacy is lower and counters the installation efficiency

η_{total}

This figure is a direct measure of how well the power that goes into the luminaire is transformed to light on the road according to the requirement.

From Figure 6.3 it can be found that the lighting installations on medium traffic roads have a higher total efficacy compared to the total efficacy for small traffic roads. This is achieved by using high light point heights combined with large spacing between the poles so light sources of high flux and high efficacy can be used. This is clearly seen for the installations in Finland and Norway and it is a combination of efficient installations and the use of high wattage light sources, which have a high luminous efficacy.

The efficacy of the Danish medium traffic road is almost at the same level despite a lower η_{system}. This is caused by the high $\eta_{installation}$.

7.3 Cost of lighting equipment

The general trend is the same as for the efficiency and efficacy with one exception: small traffic road in Finland.

The use of long spacing obvious leads to a lower cost of equipment than seen for other similar installations.

The high cost of the equipment on medium roads in Finland is caused by the use of high light point height. The cost of the pole for 15 meter light point height is twice the price of the 9 meter, but the spacing is not twice the spacing of the three other installation types.

The cost of equipment is relatively higher in Sweden compared to the three other countries which can be explained by the use of shorter pole spacing.

7.4 Energy consumption per km

Figure 6.5 shows the actual cost in terms of energy for the lighting of comparable road types in the four countries.

This reveals differences which are not related to the efficiencies of the road lighting but are related to traffic demands and national preferences.

When the energy cost in Norway is high, the reason is predominantly the use of a higher lighting class MEW2 than used in the other countries.

When the energy costs in Finland and Sweden are high, the reason is predominantly the use of double carriageway for the medium traffic roads, where the other two countries use only a single carriageway for this type of road.

The comparison shows that having high requirements to the lighting class is costly. Illuminating wide areas using double sided installations is also costly. Such effects are not addressed by the energy efficiency method, but neither intended.

8. Conclusion

The installation efficiency, the system efficacy (of the light source - control gear system) and the installation efficacy are useful tools for analysing the performance of road lighting installations in terms of the use of luminous flux.

The method of summing up the fluxes needed for the different areas of the road cross profile as explained in section 3.1 seems to work well, making it possible to compare installations designed for different sets of requirements in terms of luminous efficiency.

For revealing the actual cost of energy simpler parameters as the energy consumption per km or energy consumption per m^2 can be applied.

The analysis using the method indicates the benefit of taking a range of initiatives to increase the efficiency. The parameters that need attention are such as luminaires with high luminous efficacy, adjusting the optics to the road geometry, adjusting the light point height and pole spacing, and using a tarmac with a high ratio of light aggregates (high Q_0).

From the analysis using the method it is also possible to identify some of the causes of the found efficiency and efficacies.

On the other hand the efficiency methods as presented here are not able to account the gain of visibility by tighter restrictions on disability glare. This could be a subject for further development.

Other important aspects as the pole height compared to the height of surrounding buildings or trees and visual appearance of the installation cannot be addressed directly by the methods. In the same manner with architectural and cultural preferences they cannot be addressed by the method. However the cost of weighting such aspects can be analysed.

The analysis is based on high pressure sodium light sources which have the property that as the wattage of the light source increase, the efficiency increase. In the future it seems likely that LED will be the dominant choice of light source and the efficiency of the LED is the same regardless of the wattage. This will influence the system efficacy and thus the total efficacy favouring low wattage solutions. The outcome will be that the total efficiency will follow the trends of the installation efficiency.

9. Literature

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[2] K. Sørensen, *Annex A: Performance characteristics of road lighting*, 2012

[3] P. Øbro and T.N. Andersen, *Template for evaluation for luminaires*, ÅF – Hansen & Henneberg for the Danish Road Directorate, 2009

[4] Liikennevirasto, *Maanteillä käytettävät valaisimet*, *Tievalaistus/sähkö-tiedote nro 7D*, 2011

[5] Tiehallinto, *Tievalaistuksen suunnittelu*, 2006

[6] Statens Veivesen, *Teknisk planlegging av veg- og gatebelysning – Håndbok 264*, 2008

[7] Vägverket, *Vägar och gators utformning, Väg- och gatubelysning*, 2004

[8] CIE 144:2001, *Road Surface and Road Marking Reflection Characteristics*, 2001

[9] prEN13201-6:2012, *Road Lighting – Part 5: Energy Performance in Road Lighting*, 2012

[2] See Section 10.4 – Appendix C

10. Appendix

10.1 Appendix A - Calculations of efficiency and efficacy of road lighting installations

In order to illustrate how the calculations are conducted the principles that are described in section 3.1 will implemented using an example:

Example

Installation		
Pole spacing	38 m	
Light point height	8.0 m	
Lamp power	100 W	
Ballast power	14 W	

Geometry	**Carriageway**	**Surroundings**
Requirement	0.75 cd/m^2	2.5 lx
Width	7.0 m	7.0 m
Area	38 m × 8 m = 304 m^2	38 m × 7 m = 266 m^2
Minimum illuminance	$\frac{0.5\ \mathrm{cd/m^2}}{0.070\ \mathrm{cd/m^2/lx}} = 10.71$ lx	$\frac{2.5\ \mathrm{lx}}{0.65} = 3.85$ lx
Luminous flux	10.71 lx × 304 m^2 = 3,257 lm	3.85 lx × 266 m^2 = 1,023 lm
$\Phi_{minimum}$	$\Phi_{carriageway} + \Phi_{surroundings}$ = 3,257 lm + 1,023 lm = 4,280 lm	
Φ_{actual}	10,700 lm	
$\eta_{installation}$	4,280 lm / 10,700 lm = 0.41	
η_{system}	10,700 lm / (100W + 14W) = 82.50 lm/W	
η_{total}	0.41 × 82.50 lm/W = 33.65 lm/W	

In the following the results including all required detailed calculations are listed in the tables below for calculation of the efficiency and efficacy for each of the road geometries in the four Nordic countries.

Denmark

Small traffic roads		
Installation		
Pole spacing	35 m	
Light point height	8.0 m	
Lamp power	70 W	
Ballast power	10 W	

Geometry	Carriageway	Surroundings [5]
Requirement	0.5 cd/m²	2.5 lx
Width	7.0 m	7.0 m
Area	245 m²	245 m²
Minimum illuminance	7.14 lx	3.85 lx
Luminous flux	1,750 lm	942 lm
$\Phi_{minimum}$	2,692 lm	
Φ_{actual}	6,600 lm	
$\eta_{installation}$	0.41	
η_{system}	82.50 lm/W	
η_{total}	33.65 lm/W	

Medium traffic roads		
Installation		
Pole spacing	38 m	
Light point height	9.0 m	
Lamp power	100 W	
Ballast power	14 W	

Geometry	Carriageway	Surroundings [5]
Requirement	0.75 cd/m²	2,5 lx
Width	8.0 m	7.0 m
Area	304 m²	266 m²
Minimum illuminance	10.71 lx	3.85 lx
Luminous flux	3257 lm	1023 lm
$\Phi_{minimum}$	4280 lm	
Φ_{actual}	10,700 lm	
$\eta_{installation}$	0.40	
η_{system}	93.86 lm/W	
η_{total}	37.55 lm/W	

[5] The requirement is for average hemispherical illumination, $E_{hs,\,avg}$.

Finland

Small traffic roads		
Installation		
Pole spacing	50.6 m	
Light point height	10.0 m	
Lamp power	150 W	
Ballast power	18 W	

Geometry	Carriageway	Surroundings [6]
Requirement	0.75 cd/m^2	2.0 lx
Width	10.0 m	7.0 m
Area	354 m2	354 m2
Minimum illuminance	10.71 lx	3.08 lx
Luminous flux	3,795 lm	1,090 lm
$\Phi_{minimum}$	4,885 lm	
Φ_{actual}	18,000 lm	
$\eta_{installation}$	0.27	
η_{system}	107.14 lm/W	
η_{total}	29.08 lm/W	

Medium traffic roads – 12 m LPH		
Installation		
Pole spacing	54.7 m	
Light point height	12.0 m	
Lamp power	250 W	
Ballast power	26 W	

Geometry	Carriageway	Surroundings [6]
Requirement	1.0 cd/m^2	5.0 lx
Width	2× 7.5 m	4× 3.5 m
Area	821 m^2	821 m^2
Minimum illuminance	14.29 lx	7.69 lx
Luminous flux	11,721 lm	6,312 lm
$\Phi_{minimum}$	18,033 lm	
Φ_{actual}	66,600 lm	
$\eta_{installation}$	0.27	
η_{system}	120.65 lm/W	
η_{total}	32.67 lm/W	

[6] The requirement is for average horisontal illumination, $E_{horisontal, avg}$.

Medium traffic roads – 15 m LPH		
Installation		
Pole spacing	65.5 m	
Light point height	15.0 m	
Lamp power	250 W	
Ballast power	26 W	

Geometry	Carriageway	Surroundings [6]
Requirement	1.0 cd/m^2	5.0 lx
Width	2× 7.5 m	4× 3.5 m
Area	983 m^2	983 m^2
Minimum illuminance	14.29 lx	7.69 lx
Luminous flux	14,036 lm	7,558 lm
$\Phi_{minimum}$	21,593 lm	
Φ_{actual}	66,600 lm	
$\eta_{installation}$	0.32	
η_{system}	120.65 lm/W	
η_{total}	39.12 lm/W	

Norway

Small traffic roads – 6.0 m LPH		
Installation		
Pole spacing	22.5 m	
Light point height	6.0 m	
Lamp power	100 W	
Ballast power	14 W	

Geometry	Carriageway	Surroundings [6]
Requirement	1.0 cd/m^2	5 lx
Width	2× 3.5 m	2× 3.5 m
Area	158 m2	158 m2
Minimum illuminance	14.29 lx	5.0 lx
Luminous flux	2,250 lm	788 lm
$\Phi_{minimum}$	3,038 lm	
Φ_{actual}	10,700 lm	
$\eta_{installation}$	0.28	
η_{system}	93.86 lm/W	
η_{total}	26.64 lm/W	

Small traffic roads – 8 m LPH		
Installation		
Pole spacing	32.5 m	
Light point height	8.0 m	
Lamp power	150 W	
Ballast power	18 W	

Geometry	Carriageway	Surroundings [6]
Requirement	1.0 cd/m^2	5 lx
Width	2× 3.5 m	2× 3.5 m
Area	228 m^2	228 m^2
Minimum illuminance	14.3 lx	5.0 lx
Luminous flux	3,250 lm	1138 lm
$\Phi_{minimum}$	4,388 lm	
Φ_{actual}	18,000 lm	
$\eta_{installation}$	0.24	
η_{system}	107.14 lm/W	
η_{total}	26.12 lm/W	

Medium traffic roads – 10 m LPH		
Installation		
Pole spacing	42.5 m	
Light point height	10.0 m	
Lamp power	250 W	
Ballast power	26 W	

Geometry	Carriageway	Surroundings [6]
Requirement	1.5 cd/m^2	10.0 lx
Width	8.5 m	7.0 m
Area	361 m^2	298 m^2
Minimum illuminance	21.43 lx	10.0 lx
Luminous flux	7,741 lm	2,975 lm
$\Phi_{minimum}$	10,716 lm	
Φ_{actual}	33,300 lm	
$\eta_{installation}$	0.32	
η_{system}	120.65 lm/W	
η_{total}	38.83 lm/W	

Sweden

Small traffic roads		
Installation		
Pole spacing	30 m	
Light point height	8.0 m	
Lamp power	100 W	
Ballast power	14 W	

Geometry	Carriageway	Surroundings [5]
Requirement	0.5 cd/m^2	7.5 lx
Width	2× 3.5 m	2× 3.5 m
Area	210 m^2	210 m^2
Minimum illuminance	7.14 lx	7.5 lx
Luminous flux	1.500 lm	1,575 lm
$\Phi_{minimum}$	3,075 lm	
Φ_{actual}	10,700 lm	
$\eta_{installation}$	0.29	
η_{system}	93.86 lm/W	
η_{total}	26.97 lm/W	

Medium traffic roads		
Installation		
Pole spacing	35 m	
Light point height	10.0 m	
Lamp power	150 W	
Ballast power	18 W	

Geometry	Carriageway	Surroundings [6]
Requirement	0.75 cd/m^2	10 lx
Width	4× 3.75 m	2× 3.5 m
Area	525 m^2	245 m^2
Minimum illuminance	10.71 lx	10 lx
Luminous flux	5,625 lm	2,450 lm
$\Phi_{minimum}$	8,075 lm	
Φ_{actual}	36,000 lm	
$\eta_{installation}$	0.22	
η_{system}	107.14 lm/W	
η_{total}	24.03 lm/W	

The calculated efficiencies and efficacies are gathered and listed in a table for small traffic roads and medium traffic roads below.

Comparisons by table

Small traffic road			
Country	**$\eta_{installation}$**	**η_{system} [lm/W]**	**η_{total} [lm/W]**
Denmark	0.41	82.50	33.65
Finland	0.27	107.14	29.08
Norway	0.24	107.14	26.12
Sweden	0.29	93.86	26.97

Table A.1 Efficiency and efficacy of road lighting installations on small traffic roads in four Nordic countries.

Medium traffic road			
Country	**$\eta_{installation}$**	**η_{system} [lm/W]**	**η_{total} [lm/W]**
Denmark	0.40	93.86	37.55
Finland	0.32	120.65	39.12
Norway	0.32	120.65	38.83
Sweden	0.22	107.14	24.03

Table A.2 Efficiency and efficacy of road lighting installations on medium traffic roads in four Nordic countries.

10.2 Appendix B – Calculation of costs of equipment

Using the list prices from section 5.2 the cost of luminaires and poles are calculated as a

$$\text{Total price} = \text{Price}_{\text{luminaire}} \times \text{Price}_{\text{Pole}} \times \text{Number of poles per km}$$

The cost is listed in the tables below.

Cost of luminaires and poles per km

Small traffic road				
Country	**Light point height**	**Wattage**	**Number of poles per km**	**Total price per km**
Denmark	8 m	70 W	29	€ 35,235
Finland	10 m	150 W	20	€ 30,600
Norway	6 m	100 W	31	€ 38,440
Sweden	8 m	100 W	34	€ 45,220

Table 6.3 Average costs of installation per km on small traffic roads in four Nordic countries.

Medium traffic road				
Country	**Light point height**	**Wattage**	**Number of poles per km**	**Total price per km**
Denmark	9 m	100 W	27	€ 37,395
Finland	15 m	250 W	16	€ 38,560
Norway	10 m	250 W	24	€ 41,160
Sweden	10 m	150 W	29	€ 44,370

Table 6.4 Average costs of installation per km on medium traffic roads in four Nordic countries.

10.3 Appendix C – Values for calculation of spacing of pole in Finland

The data on luminaires, position, wattage, photometric file and pole spacing is found in [4]. The calculation of the mean and standard deviation is calculated for this report.

Luminaire fulfilling lighting class AL3 with 15 meter light point height

Luminaires – position, light source wattage and pole spacing				
Luminaire	Position	Wattage	Photometric file	Spacing
Lunalys	Pos3	ST-250S	Lunalys-HST250-Pos3-904.LDT	62 m
Arc 90, tl	1D	ST-250S	INR6287.LDT	67 m
Arc 90, k	3D	ST-250S	INR5078.LDT	67 m
CitySoul CGP431, k	P4	ST-250S	Philips Database 01042010	65 m
CitySoul CGP431, tl	P4X	ST-250S	Philips Database 01042010	65 m
Iridium SGS254 GB	P5	ST-250S	Philips Database 06052009	70 m
Iridium SGS254 FG	P6	ST-250S	Philips Database 06052009	67 m
Koffer2 SGP100 GB	P4	ST-250S	Philips Database 06052009	70 m
Koffer2 SGP100 FG	P5	ST-250S	Philips Database 06052009	69 m
611HGV AC TP	LP 15	ST-250S	Philips Database 06052009	64 m
611 HGV FG TP	LP 15	ST-250S	Philips Database 06052009	65 m
614 HGV AC TP	-	ST-250S	614HGV AC TP 1xSONTPP250W.ies	72 m
SGP340 FG	TP P4	ST-250S	Philips Database 06052009	63 m
SGP340 PC	TP P4	ST-250S	Philips Database 06052009	64 m
Ambar 3, k	33/114	ST-250S	270433	61 m
Ambar 3, tl	33/114	ST-250S	270424	61 m
SC 100, k	LP3 RP2	ST-250S	...E1ST0B_1xHST_250W_38078.ldt	69 m
SC 100, tl	LP3 RP2	ST-250S	...E1ST0F_1xHST_250W_38070.ldt	65 m
SQ 200	LP 2 RP2	ST-250S	...TT0C236_1xHST_400W_35634.ldt	73 m
SR 200	LP 40 RP 2	ST-250S	...E1ST01_1xHST_250W_35716.ldt	65 m
Mistral	-	ST-250S	9101G05S_Mistral 250W SON.LDT	58 m
Civic 2, tl	V4L7	ST-250S	96009812 --HST V4L7.LDT	61 m
Civic 2, k	V1L5	ST-250S	96009813 --HST V1L5.LDT	70 m
Dyana2	V-4L4	ST-250S	96251360--HST V-4L4.IES	57 m
Decostreet2	V6L4A	ST-250S	96002385--HST V6L4A.IES	65 m
Oracle 2W, tl	V6L4	ST-250S	96220570--V6L4 HST-MF.LDT	69 m
Oracle 2W, lk	V8L4	ST-250S	96220571--V8L4 HST-MF.LDT	66 m

Mean values and standard deaviations	
Mean pole distance	65.6 m
Standard deviation	3.9 m

Luminaire fulfilling lighting class AL3 with 12 meter light point height

Luminaires – position, light source wattage and pole spacing				
Luminaire	**Position**	**Wattage**	**Photometric file**	**Spacing**
Lumada VP (S) SAP PTL1	POS3	ST-250S	LUM. VP 250W PTL1 POS3.LDT	51 m
Lunalys	Pos3	ST-250S	Lunalys-HST250-Pos3-904.LDT	51 m
Arc 90, tl	1B	ST-250S	INR6285.LDT	56 m

Arc 90, k	2B	ST-250S	INR5066.LDT	64 m
Teorema u	pos 15	ST-250S	RC2004006.phl	57 m
CitySoul CGP431, k	P6	ST-250S	Philips Database 01042010	50 m
CitySoul CGP431, tl	P4X	ST-250S	Philips Database 01042010	52 m
Iridium SGS254 GB	P6	ST-250S	Philips Database 06052009	58 m
Iridium SGS254 FG	P6	ST-250S	Philips Database 06052009	55 m
Koffer2 SGP100 GB	P5	ST-250S	Philips Database 06052009	55 m
Koffer2 SGP100 FG	P6	ST-250S	Philips Database 06052009	55 m
611HGV AC TP	LP 15	ST-250S	Philips Database 06052009	56 m
611 HGV FG TP	LP 15	ST-250S	Philips Database 06052009	53 m
614 HGV AC TP	-	ST-250S	614HGV AC TP 1xSONTPP250W.ies	58 m
SGP340 FG	TP P3X	ST-250S	Philips Database 06052009	53 m
SGP340 PC	TP P4	ST-250S	Philips Database 06052009	54 m
Ambar 3, k	33/114	ST-250S	270433	53 m
Ambar 3, tl	33/114	ST-250S	270424	51 m
ONYX3	A4	ST-250S	92263A.PUN	49 m
ONYX2	C1	ST-250S	932347.PUN	49 m
SAPHIR2 k	F2	ST-250S	971955.PUN	54 m
DL 500 Maxi-A tl	29027_2	ST-250S	5NA 2462-1ST0AS08	54 m
SC 100, k	LP3 RP3	ST-250S	...E1ST0B_1xHST_250W_38079.ldt	55 m
SC 100, tl	LP3 RP2	ST-250S	...E1ST0F_1xHST_250W_38070.ldt	54 m
SQ 200 k	LP 3 RP 4	ST-250S	5NA 5591-1ST0B100	55 m
SQ 200 tl	LP 2 RP 2	ST-250S	5NA 5591-1ST0B200	56 m
SR 200 k	16526_1	ST-250S	5NA 5532-1ST	55 m
SR 200 tl	16713_1	ST-250S	5NA 5532-1ST	53 m
Civic 2, tl	V1L7	ST-250S	96009812 --HST V1L7.LDT	52 m
Civic 2, k	V1L4	ST-250S	96009813 --HST V1L4.LDT	60 m
Decostreet2	V7L3A	ST-250S	96002385--HST V7L3A.IES	59 m
Oracle 2W, tl	V6L3	ST-250S	96220570--V6L3 HST-MF.LDT	61 m
Oracle 2W, lk	V8L3	ST-250S	96220571--V8L3 HST-MF.LDT	58 m

Mean values and standard deaviations	
Mean pole distance	54.7 m
Standard deviation	3.4 m

Luminaire fulfilling lighting class AL4b with 10 meter light point height

Luminaires – position, light source wattage and pole spacing				
Luminaire	**Position**	**Wattage**	**Photometric file**	**Spacing**
Lumada VP HPST/SAP		ST-150S	LUMADAVPHPST150-010150LUMADAVPHPST(OPS).LDT	40 m
Lunalys	Pos2	ST-150S	Lunalys-HST150-Pos2-902.LDT	49 m
Arc 90, tl	1C	ST-150S	INR6488.LDT	53 m
Arc 90, k	3C	ST-150S	INR5100.LDT	51 m
Airtrace 1 (SIP-optiikka)	3A	M-140	8092903s.ldt	47 m

2 Tone, ExaCT-Performer	E	M-140	INR537B.LDT	49 m
2 Tone, ExaCT-Comfort	F	M-140	INR516B.LDT	48 m
LSL90		90 LED 122W	3033004N.LDT	41 m
Archilede - 98 LED		117W	BE90_LH89.LDT	36 m
Teorema u	pos 15	ST-150S	RC2004005.phl	53 m
CitySoul CGP431, k	P7X	ST-150S	Philips Database 01042010	50 m
CitySoul CGP431, tl	P8	ST-150S	Philips Database 01042010	52 m
CitySoul LED DM 112 LED		140W	DM 140W GreenLine.phl	41 m
Iridium SGS254 GB	P6	ST-150S	Philips Database 06052009	54 m
Iridium SGS254 FG	P6	ST-150S	Philips Database 06052009	50 m
Iridium SGS253 GB	P6	ST-150S	Philips Database 06052009	49 m
Iridium SGS253 FG	P6	ST-150S	Philips Database 06052009	49 m
Koffer2 SGP100 GB	P5	ST-150S	Philips Database 06052009	55 m
Koffer2 SGP100 FG	P6	ST-150S	Philips Database 06052009	54 m
611 HGV AC TP	LP 15	ST-150S	Philips Database 06052009	54 m
611 HGV FG TP	LP 25	ST-150S	Philips Database 06052009	52 m
621HGV FG TP	LP 20	ST-150S	Philips Database 06052009	49 m
621HGV AC TP	LP 20	ST-150S	Philips Database 06052009	50 m
SGP340 FG	TP P4	ST-150S	Philips Database 06052009	49 m
SGP340 PC	TP P3X	ST-150S	Philips Database 06052009	51 m
SpeedStar BGP323 LED DC	160 LED	199W DC	199W GreenLine.phl	53 m
Ambar 3, k	35/118	ST-150S	273677	50 m
Ambar 3, tl	36/128	ST-150S	273666	48 m
Ambar 2, k	35/110	ST-150S	274336	48 m
Ambar 2, tl	35/110	ST-150S	280567	45 m
ONYX2	B3	ST-150S	93231B.PUN	52 m
SAPHIR2 k	A3	ST-150S	972067.PUN	50 m
DL 500 Maxi-A k	28924_4	ST-150S	5NA 2462-1PT0AW08	52 m
DL 500 Maxi-A tl	29017_4	ST-150S	5NA 2462-1PT0AS08	58 m
SC 100, k	LP3 RP4	ST-150S	...E1PT0B_1xHST_150W_37890.ldt	53 m
SC 100, tl	LP2 RP3	ST-150S	...E1PT0F_1xHST_150W_37826.ldt	50 m
SQ 200 k	LP 2 RP 4	ST-150S	5NA 5591-1PT0B100	58 m
SQ 200 tl	LP 1 RP 5	ST-150S	5NA 5591-1PT0B200	50 m
SR 100	26069_5	ST-150S	5NA 5522-1PT	43 m
Mistral	-	ST-150S	9101G06S_Mistral 150W SON.LDT	46 m
Civic 2, tl	V4L7	ST-150S	96009806 --HST V4L7.LDT	46 m
Civic 2, k	V3L7	ST-150S	96009807--HST V3L7.LDT	53 m
Jet2	V2L3	ST-150S	96220114--HST V2L3.IES	56 m
Dyana2	V-4L0	ST-150S	96251354--V-4L0.IES	54 m
Decostreet2	V7L2A	ST-150S	96002384--V7L2A.IES	48 m
Oracle 2C, tl	V2L3	ST-150S	96220576[V2L3].LDT	49 m
Oracle 2C, lk	V3L3	ST-150S	96220581[V3L3].LDT	54 m
Oracle S, tl	L2	ST-150S	96257793_(L2).LDT	50 m

Oracle S, lk	V2L3	ST-150S	96258250_(V2L3).LDT	55 m
Cosmo	SHP-T	ST-150S	COSMO 150WSHP.LDT	43 m

For this only the 150 W sources are included in the calculation of the mean pole spacing and standard deviation. The 150 W sources are the major representative in the list.

Mean values and standard deaviations	
Mean pole distance	50.6 m
Standard deviation	3.4 m

10.4 Appendix D – Efficiency of road lighting in the Nordic countries

As the draft for the report has not been published it is included with this report.

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

2.1System luminous efficacy of a light source

The luminous efficacy of a light source $\eta_{\text{light source}}$ 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 $\eta_{\text{light source}}$. Table 1 provides typical values of $\eta_{\text{light source}}$ 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 W	88	72
	70 W	94	82
	100 W	105	96
	150 W	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:

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

where Φ_{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 $\eta_{\text{installation}}$ 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 $\eta_{\text{installation}}$)
d. excess illumination of one or more of the areas to be illuminated (reduces the value of $\eta_{\text{installation}}$)

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

Kai Sørensen, DELTA, 25 May 2010

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.

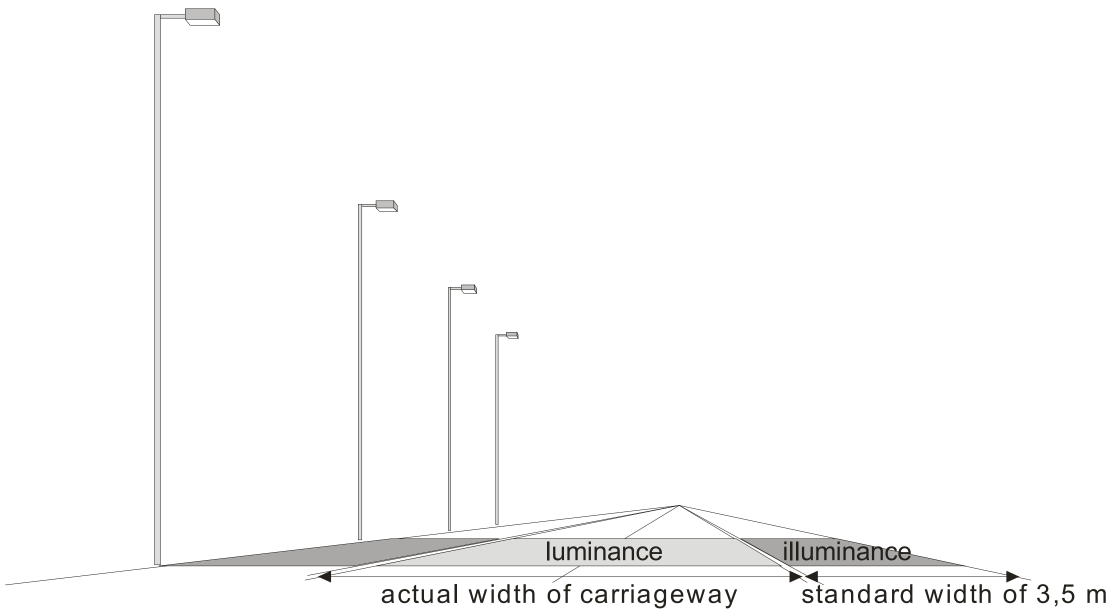

Figure B.1: Fields used to derive values for the luminance of the carriageway and for the illuminance of the surroundings to both sides of the carriageway.

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

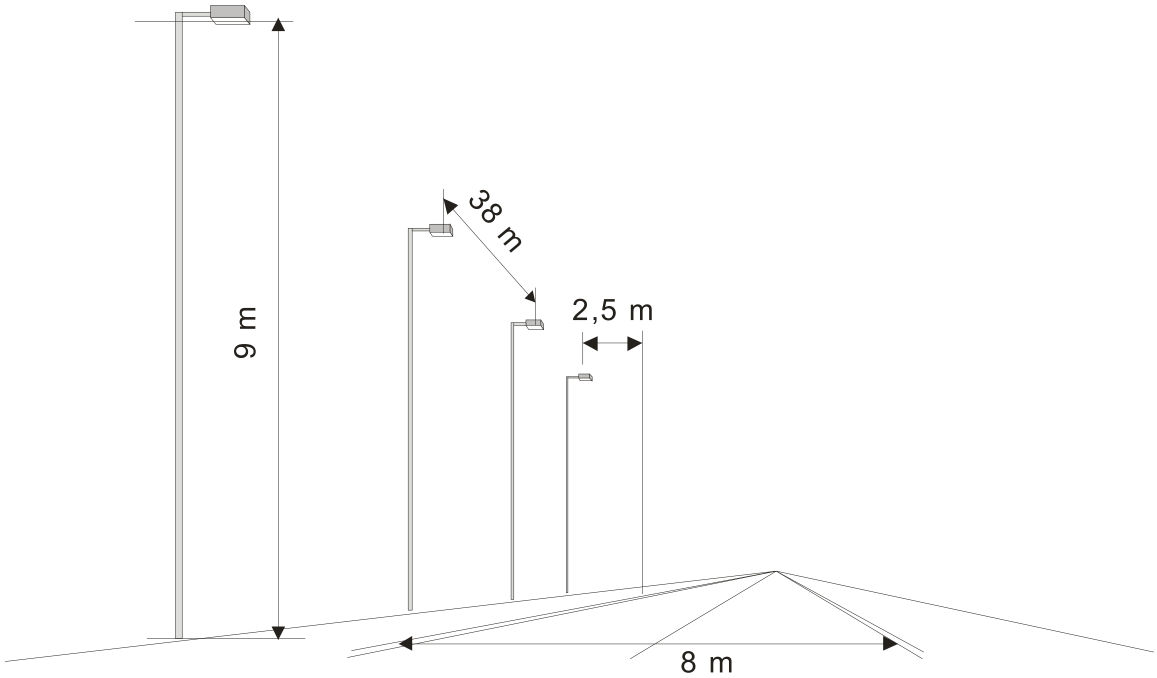

Figure B.2: Typical installation for lighting class L7a.

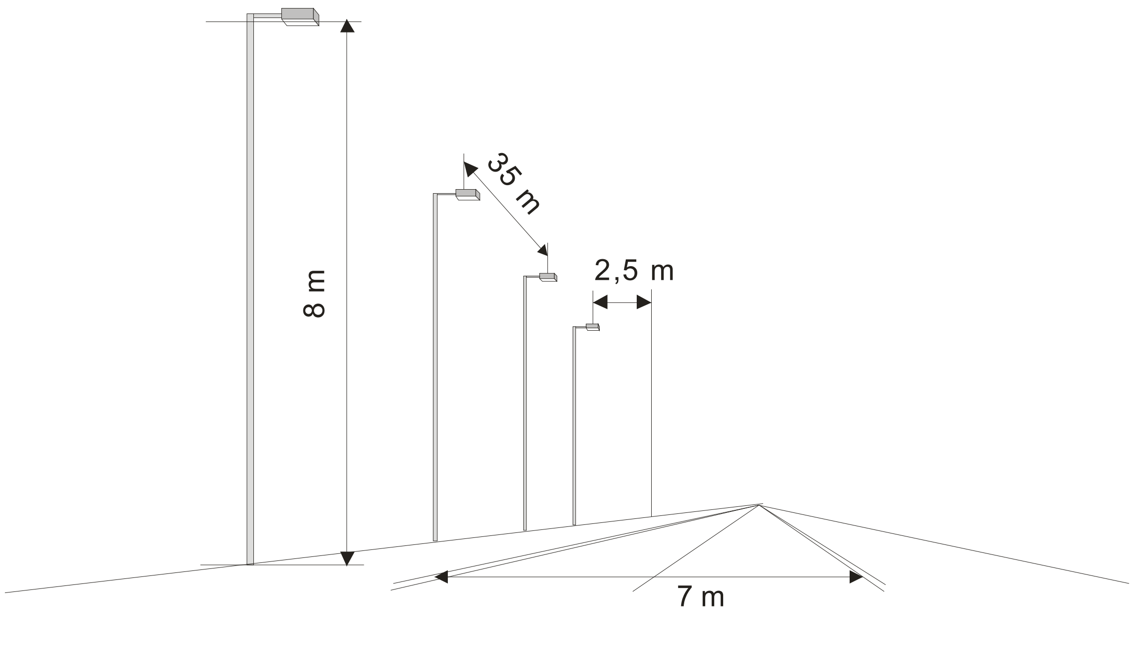

Figure B.3: Typical installation for lighting class L7b.