Draft Regulation on the Drafting of Lighting Studies for Outdoor Road Works and Tunnels — Design and Appropriate Implementation

Content

1. Introduction

This Regulation concerns and lays down the method and parameters for the design of new lighting installations in road works or the modification/upgrading/maintenance of any elements of an existing lighting installation in road works, upon decision of the competent authorities.

In particular, in the case of existing networks, the provisions of this Regulation shall apply individually to the elements of the existing installation, which are modified/upgraded/maintained. The work designer, in consultation with the competent authorities, shall ensure that the overall installation is adapted as far as possible to this Regulation.

This Regulation covers, from a phototechnical point of view, all aspects of the technical design, implementation and inspection of road lighting works.

2. Categorisation of road lighting class

2.1 General information on road lighting design

This Regulation, in line with the European Standard EN 13201, concerns and lays down a set of steps/actions to be carried out by the work designer, from the beginning of the work until its implementation. The necessary steps for the proper and integrated design of road lighting works are the following:

1. Laying down the applicable road lighting classes
2. Laying down the requirements for road lighting classes
3. Drafting of road lighting study
4. Calculation of energy performance indicators

In addition to the above, an assessment of the lighting installation through on-site measurements is required. Measurements can potentially trigger (in extreme cases) the need to redesign the lighting in order to correct any deviations from the targets.

2.2 Selection of road lighting classes

2.2.1 General information on road lighting classes

Lighting classes, as defined in European Standard CEN/TR 13201-1, are grouped into three main categories: M Classes – Motorised, C Classes – Conflict Areas and P Classes – Pedestrians and Pedal Cyclists.

Category M lighting classes (Motorised) shall be selected where the main road users are motor vehicles and lighting is important for safe driving. The main measurable characteristic for which calculations and on-site measurements are carried out is luminance ($(cd/m)^2$), which essentially expresses how bright the asphalt appears and in particular at a distance of 60 m in front of the observation point. Such roads are mainly motorways (traffic lanes including the Emergency Lane), the provincial road network, avenues or roads within urban areas where the use area is clearly separated from the use surface of other users, e.g. through pavements, separating lanes, etc.

The definition of M classes depends on the geometric characteristics of the road, the traffic flow and the respective usage parameters. The selection of the appropriate class shall be made taking into account the road operation, the driving speed, the traffic flow and the surrounding conditions. Basic measurable characteristics of this category are luminance and glare index (TI).

Category C lighting classes (Conflict Areas) are selected for areas classified as areas of increased risk, such as specific sections of road junctions, intersections, roads with high frequency of intersections and within urban centres, where several categories of users (pedestrians, cyclists, two-wheelers and motor vehicles) coexist. The main measurable characteristic for which the calculations and the on-site measurements are carried out is illuminance (lx), which indicates the amount of luminous flux on a surface regardless of the direction in which it is viewed. The most important aspect in this category is the identification of objects by all road users from a relatively close distance and from multiple directions.

Classes C generally refer to cases where vehicle flows intersect or encounter areas where other users are located (pedestrians, two-wheelers, bicycles, other users) or when road geometry changes significantly. In several cases they are selected so that their level of illumination is greater than that on the approach roads and so that they increase the attention in the intersection area, requiring great uniformity of horizontal illuminance.

In any case, the area classified as class C should not have a class C lighting class lower than the corresponding class M lighting class of the approach roads (when approach roads have been classified as class M).

The lighting classes of category P (Pedestrian & Pedal Cyclists) are selected in the case of pedestrian areas, low-speed vehicle traffic areas (<40km/h), parking lanes, local urban roads for the purpose of serving residential streets, parking stations, etc. The primary measurable characteristic for which calculations and on-site measurements are carried out is, as in Class C, the illuminance (lx).

2.2.2 Roads with motor vehicles (M) as main users

It regards road and areas lighting where the main users are mostly motor vehicles, which run at low, medium or high speed. The measurable characteristic for the design and evaluation of road lighting class ***M*** is the road surface luminance (in $cd/m)^2$).

The criteria for selecting classes M are the following 8 and have been taken from technical report CEN/TR 13201-1:2014.

The first criterion is the **design speed or road speed limit**. If the speed limit of a road changes along its length or during the night, then the corresponding weight shall be selected for each case. The design speed results from the respective traffic study. The second criterion is **the road traffic volume as a percentage of the maximum capacity**. For motorways with multiple lanes, it shall be separated per direction or smaller roads. If the traffic load changes along its length or during the night, then the corresponding weight shall be selected for each case.

The third criterion is **the composition of road users**, i.e. whether the main road user is motor vehicles, slow-moving vehicles, cyclists and combination of the above. If the composition of the users changes along its length or during the night, then the corresponding weight shall be selected for each case.

The fourth criterion is **whether there is a separation of the directions of a road**. The separation can be guard-rail, metal bar, plants, trench, etc. If the separation varies along the road, then the corresponding weight shall be selected for each case.

The fifth criterion is **the density of the road junctions**. Intersections refer to roads that meet at the same level (road junctions), while grade-separated junctions refer to grade-separated entrances, exits, etc. Density refers to the sections under study when they have more than one junctions.

The sixth criterion is the **presence or absence of parked vehicles** on the road under consideration. It should be noted that in the case of roads on which there are informally parked vehicles, i.e. in non-reserved and not specially designated places, then for safety reasons they should be considered parked vehicles.

The seventh criterion is the **ambient lighting** of the road under consideration. Intense lighting may be due to high density from illuminated buildings adjacent to the street, billboards, shops, sports and outdoor lighting installations etc. In practice, intense lighting is found in the center of urban areas where there is intense commercial activity.

The average ambient lighting refers to normal conditions in cities not falling into the previous case, while low lighting is usually found on roads outside the urban fabric without the presence of artificial lighting other than road lighting. If ambient lighting changes during the night (for example after shops opening hours) or along the road, then the corresponding weight shall be selected for each case.

The connection of the ambient brightness to the respective environmental zones is determined by the following interconnection/standardisation of the following Tables 4 and 5.

Table 4. Environmental brightness zones according to ILP GN01:2011

Zone	*Ambient lighting*	*Examples*
E0	Completely dark	UNESCO Protected Areas, IDA dark-sky
E1	Dark	Relatively uninhabited rural areas
E2	Low-level brightness	Sparsely populated rural areas
E3	Medium-level brightness	Densely populated rural and urban/semi-urban areas
E4	High-level brightness	City centre, main urban fabric, commercial areas with intense brightness and activity

Table 5. Matching environmental zones and background luminance

CEN/TR 13201-1:2014	***CIE 150:2017***
Low	E2, E1, E0
Moderate	E3
High	E4

No lighting is proposed in environmental zones E0.

The eighth criterion is the **driving difficulty** which relates to the driver’s field of vision and the effort needed, as a result of the information presented to him or other changing circumstances, in order to choose a road or lane and maintain or change speed or position on the road. According to CIE 100:1992 the driving difficulty can be divided into the following individual levels:

- Positional level. It reflects the effort needed by the driver to remain in the correct position on the road surface by adjusting his/her route and/or adjusting the speed of the vehicle etc.
- Situational level. It reflects the actions needed by the driver to cope with changes in the structure/geometry of the road, changes in his/her route, changes in weather conditions, changes in road operation conditions, e.g. works. These actions can be speed change, change of direction and position on the road, etc.

- Navigational level. It reflects the effort needed by the driver to follow a specific route in order to reach the desired destination, which includes reading traffic signs and destination signals.

Therefore, driving difficulty is very high in cases where the driver is required to understand complex signs, drive on roads with multiple exits and entrances and complex structure, intersections of several traffic lanes, etc. Driving difficulty is high in cases of traffic at roundabouts or simple intersections. Driving difficulty is low where the driver performs a simple lane change, change in vehicle speed, entry, exit, etc. and drives on a particular road or lane without objectively requiring any significant effort. Where the driving difficulty changes along the road, the corresponding weight shall be selected for each case.

In any case, the final choice of lighting class shall be made by summing the weights of each criterion and using the following equation:

$$M = 6 - VWS \qquad (1)$$

where ***M*** is the corresponding lighting class and VWS is the sum of the weights of the criteria according to Table 6. Classes M1, M2, M3, M4, M5 and M6 derive from equation (1).

The following shall apply:

- If VWS < 0 then VWS=0
- If M ≤ 0 then M=1 (M1 class)

Table 6. Selection criteria for lighting classes of category M

Criterion	Options	Description		Weight
Design speed or speed limit	Very high	$v \geq 100$ km/h		2
	High	$70 < v < 100$ km/h		1
	Medium	$40 < v \leq 70$ km/h		-1
	Low	$v \leq 40$ km/h		-2
Traffic volume		Motorways, multi-lane directions	Two-lane directions	
	High	> 65 % of maximum capacity	> 45 % of maximum capacity	1
	Medium	35 – 65 % of maximum capacity	15 % – 45 % of maximum capacity	0
	Low	< 35 % of maximum capacity	< 15 % of maximum capacity	-1
User composition	Mixed, with a large proportion of non-motorised vehicles			2
	Mixed			1
	Motorised only			0
Separation of traffic directions	No			1
	Yes			0
Density of road junctions		Intersections/km	Distance between grade-separated junctions, km	
	High	> 3	< 3	1
	Medium	≤ 3	≥ 3	0
Parked vehicles	Present			1
	Absent			0
Ambient lighting	High	Commercial roads, billboards, sports facilities, stations, etc.		1
	Medium	Normal situations		0
	Low			-1
Driving difficulty	Very high			2
	High			1
	Low			0

In the case of road sections to which, in principle, lighting classes ***M*** are applicable according to the above criteria, but which lie between two “conflict areas” (to be defined on a later stage), and if the distance between these two “risk areas” is less than the relevant safe stopping distance (SD), then the corresponding class ***C*** should also be selected for the above intermediate section and not the original class ***M*** resulting from the above criteria and weights. Typical examples are local roads within urban centres and/or local distributor roads, where intersection frequency is so high that the roads practically form a single “conflict area”.

2.2.3 Risk areas lighting classes (C)

C classes are used in areas of increased risk, i.e. where two or more traffic streams, roads and road users are involved. The main user of these areas is motor vehicles.

More specifically, risk areas are areas where different vehicle flows meet at the same level, i.e. junctions, intersections, etc., or meet/cross at the same level with areas often used by other types of users, such as pedestrians, cyclists, etc.

Areas with reduced number of lanes or reduced lane width or overall width shall also be considered risk areas, except for the cases described below. Risk areas have a high probability of collision between vehicles, vehicles and pedestrians, cyclists with other users or cars with fixed obstacles, etc.

The risk area is delimited by the area where the roads intersect or meet, plus the area defined by the respective safe stopping distance of each intersecting road.

For risk areas it is preferable to use luminance as design and evaluation characteristic. However, this is not possible in cases where the viewing distances of the standard observer (driver) are short (< 60 m) or there are multiple observers (from different directions, e.g. intersections, entry-exit ramps, etc.). In such cases, illuminance (lx) is used as design and evaluation characteristic.

The application of illuminance as evaluation characteristic shall apply either to the individual parts of the risk area, where luminance cannot be used, or to the wider risk area, e.g. to the entire road junction (subject to conditions), the intersection, etc.

Lighting classes ***M*** and ***C*** (luminance and illuminance) are assigned by simultaneously estimating or knowing the total reflectance factor of the road surface Q_0 as shown in Table 7.

Table 7. Assigning of M and C classes to conflict areas

Lighting class M			**M1**	**M2**	**M3**	**M4**	**M5**	**M6**
Lighting Class C for $Q_0 \leq 0.05$			C0	C1	C2	C3	C4	C5
Lighting Class C for $0.05 < Q_0 \leq 0.08$		C0	C1	C2	C3	C4	C5	C5
Lighting Class C for $Q_0 > 0.09$	C0	C1	C2	C3	C4	C5	C5	C5

Since C lighting classes are designed for the same users as those of M classes, Table 7 should be used to define classes in risk areas belonging to roads for which M classes have already been defined. The class of risk areas should not be lower than the highest class of the intersecting roads. Therefore, in such cases C class is derived indirectly from the M classes of the intersecting roads.

Where necessary and in order to increase safety, the work designer may select a lighting class of one grade higher than the one resulting from the assignment of classes.

To facilitate the work of the work designers, it is proposed to apply an increase of the lighting class by one grade in relation to the comparable M class in cases of cross junctions and sections of grade-separated junctions where there is a real need due to a critical change in road geometry and an overall change in the road width.

More specifically, based on the Road Design Guidelines Manual (OMOE) – Book 2: Cross-sections (OMOE-Δ), the following cases are distinguished, which are presented indicatively and not restrictively.

1. Case of non-critical cross-sectional change of type "β2+ 1" road surface at a road junction (Figure 1). In this case it is not necessary to increase the lighting level of C class by 1 grade

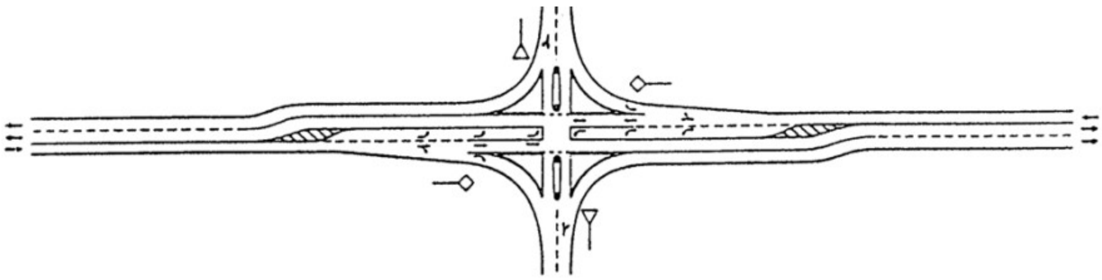


Figure 1. Road with non-critical cross-sectional change of type “β2+ 1” road surface at a road junction

2. Case of critical cross-sectional change of type “β2+ 1” road surface at a road junction (Figure 2). In this case it is proposed to increase the lighting level of C class by 1 grade

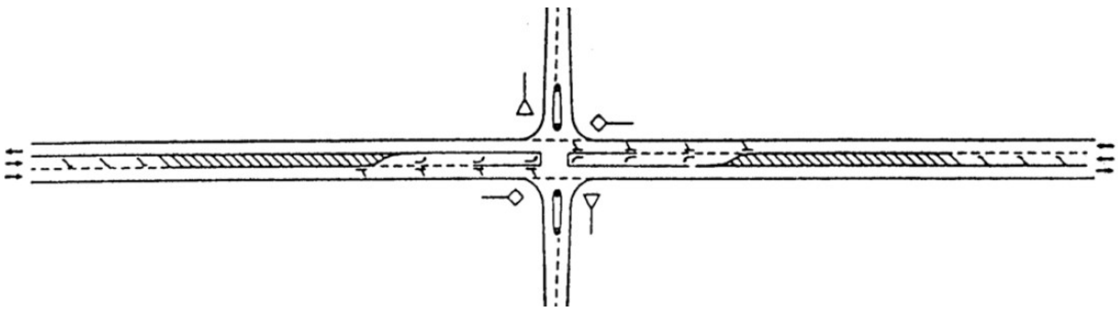


Figure 2. Road with critical cross-sectional change of type “β2+ 1” road surface at a road junction

3. Case of non-critical cross-sectional change of type “β2+ 1” road surface at a grade-separated junction (Figure 3). In this case it is not necessary to increase the lighting level of C class by 1 grade.

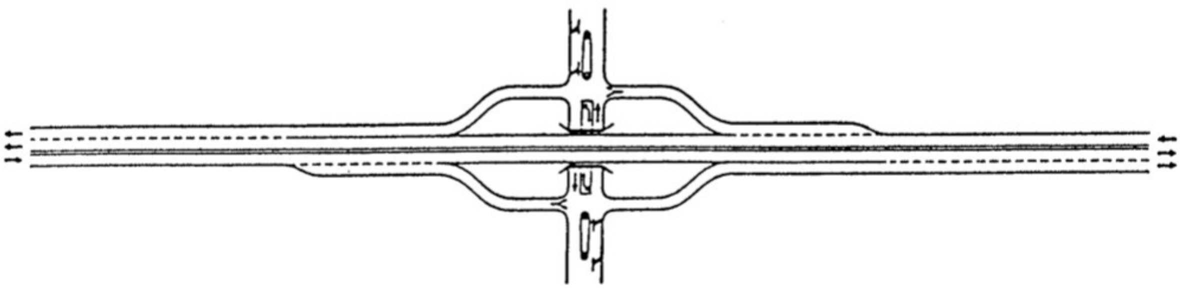


Figure 3. Road with non-critical cross-sectional change of type “β2+ 1” road surface at a grade-separated junction

Therefore, in the case of grade-separated junctions encountered mainly on motorways, the risk area which is necessarily assigned class C does not concern, in most cases, the entry/exit areas of the motorway, but the areas of grade-separated crossing, e.g. the T-junction, circular route, etc. Figure 4: As a consequence, the acceleration/deceleration lanes are assigned a lighting class M equal to that of the main road section, and pure risk areas are assigned a class C equal to and/or greater than the corresponding class of the main section, depending on how critical the cross-sectional change is, as analysed above.

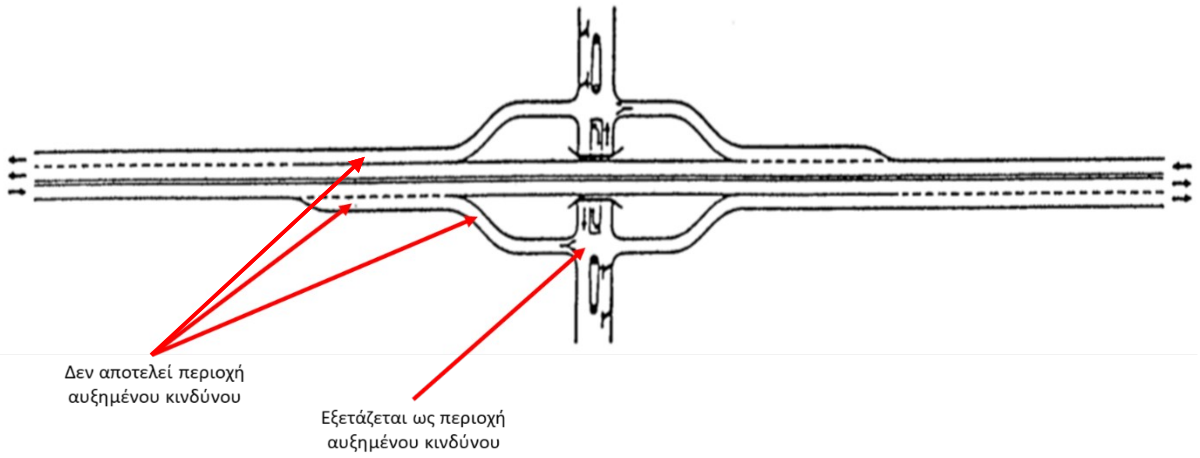


Figure 4. Standard road junction areas considered or not as areas of increased risk

Δεν αποτελεί περιοχή αυξημένου κινδύνου	Not an area of increased risk
Εξετάζεται ως περιοχή αυξημένου κινδύνου	Considered as an area of increased risk

If lighting class ***C*** is not determined based on the corresponding class ***M*** but a separate analysis is carried out, then the following weighted calculation methodology shall be used for selecting the lighting class ***C*** in accordance with CEN/TR 13201-1.

The selection criteria are largely identical to those in class M. In particular:

The first criterion is the **design speed or road speed limit**. The criterion is similar to that analysed for class M.

The second criterion is **the road traffic volume as a percentage of the maximum capacity**. The criterion is similar to that analysed for class M but without specifying the load percentages.

The third criterion is the **composition of road users**. The criterion is similar to that analysed for class M.

The fourth criterion is whether there is **separation of the directions of a road**. The criterion is similar to that analysed for class M.

The fifth criterion is the **presence or absence of parked vehicles** on the road under consideration. The criterion is similar to that analysed for class M.

The sixth criterion is the **ambient lighting** of the road under consideration. The criterion is similar to that analysed for class M.

The seventh criterion is the **driving difficulty** related to the driver’s field of vision. The criterion is similar to that analysed for class M.

The choice of lighting class ***C*** is performed by summing the weights of each criterion and using the following equation.

$$C = 6 - VWS \quad (2)$$

where ***C*** is the corresponding lighting class and VWS is the sum of the weights of the criteria derived from Table 8. Classes C0, C1, C2, C3, C4 and C5 derive from equation (2).

The following shall apply:

- If VWS ≤ 0 then VWS=1
- If C < 0 then C=0 (class C0)

Table 8. Selection criteria for lighting classes of category C according to CEN/TR 13201-1

Criterion	Options	Description	Weight
Design speed or speed limit	Very high	v ≥ 100 km/h	3
	High	70 < v < 100 km/h	2
	Medium	40 < v ≤ 70 km/h	0
	Low	v ≤ 40 km/h	-1
Traffic volume	High		1
	Medium		0
	Low		-1
User composition	Mixed, with a large proportion of non-motorised vehicles		2
	Mixed		1
	Motorised only		0
Separation of traffic directions	No		1
	Yes		0
Parked vehicles	Present		1
	Absent		0
Ambient lighting	High	Commercial roads, billboards, sports facilities, stations, etc.	1
	Medium	Normal situations	0
	Low		-1
Driving difficulty	Very high		2
	High		1
	Low		0

2.2.4 Roads with pedestrian and slow-moving vehicles (P) as main users

These classes concern the lighting of traffic areas with pedestrians and cyclists as main users or of mixed-use roads which are traffic calming zones.

The definition of lighting classes ***P*** is carried out using the criteria below.

The first criterion is the **design speed or road speed limit**. The criterion is similar to that described in class M.

The second criterion is the **traffic volume of the road** as a general description of the volume. The criterion is similar to that described in class M but without specifying the volume percentages.

The third criterion is the **composition of road users**. The criterion is similar to that described in class M.

The fourth criterion is the **presence or absence of parked vehicles** on the road under consideration. The criterion is similar to that described in class M.

The fifth criterion is the **ambient lighting** of the road under consideration. The criterion is similar to that described in class M.

Table 9. Selection criteria for lighting classes of category P according to CEN/TR 13201-1

Criterion	Options	Description	Weight
Design speed or speed limit	Low	v ≤ 40 km/h	1
	Very low (walking)	Walking speed	0
Traffic load	High		1
	Medium		0
	Low		-1
User composition	Pedestrians, cyclists and motorised traffic		2
	Pedestrians and motorised traffic		1
	Pedestrians and cyclists		1
	Pedestrians		0
	Cyclists		0
Parked vehicles	Present		1
	Absent		0
Ambient lighting	High	Commercial roads, billboards, sports facilities, stations, etc.	1
	Medium	Normal situations	0
	Low		-1

2.2.5 Adaptive lighting classes

This methodology for selecting lighting classes using weights, designed by CIE and adopted by CEN, was developed with the aim of flexible selection of adaptive lighting classes. In this way it is possible, when conditions allow it, for an illuminated road to change lighting class and therefore requirements in terms of lighting levels, uniformity, etc. This requires the appropriate design of the lighting system in order to have the appropriate corresponding luminous flux settings/changes.

The change in the lighting class shall take place if one or more of the selection criteria changes its weight during the operation of the lighting system. Most of the selection criteria for all classes can be changed, except, of course, for those relating to construction elements such as the density of road junctions and lane separation.

In this way, multiple levels of lighting are achieved during the night, which serve the local and hourly road lighting needs, offering optimal conditions to the driver while maintaining energy consumption and limiting light pollution to optimal levels.

It is therefore necessary, when selecting road lighting classes, to investigate the possibility of defining adaptive lighting classes and the corresponding periods of time during which the change takes place.

The maximum M/C/P class resulting from the weight selection methodology is the “nominal lighting class”, while the other classes selected for certain periods and covering the same part of the road are called “adaptive lighting classes”.

An Explanatory Guide and examples of selecting nominal and adaptive lighting classes are presented in the next section.

2.3 Guide for determining road lighting classes

2.3.1 Guide for determining lighting classes of motorways and sections of the national road network

The road network consisting of motorways and sections of the national road network is a clearly delimited and defined network with clear geometrical characteristics and specific standard cross-sections.

Particularly in the case of motorways, which all have advanced systems for measuring and/or predicting traffic load, the lighting class in a static and/or dynamically variable mode (Dynamic Adaptive Lighting) can be precisely defined.

In these type of networks, class M shall be used for open road construction, where there is lighting, and Class C in risk areas as defined in §2.3 above.

In particular, the following shall apply to each lighting class selection criterion of a motorway:

a. Design speed.

The clearly defined speed limit per section of the motorway.

b. Traffic volume

The traffic volume of motorways is taken from historical traffic records e.g. via loops, toll stations, etc. If these data are provided directly throughout the day, the weight of the criterion will change accordingly.

The **nominal lighting class** for each motorway section is derived from **the percentage of cumulated 24-hour traffic of the standard day of the year (average annual daily traffic (AADT)) multiplied by the maximum traffic capacity of the section under consideration** of the motorway (Figure 5 – Average annual daily traffic). In order to take account of any future increase in traffic volumes in the above definition of the nominal class, it is proposed that the corresponding traffic forecasts be taken over a period of 10 years, if of course available.

If there are different traffic volume profiles per day of the week, or per season, also if there are significant long-lasting seasonal changes and if historical traffic data are available per standard day of the year (Figure 5 – Standard Monday to Standard Sunday), the nominal lighting class shall be derived from the **cumulative 24-hour traffic of the standard day of the week of the season with the highest traffic volume.**

The definition and implementation of **adaptive lighting classes,** during the night hours of road lighting operation, will be based on the updated traffic load measurements, forecasts and/or real-time traffic recording data, i.e. the percentage of traffic volume at the relevant night hours over the maximum traffic capacity of the road section and for each Δt period as shown in the examples in section 2.3.3.

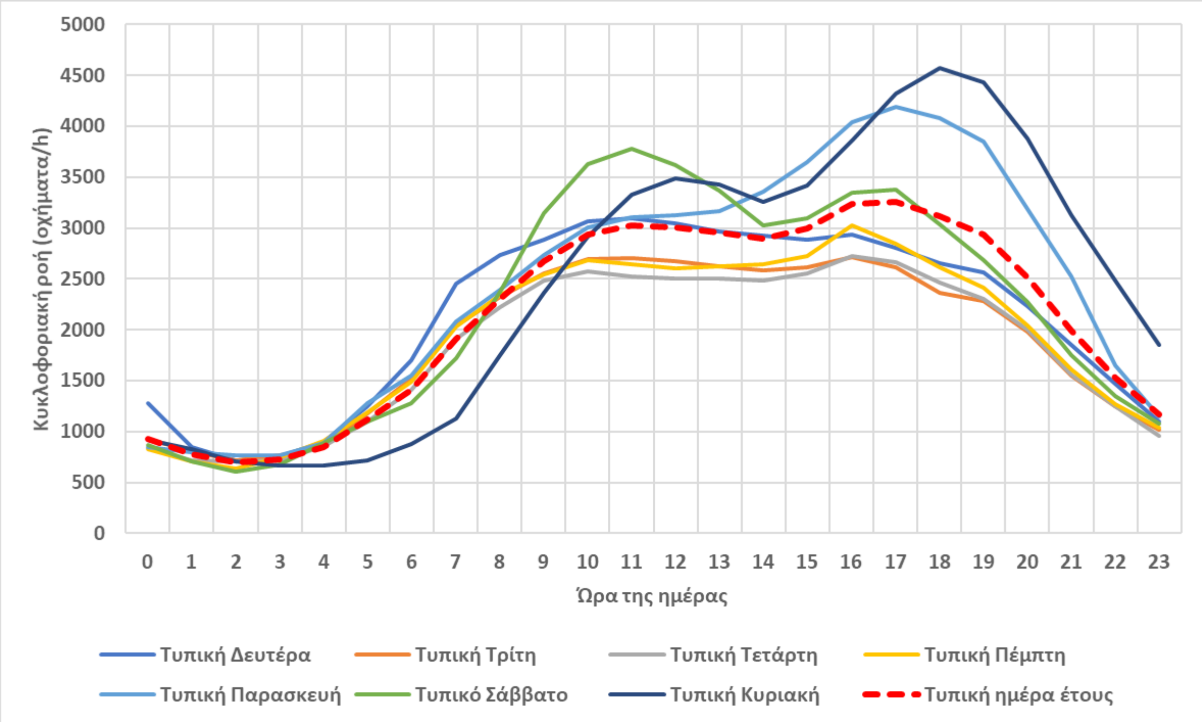


Figure 5. Example of the average annual traffic per week day of a Greek motorway section

Κυκλοφοριακή ροή (οχήματα/h)	Traffic flow (vehicles/h)
Ώρα της ημέρας	Time of day
Τυπική Δευτέρα	Standard Monday
Τυπική Τρίτη	Standard Tuesday
Τυπική Τετάρτη	Standard Wednesday
Τυπική Πέμπτη	Standard Thursday
Τυπική Παρασκευή	Standard Friday
Τυπικό Σάββατο	Standard Saturday
Τυπική Κυριακή	Standard Sunday
Τυπική ημέρα έτους	Standard day of the year

c. Composition of users

The composition of users is determined by the type of motorway and is generally stable. If a change in the composition of users during the night is statistically established, then the weight may change accordingly.

d. Separation of traffic directions

This criterion has a fixed weight.

e. Density of road junctions

The density of road junctions shall be calculated for the entire section of the motorway under consideration.

f. Parked vehicles

As a rule, there is no on-the-road-parking of vehicles on Greek motorways. It should be noted that the Emergency Lane is not a designated parking lane.

g. Ambient lighting

Ambient lighting for Greek motorways shall be assessed on a case-by-case basis:

- *High*: In sections passing at the same level through dense urban fabric with adjacent illuminated streets, shops, sports facilities, etc.
- *Medium*: In sections passing at the same level through semi-urban, relatively sparsely-built areas and where artificial ambient lighting consists of smaller adjacent roads, houses and a small percentage of shops.
- *Low*: In all sections between urban areas. Ambient lighting is also considered to be low if at certain individual places the motorway passes close to settlements.

h. Driving difficulty

Driving difficulty, as explained in §2.3, can be determined in a more specific way on motorways due to the envisaged cross-sections, markings and visual guidance (Table 14).

Table 14 – Driving difficulty by standard motorway section

Motorway areas	**Driving difficulty**
Open section (main axis)	Low
Acceleration/deceleration lane	Low
Entry/Exit section	Low
Upper/lower junction crossing	Low[1]/High
Roundabout area	Very high
Intersection area	Very high

2.3.2 Guide for determining lighting classes of standard urban roads

In most cases, the road network within the Greek urban centres has common characteristics, both in terms of geometric characteristics and traffic characteristics. For the classification of roads in line with EN 13201, it is necessary to characterise them in terms of traffic data in order to assign the correct lighting classes. Therefore, also in the context of this Regulation, it is necessary to connect the lighting class and its category to the road status based on its traffic data.

For this purpose, in every such case of urban road, it is necessary to draft a traffic study or characterize the road in terms of traffic data, in order to indicate to the road lighting designer the road status for which the designer shall assign lighting classes. Therefore, given the common characteristics of most of these standard cases, within the framework of this Regulation the following guidelines are given for determining the lighting class in the absence of a traffic study.

To cover as far as possible all cases of urban roads, within the framework of this Regulation the following traffic classification is followed based on Table 1-2 of the Road Design Guidelines Manual (OMOE) – Book 2: Cross-sections (OMOE-Δ).

[1] *If there is a separation of directions with a guard-rail, driving difficulty is considered low.*

Urban roads with access as a main function (Figure 6), i.e.:

- Local roads (ΔV)
- Local distributor roads (ΔIV)

Roads running through areas within or outside the urban fabric (peri-urban & urban areas) with the main function of connection and with the possibility of servicing the roadside properties, i.e.

- Main local distributor roads (ΓIV)
- Urban arterial roads (ΓIII)

All the above road cases will be studied after having been directly assigned class C, given their common characteristics, the most important of which are:

1. Generally average to low traffic speed.
2. Frequent road junctions in a distance, in many cases, less than the safe stopping distance (SD).
3. Cases of informally parked vehicles on one side of the road or even in the two directions, which increase the complexity of the driver’s effort.
4. Presence of other types of users (pedestrians etc.) on the carriageway due to absence of crossings.
5. Other obstacles on the carriageway such as waste bins that have been moved etc.
6. Increased driving difficulty due to frequent stops of passing vehicles or other types of users, given the commercial activity that characterises this road type.

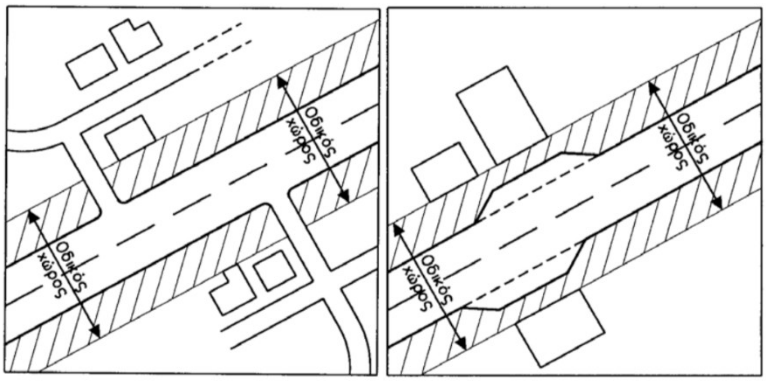


Figure 6. Cases of road types C&D according to OMOE

Οδικός χώρος	Road space

Similar to C classes, there are cases within the road network that will be directly connected to P classes, taking into account their geometrical characteristics and the traffic role they serve.

In particular, the cases of urban roads with stay as their main function, i.e. local roads type EV, EVI, are all cases that will be studied directly with P classes (Figure 7).

In these of roads, the following common characteristics are observed in most of the cases:

1. Extremely low traffic speed due to speed limitation measures (traffic calming roads).

2. Presence of other types of users (pedestrians, cyclists etc.) on the carriageway.
3. Other obstacles on the carriageway, such as trash bins, that have been moved etc.
4. Roads with stay as their main function and which serve roadside properties.

In addition, roads in neighbourhoods of municipalities located outside the urban fabric with stay as their main function and which serve almost exclusively the inhabitants of these areas, will be studied directly with P classes.

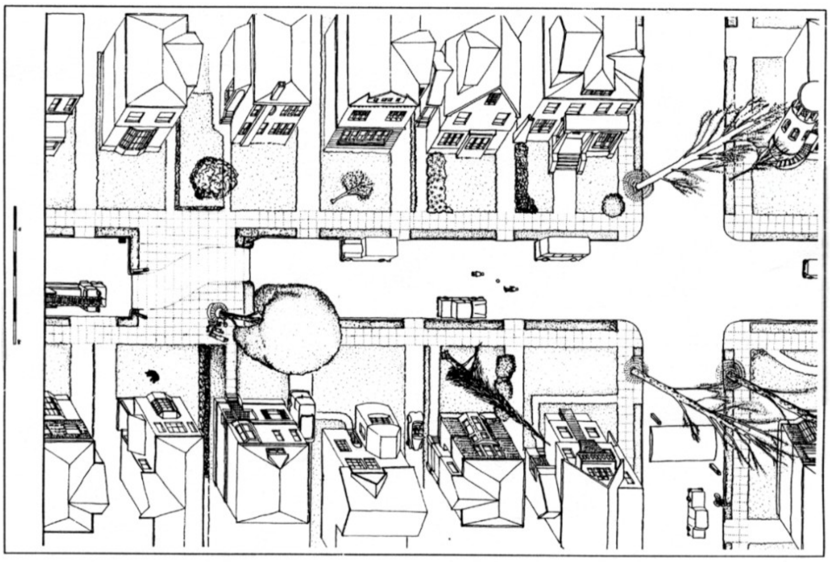


Figure 7. Cases of E-type roads according to OMOE-1

As previously mentioned, the above cases of urban roads are listed indicatively and not exhaustively, with the main purpose to cover the relevant cases as fully as possible as part of this Regulation, but also with the following broader overall objectives:

1. First of all, as already mentioned, support of the work designers in the absence of traffic studies.
2. Support of work designers when there is a need to conduct collective studies and groupings of several road cases.
3. Uniformity in the urban master planning.
4. Support of the evaluation and monitoring/maintenance of the urban road lighting facility.

2.3.3 Examples of selecting nominal and adaptive lighting classes

Tables 10-13 provide illustrative examples of lighting classes of standard roads in the Greek road network within and outside cities.

These examples show how lighting classes change when the weight of one or more criteria changes and the total sum changes by at least one point. The time intervals shown relate to intervals of hours between which weights change and clearly do not generally relate to the same hours for all roads.

Road lighting studies should be carried out on the basis of nominal classes and additional calculations should be performed to define the minimum required luminous flux from lighting devices to achieve each class of adaptive lighting.

Table 10. Examples of selection of M lighting classes

Criterion	Options	Description		Road 1			Road 2	
				Δt_1	Δt_2	Δt_3	Δt_1	Δt_2
Design speed or speed limit	Very high	$v \geq 100$ km/h		2	2	2	2	2
	High	$70 < v < 100$ km/h						
	Medium	$40 < v < 70$ km/h						
	Low	$v \leq 40$ km/h						
Traffic volume		Motorways, multi-lane directions	Two-lane directions					
	High	> 65 % of maximum capacity	> 45 % of maximum capacity	1				
	Medium	35 – 65 % of maximum capacity	15 % – 45 % of maximum capacity		0		0	
	Low	< 35 % of maximum capacity	< 15 % of maximum capacity			-1		-1
User composition	Mixed, with a large proportion of non-motorised vehicles							
	Mixed							
	Motorised only			0	0	0	0	0
Separation of traffic directions	No							
	Yes			0	0	0	0	
Density of road junctions		Intersections/km	Distance between grade-separated junctions, km					
	High	> 3	< 3	1	1	1		
	Medium	≤ 3	≥ 3				0	0
Parked vehicles	Present							
	Absent			0	0	0	0	0
Ambient lighting	High	Commercial roads, billboards, sports facilities, stations, etc.		1				
	Medium	Normal situations			0	0		
	Low						-1	-1
Driving difficulty	Very high							
	High							
	Low			0	0	0	0	0
Sum of weights (VWS)				**5**	**3**	**2**	**1**	**0**
Lighting Class M (6-VWS)				**M1**	**M3**	**M4**	**M5**	**M6**

Road 1*: Section of a closed motorway with a separation lane, within the urban fabric with high density of road junctions and variable ambient lighting. The traffic volume is also variable. Class selection refers to the sections between the grade-separated junctions.*

Road 2*: Section of a closed motorway with a separation lane, outside the urban fabric with low density of road junctions, medium or low traffic volume and low ambient lighting. Class selection refers to the sections between the grade-separated junctions.*

Table 11. Examples of selection of M lighting classes

Criterion	Options	Description		Road 3			Road 4	
				Δt_1	Δt_2	Δt_3	Δt_1	Δt_2
Design speed or speed limit	Very high	v ≥100 km/h						
	High	70 < v < 100 km/h					1	1
	Medium	40 < v < 70 km/h		-1	-1	-1		
	Low	v ≤ 40 km/h						
Traffic volume		Motorways, multi-lane directions	Two-lane directions					
	High	> 65 % of maximum capacity	> 45 % of maximum capacity	1				
	Medium	35 – 65 % of maximum capacity	15 % – 45 % of maximum capacity		0		0	
	Low	< 35 % of maximum capacity	< 15 % of maximum capacity			-1		-1
User composition	Mixed, with a large proportion of non-motorised vehicles							
	Mixed			1	1	1	1	1
	Motorised only							
Separation of traffic directions	No			1	1	1	1	1
	Yes							
Density of road junctions		Intersections/km	Distance between grade-separated junctions, km					
	High	> 3	< 3	1	1	1		
	Medium	≤ 3	≥ 3				0	0
Parked vehicles	Present			1	1	1		
	Absent						0	0
Ambient lighting	High	Commercial roads, billboards, sports facilities, stations, etc.						
	Medium	Normal situations		0	0	0		
	Low						-1	-1
Driving difficulty	Very high							
	High							
	Low			0	0	0	0	0
Sum of weights (VWS)				**4**	**3**	**2**	**2**	**1**
Lighting Class M (6-VWS)				**M2**	**M3**	**M4**	**M4**	**M5**

***Road 3**: Urban avenue without separation, high density of road junctions and fluctuating traffic load as well as variable ambient lighting. Class selection refers to the sections between intersections.*

***Road 4**: Two-way provincial road without separation of directions, with sparse intersections and low ambient lighting. Class selection refers to the sections between road junction crossings.*

Table 12. Examples of selection of C lighting classes

Criterion	Options	Description	Road 5		Road 6		
			Δt_1	Δt_2	Δt_1	Δt_2	Δt_3
Design speed or speed limit	Very high	v ≥ 100 km/h					
	High	70 < v < 100 km/h	2	2			
	Medium	40 < v < 70 km/h					
	Low	v <= 40 km/h			-1	-1	-1
Traffic volume	High				1		
	Medium		0			0	
	Low			-1			-1
User composition	Mixed, with a large proportion of non-motorised vehicles		2	2			
	Mixed				1	1	1
	Motorised only						
Separation of traffic directions	No		1	1	1	1	1
	Yes						
Parked vehicles	Present				1	1	
	Absent		0	0			0
Ambient lighting	High	Commercial roads, billboards, sports facilities, stations, etc.			1		
	Medium	Normal situations				0	0
	Low		-1	-1			
Driving difficulty	Very high						
	High						
	Low		0	0		0	0
		Sum of weights (VWS)	**4**	**3**	**4**	**2**	**0**
		Class C (6-VWS)	**C2**	**C3**	**C2**	**C4**	**C6**

Road 5: *T-intersection on a two-way provincial road without separation of directions and low ambient lighting. Class selection refers to the area delimited by the intersecting roads, plus the safe stopping distance in each direction.*

Road 6: *Urban T-intersection without separation of directions, with or without parked cars. Class selection refers to the area delimited by the intersecting roads, plus the safe stopping distance in each direction.*

Table 13. Examples of selection of P lighting classes

Criterion	Options	Description	Road 7		Road 8	
			Δt_1	Δt_2	Δt_1	Δt_2
Design speed or speed limit	Low	v ≤ 40 km/h	1			
	Very low (walking)	Walking speed			0	0
Traffic volume	High					
	Medium		0			
	Low			-1	-1	-1
User composition	Pedestrians, cyclists and motorised traffic		2	2		
	Pedestrians and motorised traffic					
	Pedestrians and cyclists				1	1
	Pedestrians					
	Cyclists					
Parked vehicles	Present		1	1		
	Absent				0	0

Ambient lighting	High	Commercial roads, billboards, sports facilities, stations, etc.			1	
	Medium	Normal situations	0	0		0
	Low					
		Sum of weights (VWS)	**4**	**2**	**1**	**0**
		Lighting class P (6-VWS)	**P2**	**P4**	**P5**	**P6**

Road 7*: Urban traffic calming road with parked cars and variable number of users.*

Road 8*: Pedestrian street also used by cyclists within the urban fabric and in a commercial area with changing ambient lighting.*

2.4 Requirements for road lighting classes

Each lighting class is governed by the corresponding lighting requirements. These requirements are defined by ELOT standard EN 13201-2 and are mandatory. The requirements are both qualitative and quantitative. The basic quantitative characteristic of ***M*** class is **luminance *L*** of the road surface from the standard observer (driver) position calculated in cd/m². The basic quantitative characteristic of classes ***C*** and ***P*** is **illuminance *E*** which is calculated in lx. The lighting requirements of each class are shown in Tables 15-17.

Table 15. Requirements for M lighting classes according to ELOT EN 13201-2:2016

Class	**Carriageway luminance for dry and wet carriageway**				**Glare index**	**Adjacent areas lighting**
	Dry			**Wet**	**Dry**	**Dry**
	L_m (cd/m^2)	**U_o**	**U_l**	**U_{ow}**	**f_{TI}**	**R_{EI}**
M1	2.00	0.40	0.70	0.15	10	0.35
M2	1.50	0.40	0.70	0.15	10	0.35
M3	1.00	0.40	0.60	0.15	15	0.30
M4	0.75	0.40	0.60	0.15	15	0.30
M5	0.50	0.35	0.40	0.15	15	0.30
M6	0.30	0.35	0.40	0.15	20	0.30

where:

- L_m : Average carriageway luminance (minimum)
- U_o: Luminance uniformity (minimum)
- U_l : Longitudinal luminance uniformity (minimum)
- U_{ow} : Luminance uniformity on wet carriageway (minimum)
- f_{TI} : Glare index (maximum value)
- R_{EI} : Lighting index of the areas adjacent to the road (minimum)

Table 16. Lighting class C requirements according to ELOT EN 13201-2:2016

Class	Mandatory requirements		Optional requirement
	E_m (lx)	U_o	f_{TI} (%)
C0	50.0	0.40	15
C1	30.0	0.40	15
C2	20.0	0.40	15
C3	15.0	0.40	20
C4	10.0	0.40	20
C5	7.50	0.40	20

where:

E_m : Average illuminance on the carriageway (minimum)

U_o: Uniformity of illuminance (minimum)

Table 17. Lighting class P requirements according to ELOT EN 13201-2:2016

Class	Mandatory requirements		Optional requirements		
	E_m (lx)	E_{min} (lx)	f_{TI} (%)	$E_{v,min}$ (lx)	$E_{sc,min}$ (lx)
P1	15.0	3.00	20	5.00	5.00
P2	10.0	2.00	25	3.00	2.00
P3	7.50	1.50	25	2.50	1.50
P4	5.00	1.00	30	1.50	1.00
P5	3.00	0.60	30	1.00	0.60
P6	2.00	0.40	35	0.60	0.20
P7	There is no quantitative and qualitative requirement				

where:

E_m : Average illuminance on the carriageway (minimum)

$E_{v,min}$: Minimum value of vertical lighting intensity on the carriageway

$E_{sc,min}$: Minimum value of semi-cylindrical illumination on the carriageway

E_{min}: Minimum illuminance value

To ensure uniformity in ***P*** classes, the average illuminance value calculated or measured in each case shall not be more than 150 % of the nominal value. For more details on the minimum requirements of each lighting class, the work designer shall consult the ELOT EN 13201-2 standard.

Please note that the use of the optional requirement for glare in class C is left to the discretion of lighting project owners, if appropriate. The use of the optional requirements for glare, vertical lighting intensity and semi-cylindrical lighting in classes P is also left to the discretion of the lighting project owners, for reasons of facial recognition or other reasons.

3. Road lighting design, lighting studies

Road lighting design should meet the minimum requirements of the respective lighting classes, as selected through the procedure analysed in Chapter 2, and includes the selection of the equipment and its fitting device on the road section under consideration. Phototechnical calculations shall be performed according to ELOT EN 13201-3:2015 or later version.

Class requirements differ and depend primarily on the type of selected lighting class, i.e. whether it is aimed at covering luminance (M classes) or illuminance (C, P classes) requirement

Class M roads require the calculation of $\boldsymbol{L_{av}}$ ***(cd/m²)***, $\boldsymbol{U_o}$, $\boldsymbol{U_l}$, $\boldsymbol{U_{ow}}$, $\boldsymbol{f_{TI}}$, $\boldsymbol{R_{EI}}$.

Class C roads require the calculation of ***E (lx),*** $\boldsymbol{U_o}$ and optionally $\boldsymbol{f_{TI}}$ ***(%).***

Class P roads require the calculation of ***E (lx)*** $\boldsymbol{E_{min}}$ ***(lx)*** , while optionally the following are calculated $\boldsymbol{E_v}$ ***(lx),*** $\boldsymbol{E_{sc}}$ ***(lx)*** και $\boldsymbol{f_{TI}}$ ***(%)***.

The above are defined by the requirements of each lighting class as set out in Chapter 2. The calculations of photometric characteristics shall be carried out on a standard grid in accordance with the requirements of ELOT EN13201-3:2015 or later version thereof.

3.1 Selection of standard geometries

For the purpose of carrying out the lighting studies, the work designer shall have at his/her disposal, in addition to the data of the class requirements, the following additional data as presented in Table 18.

Table 18. Additional data necessary for road lighting studies

Road geometrical characteristics	• road **width** • number of **sidewalks** • **sidewalks** width (if any) • **separation lane(s)** width (if any) • number of **traffic lanes** • **type** of carriageway asphalt
Characteristics of road lighting device	• **height** of the lighting poles • **configuration** of the lighting poles on the roadsides • **distance** between two consecutive lighting poles • **distance** of the lighting poles from the kerb • arm **length** • **inclination** of the arm/luminaire
Other data	• **Maintenance factor** of the installation

If luminaires are not installed on poles (surface support, cable suspension, etc.), the work designer shall ensure that the results of his/her study are in accordance with the requirements of the Regulation.

If lighting concerns a new network of poles infrastructure with the possibility to chose these locations, then the work designer shall examine and choose the optimal positioning of the luminaires (e.g. pole height, pole spacing, slope, etc.) based on the energy efficiency of the installation, the quality of the lighting service provided and the local restrictive conditions of the work. At the same time, the lighting equipment chosen shall be optimal from an energy and phototechnical perspective.

In new lighting installations, phototechnical studies will be carried out for all the different geometries present, in order to ensure the required lighting effect according to each class at each point of the installation. Where discrepancies between the different geometries are minor, or not minor but numerous and unavoidable due to various difficulties in the work design, then the work designer, through appropriate grouping, may choose to carry out studies for representative cases, which are considered to be “standard calculation grids”.

Standard calculation grids are most critical in the case of studies on an existing road lighting network, where there is no room for modifications and interventions in pole layouts. In these cases, the work designer shall group the different cases and create representative cases of roads and geometries. The geometrical characteristics of the roads shall be grouped in such a way that roads belonging to the same group are phototechnically covered by a photometric solution (type of luminaire, luminous intensity distribution, total luminous flux, etc.). Therefore, this method creates a set of different cases for meeting phototechnical requirements, the number of which depends on:

- The total number of luminaires included in the intervention.
- The number of different cases of geometries resulting from particularities and lack of uniformity of the area under study.
- The degree of presence of multiple types of lighting equipment due to aesthetic or other requirements, etc.

The above set of representative roads is defined as the **Phototechnical Standard** of the intervention.

Each standard case is accompanied by the corresponding number of luminaires that it represents, so that its effect on the overall energy consumption of the solution can be assessed.

It is noted that the work designer shall select the standard grids based on the most unfavourable geometrical characteristics, so as to ensure that all “represented” geometries are adequately covered from a phototechnical perspective.

It is noted that if the road characteristics differ, the work designer chooses a standard grid for each distinct section. Therefore, the choice of a standard grid with the most unfavourable characteristics is relevant only to this section and not the other sections.

Therefore, the selection of the geometric characteristics of the standard geometries of the Phototechnical Standard are selected in order to meet the phototechnical requirements of the roads to the greatest possible extent.

The Phototechnical Standard shall be complete, i.e. shall include all those characteristics required for carrying out phototechnical studies, but shall also focus on the application of optimisation requirements for the lighting design with performance assessment indicators, as presented in §3.4.

Table 19 presents examples of standard calculation grid of a phototechnical standard. Values shown are indicative.

Table 19. Example of standard calculation grids of a Phototechnical Standard.

Standard grid	Installation of poles	Separation lane width (m)	Road width (m)	Number of lanes per direction of traffic	Poles spacing (m)	Luminaire support height (m)	Luminaire distance from the carriageway (m)	Existing arm angle (^{o})	Lighting class
1	Separation lane	-	6.0	1	35	9	0.35	5	M2
2	Right	-	12.5	3	40	12	0.70	0	M2
3	Right	-	9.0	2	27	9	0.50	5	M3
4	Separation lane	6	6.0	1	26	9	-1.20	0	M3
5	Separation lane	4	7.0	2	24	9	-0.25	0	M3
6	Crossed	-	7.5	2	36	9	0.00	10	M4
7	Right	-	8.0	2	28	9	1.50	0	M4
8	Right	-	8.0	2	28	9	1.50	0	M5
9	Right	-	10.0	2	33	7	0.35	5	M5
10	Right	-	12.0	3	30	7	-1.50	15	M5
11	Right		5.0	1	30	7	0.60	0	C2
12	Right		6.0	1	29	7	0.10	5	C2
13	Right		6.5	1	32	7	0.40	5	C3
14	Right		6.5	1	31	9	1.50	0	C3
15	Right		6.5	1	34	7	-2.00	5	C3
16	Crossed		6.5	1	38	9	1.00	0	C3
17	Right		7.0	2	35	7	-1.20	0	C4
18	Right		7.0	2	25	9	-1.70	0	C4
19	Right		7.0	2	32	7	-1.50	5	C5
20	Right		8.0	2	30	7	0.00	5	C5

3.2 Maintenance factor

A key element of the lighting design is laying down the maintenance factor for the reduction of the lighting capacity of the installation over time.

Each lighting study shall calculate the respective Maintenance Factor (MF) of the installation. The value of the maintenance factor is applied to the calculated photometric characteristics and thus affects installed power and electricity consumption.

The maintenance factor is the ratio of luminance or illuminance achieved by a lighting system after a clearly defined period of operation to the luminance or illuminance respectively achieved by the system on the first day of operation (new system). The calculation methodology is described in CIE-154:2003 technical report and in ISO/CIE TS 22012:2019 standard.

The maintenance factor is defined as follows: $MF=E_m/E_{in}$ (3)

where:

E_m: The luminance or illuminance after a clearly defined operation period (maintained)

E_{in}: Luminance or illuminance on the first day of operation (initial)

The calculation of the maintenance factor, as defined above, is relevant to a specific and clearly defined period of operation of the installation. This means that for the same installation a different maintenance factor is calculated for a different period of time. Therefore, another maintenance factor is calculated, for example, for 2 years and another maintenance factor for 4 years. This time period should be considered by the work designer as equal to the expected/prescribed useful lifetime of the selected types of luminaires, as determined according to the relevant and duly certified manufacturer’s data below.

The maintenance factor shall be calculated as a product of three sub-factors according to the following equation.

$$MF=LLMF \times LSF \times LMF \quad (4)$$

Each factor is defined and calculated as follows:

LLMF – Lamp Lumen Maintenance Factor:
The maintenance factor calculates the decrease in the luminous flux of the light sources over operating hours. It is calculated based on the technical characteristics of each light source. For LED sources the factor shall be calculated based on the data provided by the manufacturer of the LED light source in accordance with IES-LM-80 and IES-TM-21 and/or IEC 62717 and for the period of time related to the calculated maintenance factor

LSF – Lamp Survival Factor:
Calculates the probability of failure of light sources and is provided by the manufacturer of the light sources.

LMF – Luminaire Maintenance Factor:

Calculates the decrease of luminaire performance with regard to optical parts such as lenses, reflector, caps, etc. The calculation is done in conjunction with the IP protection index of the luminaire. Examples are provided in the corresponding tables of CIE 154:2003 and ISO/CIE TS 22012:2019. For this calculation, the work designer shall take into account the planned maintenance/cleaning frequency of the luminaires, based on the specifications/manuals of the work under consideration.

3.3 Lighting design software

The design software shall be able to carry out the necessary phototechnical calculations. It shall incorporate any revisions to European and applicable standards (e.g. EN 13201)**)**, and also have the possibility to produce 3D models of photometric analysis. It is also necessary to be compatible with the photometrics of most industrial luminaires of the international market in the most recognizable file formats (.ldt,.ies) or newer ones.

3.4 Design optimisation

As discussed in §3.1, the work designer in any case shall draw up the complete Phototechnical Standard containing all the characteristics necessary for drawing up phototechnical studies on specific requirements, so that its optimisation can then be carried out based on the energy footprint of the intervention, as well as the efficiency of the utilisation of the lighting produced.

Optimisation is about finding/exploring the alternative photometric solutions resulting from the equipment for each case of the Phototechnical Standard, as well as finding the best solution in each grid separately and/or overall in the installation under consideration. Optimisation is therefore about finding the most energy-efficient solution, i.e. the solution with the lowest absorbed electrical power.

At the same time, the work designer shall calculate the following quality and energy performance indicators laid down in ELOT EN 13201-5:2016.

3.4.1 Power Density Indicator

$$D_p = \frac{P}{\sum_{i=1}^{n} (E_i \cdot A_i)} \frac{W}{lx \cdot m^2} \quad (5)$$

where:

- ***D_p***: Power density indicator
- ***P***: The total power of the luminaires covering the area concerned
- ***E_i***: The average horizontal illuminance of the sub-area ***i***
- ***A_i***: The surface area of the sub-area ***i*** illuminated by the lighting system
- ***n***: The number of illuminated sub-areas

The ***D_p*** indicator calculates the performance of the lighting system in the area of interest (carriageway, sidewalks, etc.) presenting the amount of absorbed power required for road lighting. It should be noted that the Dp indicator is an evaluation of the lighting solution based on the illuminance criterion, i.e. for lighting classes C and P

The detailed instructions for use of this indicator are described in ELOT EN 13201-5:2016.

3.4.2 Luminance factor

When the design criterion relates to luminance, i.e. M classes, the work designer shall calculate the luminance factor q_{inst} as set out below and in more detail in ELOT EN 13201-5.

$$q_{inst}=\frac{\overline{L}}{Q_0\cdot\overline{E}}\quad(6)$$

where:

q_{inst}: Luminance factor
$\overline{L}$: Average luminance of the carriageway
$\overline{E}$: Average illuminance on the carriageway
Q_0: The total asphalt reflectance

The luminance factor shows the efficiency of the lighting distribution and the positioning of the luminaires in order to produce the greatest possible luminance with the least possible illuminance on the carriageway for a given asphalt reflectance factor.

3.4.3 Overall efficiency indicator of the installation.

The overall efficiency of a lighting installation may be calculated for installations, with luminance or illuminance as a calculation criterion, using the following equation.

$n_{inst}=C_L\cdot f_M\cdot U\cdot R_{LO}\cdot n_{ls}\cdot n_p\,(7)$ where:

n_{inst}: Total efficiency of the road lighting installation
C_L: Luminance correction factor
f_M: Total maintenance factor of the installation
U: Utilisation factor of the installation
R_{LO}: Optical output ratio of luminaires
n_{ls}: Efficiency of light sources in lm/W
n_p: Power efficiency of luminaires

The detailed instructions for use of this indicator are described in ELOT EN 13201-5:2016.

3.4.4 Annual Energy Consumption Indicator

The Annual Energy Consumption Indicator D_e calculates the performance of the lighting system during the period considered (e.g. year) in the area of interest. This indicator specifies the amount of consumed energy required for road lighting.

$$D_E=\frac{\sum_{j=1}^{m}(P_j\cdot t_j)}{A}\,\frac{Wh}{m^2}\quad(8)$$

where:

D_e: Annual Energy Consumption Indicator
P_j: The total power of the luminaires covering the area concerned during the period of operation j
t_j: Duration of the operation period j
A: Surface area of the area illuminated by the lighting system
m: Number of different operation periods

The work designer may refer to ELOT EN 13201-5 standard for more detailed information on the explanation of the individual elements and the implementation of the performance indicators.

The detailed instructions for use of this indicator are described in ELOT EN 13201-5:2016.

The work designer has the option to introduce other quality criteria which result to the upgrade of the provided lighting service. Examples include the calculation of the installed power per road kilometre (kW/km), the assessment of the different lighting proposals according to the overall lighting uniformity (luminance and/or illuminance) and longitudinal luminance uniformity.

It is proposed that the quality criteria of the Phototechnical Standard be used as technical evaluation criteria for the evaluation of alternative tenders in the tendering procedures, as they are a purely objective evaluation method that promotes a positive lighting result.

3.5 Light pollution restriction and colour temperature of light sources

Light pollution is an important side effect of outdoor lighting that affects both the users themselves and the surrounding environment. In order to limit stray light and light pollution in adjacent areas, luminaires used in road lighting shall have zero light emission in the upper hemisphere by design, i.e. ULOR = 0 %. The evaluation of these indicators shall be carried out with reference to positioning of the luminaires at 0 degrees angle. It should be noted that this requirement concerns road luminaires and not architectural luminaires (ceiling lamps, decorative lighting, etc.). In special cases of road lighting with the use of highly asymmetrical headlamps or luminaires, a deviation from the specification up to and including category U1 may be allowed.

In cases where it is considered appropriate to place the luminaires at an angle greater than 0 degrees (due to a more efficient solution), it is suggested that the angle of the luminaires should not exceed 10 degrees and it is specified that in no case should it exceed 15 degrees.

According to the “Revision of the EU Green Public Procurement Criteria for Road Lighting and traffic signals” of the JRC of the EU, in order to reduce the effect of high colour temperature on human circadian rhythm and suppress melatonin secretion and to limit the impact on living beings, as well as according to the regulations of other European countries, the nominal colour temperature of light sources for use on the national road network should be ≤ 4000 K (recommended ≤ 3000K), while for residential areas the use of light sources with a nominal colour temperature ≤ 3000K is required.

4. Equipment specifications

4.1 Minimum technical specifications for road lighting luminaires

Arm-mounted luminaires or equivalent road headlamps used for exterior illumination of each type of road shall have the following minimum technical characteristics and certifications. Road or urban luminaires with architectural decorative design are excluded. It should be noted that each Contracting Authority may require additional specifications from those listed below, as well as incorporate the specifications of the applicable HTS (Hellenic Technical Specifications).

4.1.1 Constructional characteristics of a luminaire

The luminaire body shall be made of a suitable material for the operation conditions and requirements. In cases where lighting equipment is close to a seaside environment, it shall withstand the seaside environment. The construction of the luminaire body will ensure the ability to dissipate the heat produced for both the optical source and the electrical parts. The luminaire may have the ability of angle adjustment if required by the respective lighting studies. Accordingly, headlamps shall be fitted with suitable supports for their proper adjustment on the bases of the poles.

In the case of headlamps where the electrical instruments are in a separate housing from the optical unit, they shall be locked in an appropriate frame for their proper operation and shall be accompanied by the appropriate wiring to the optical unit.

4.1.2 Protective cover

The protective cover is designed to protect the optical unit from the external environment. The cover used to protect the optical unit may have the following 2 forms.

- In the case of optical LED sources, the protective cover shall be made of tempered glass, which protects the optical source and the light diffusion lenses or reflectors as a whole. The cover may be clear or translucent (Frosted type).
- Protective cover made of polycarbonate material with ultraviolet (UV) resistance. In this case, the protective cover may also be fitted with diffusion lenses.

4.1.3 Optical unit materials

In the case of a glass or polycarbonate cover without diffusion lenses, diffusion is achieved by aluminium lenses or reflectors. Lenses may be made of PMMA or silicone or other equivalent material resistant to operating temperatures. Reflectors shall be made of anodised aluminium or other material of higher reflectance.

4.1.4 Operating characteristics

4.1.4.1. Photometric data

Photometric data are obtained at a Ta 25ºC temperature. Photometric data are obtained in accordance with EN13032 or IES LM 79 (their newest versions).

Power and luminous flux of the luminaires are selected based on the lighting needs of each application. In addition, in the case of use of LED luminaires, the correlated colour temperature (CCT) shall not exceed 4000 K (see §3.5). The combination of CCT & CRI shall be expressed in colour codes according to IEC 62717 e.g. 740 (CRI 70, 4000K), 730 (CRI 70, 3000K) etc.

The luminous intensity distribution of the luminaire shall be selected by the work designer according to the requirements.

4.1.4.2. Electrical characteristics

The luminaire shall have the following minimum electrical characteristics:

- Operation on a network with a nominal operating voltage of 230V AC 50 Hz and tolerance to fluctuation on the nominal operating value of at least 220-240V.
- Protection against overvoltage of at least 10 kV (according to ELOT EN 61000-4-5, test class X).
- Electrical shock protection class I or II (according to EN 60598-1).
- Power factor of at least 0.9 in full load mode of the luminaire. In cases where the luminaire is also operating under dimming conditions, the work designer shall ensure that the power factor is kept as high as possible and as close as possible to the above value.
- Light flicker control (PstLM, SVM according to IEC TR 61547-1:2020 and IEC TR 63158:2018).

4.1.4.3. Degrees of protection against external influences

The luminaire shall be watertight and dust-tight of at least IP66 category and shall have shock resistance of at least IK08.

The luminaire shall be suitable for operation in an external environment between -20°C and +40°C. Given the importance of the high temperature in the functionality of luminaires, the upper temperature limit complies with EN/IEC 60598. In particular, each luminaire shall be able to operate at a temperature of up to Ta 40°C or greater depending on the external environment conditions.

4.1.4.4 Connectivity

LED luminaires shall have a luminous flux dimming function. For this purpose, their power supply units shall be able to receive appropriate commands via DALI or 1-10V (0-10V) or PWM or other type depending on the technological advances.

If luminaires are not supplied with the above management solution built-in, they shall be supplied with suitable future expansion sockets. These sockets ensure the smooth operation of the luminaire until a controller is installed. In particular, each road luminaire shall be equipped with NEMA Socket 7 PIN C136.41 or Zhaga Socket or another standardised equivalent according to the technological advances and connectivity techniques.

All internal connections of the luminaire shall be implemented during its production and the future installation of a controller shall be as simple as possible.

4.1.4.5 Maintenance of luminous flux

The maintenance of the luminous flux of LED sources is expressed through IES LM-80 and IES TM-21 technical report. Luminaires shall have LED sources with a minimum value of L80 calculated at 50 000 hours at an outdoor temperature of at least 25°C. The LM 80 report shall be used as evidence for this statement, which shall contain one or more representative datasets of the luminaire function, i.e. combinations of driving current (If-mA) & temperature Ts (or Tsp).

It is noted that if a declaration of luminous flux maintenance is requested, with a Byy coefficient other than B50, then IEC 62717 may also be used for the calculation.

4.1.4.6 Certifications

Luminaires shall have at least the following certifications:

1. Manufacturer's declaration of conformity according to CE. The declaration shall include compliance with the Directives and their corresponding harmonisation standards as applicable.
    a. Low Voltage Directive (LVD) 2014/35/EU
    b. Electromagnetic Compatibility Directive (EMC) 2014/30/EU
    c. Eco Design Directive 2009/125/EC
    d. Regulation (EU) 2017/1369 as supplemented by Regulation (EU) 2019/2015
    e. ATEX 2014/34/EU for products intended for use in potentially explosive atmospheres, where appropriate and if the study provides for the creation of such conditions in the places where the products are to be placed
    f. Rohs Directive 2011/65/EU
2. The manufacturer of luminaires shall have an active quality management system ISO 9001:2015 and environmental management system ISO 14001:2015 or newer. The certification shall include the manufacture and placing on the market of lighting products.
3. ENEC or other equivalent ISO Type 5 certificate which meets the requirements of the low voltage standards (EN 60598-1, EN 60598 2-3).
4. Optional – ENEC+ type certificate or other equivalent ISO Type 5 certificate relevant to the application of EPRS 003 (application of EN/IEC 62722-2-1).
5. Photometric data shall be obtained from an ISO 17025-accredited laboratory of an EA-MLA or IAF/ILAC body. The Contracting Authority may also require, in addition to an accredited laboratory, that the laboratory of the photometric data be alternatively Approved/Recognized by an accredited body according to ISO 17025. In this case a laboratory declaration shall be submitted that the photometric data originate from the laboratory. Evidence of the origin of photometric data may be a statement from the issuing laboratory or the manufacturer's laboratory if available.
6. It is recommended that accreditation of the laboratory by an EA-MLA body (and not generally by IAF/ILAC) is required, since only European bodies belong to this group of accreditation bodies.
7. The luminous flux maintenance data according to LM 80 shall be obtained from an ISO 17025, EA-MLA or IAF/ILAC accredited laboratory.

It is noted that the above certifications, as well as the construction characteristics, are minimum requirements and each work designer may enhance the requirements with characteristics that promote the quality of the products offered. More specific certificates and/or test reports (e.g. wind pressures, vibrations, thermal resistance etc.) may also be requested depending on the conditions of each application.

Finally, it is necessary to provide additional information material, photographs, installation manuals and other technical material supporting compliance with the specifications.

4.2 Minimum technical specifications for remote control systems of external lighting

4.2.1 Interoperability

Control systems of road lighting installations shall be equipped with the appropriate technology to enable interoperability with other control systems. Interoperability concerns the following parameters:

a) The ability to exchange operational data and control signals between two or more control systems of different manufacturers under common control software. This requires the provision of an appropriate application programming interface (API, SDK, etc.) by the control system manufacturer.

b) In order to enable the upgradability of the lighting controllers, as well as the possibility of expanding the options of the operator, it is proposed to use NEMA Socket or Zhaga type lighting controllers, so that the lighting installation can easily be upgraded in the future.

4.2.2 Operating characteristics

The remote control system consists of the field devices and the corresponding software. Field devices, in terms of their characteristics and their number, depend on the corresponding communication technology. There are 3 basic categories of remote control systems

- Systems with central segment controller
- Systems with technologies that allow each luminaire to communicate directly with the management cloud without the mediation of a central segment controller.
- It is permitted to use hybrid systems with 2 types of controllers creating a mesh network at an appropriate unbundled frequency for the communication of the controllers with the cloud. The first type of controller will communicate both with the mobile network and the local mesh network. The second type of controller will have communication at least with the local mesh network.

In the case of systems with a central segment controller, communication between the luminaire controllers and the respective segment controller can be achieved either by wireless or wired means. In the case of wireless communication, the wireless segment controller may be placed close to or within an electrical supply panel (e.g. lighting systems of road and squares).

All control systems shall have the following minimum operating characteristics:

1. Direct dynamic control of any luminaire or group of luminaires (switching on/off and adjusting luminous flux at intermediate levels).
2. Ability to create groups of luminaires according to the installation needs.
3. Supervision of the luminaires operating condition.
4. Ability to connect additional sensors (motion, presence of photocells, weather conditions, etc.) which increase the functionality of the installation.
5. Visual operation information on a GIS system (e.g. Google Maps etc.).
6. Storage of operating parameters in a database.
7. Creation of operating reports.
8. Creation of error alarms.

It is noted that the work designer may request more operating characteristics as well as construction features than those mentioned, depending on the requirements of each application and the technology he/she wishes to use.

5. Adaptive lighting operation methodology

5.1 Introduction

According to ELOT EN 13201, adaptive lighting is a technique for adjusting the lighting class taking into account changes in specific class selection criteria during the installation operation. When applied, adaptive lighting results to a reduced energy footprint of the lighting installation and environmental protection both in terms of greenhouse gas emission and light pollution.

In particular, according to CEN/TR 13201-1, it is allowed to change the lighting class of a road, i.e. the nominal lighting class, if during the operation of the road lighting system, the weight of one or more of the criteria changes, since this is a change of parameters as a whole. In this case and for the duration of the weight variations, the road is assigned a lower lighting class, also called adaptive lighting class.

In this way, multiple lighting levels are achieved during the night, serving the local and hourly road lighting needs, offering optimal conditions to the driver while keeping energy consumption as low as possible. A nominal lighting class and, where applicable, one or more adaptive lighting classes are assigned to each road under study, if the weight of one or more class selection criteria changes.

5.2 Design of an adaptive lighting work

The design of an adaptive lighting work requires that the lighting equipment shall be able to adjust the luminous flux for specific periods of time, whether for autonomous programming or remote management.

Given the nominal class and the adaptive lighting classes, the required luminous flux levels or “Dimming levels” are defined. These levels are identified by the lighting designer after the corresponding calculations of adaptive lighting.

The number of levels of luminance adjustment is derived from the number of adaptive classes that the work designer has defined. Depending on the capabilities of the lighting equipment and the remote management system, the following luminous flux control profiles can be implemented:

1. **Fixed dimming level.** In this case, there are fixed operating profiles that are activated at specific times selected by the work designer, depending on the local conditions of the changing parameters. The fixed dimming level may relate, for example, to one or more intermediate levels other than the nominal. The fixed dimming level is achieved either by pre-programming the luminaires during the installation phase or by means of a remote lighting management system.
2. **Variable dimming level.** If the installation is able to monitor in near real time the change in parameters affecting the adaptive lighting classes, then a variable dimming level may be used. This method is applied to motorways and/or urban avenues with traffic flow surveillance. Variable dimming level can be achieved through the

interconnection of the lighting system with traffic data and with appropriate processing. This method achieves greater energy saving and also ensures that the lighting will always respond to traffic conditions, even in the event of an emergency.

6. Compliance control of road lighting equipment

6.1 Introduction

Road lighting studies stipulate that a specific chapter should be included, i.e. “Guidelines for Compliance Control during Implementation (GCCI)”, describing the procedures to be followed for compliance control during the implementation phase of the study.

The compliance control relates to the qualitative and quantitative controls to be carried out during implementation and after completion of the installation works of road lighting equipment.

The control aims at confirmation, by sampling, of the results obtained, whether on the equipment itself (luminaires, control system, etc.) or the installation as a whole (lighting performance on-site).

The compliance control procedures should in any case be in accordance with the provisions (certification data, proper operation tests, acceptance criteria of finished work, etc.) of the relevant Hellenic Technical Specifications (HTS/ELOT TS 1501-05-07-02-00 “Road lighting columns fixtures”). Compliance control shall not in any case replace the controls from which the certificates of compliance provided for in the Technical Specifications result nor shall it certify the production process of the equipment.

The controls to be provided for in the GCCI, particularly with regard to luminaires and their performance after integration into the road lighting installation, should include laboratory measurements and on-site controls described below.

6.2 Laboratory measurements

Sample controls of the equipment should be provided for each new installation of luminaires in road lighting works (or upgrade of an existing installation). The number of samples to be controlled depends on the work and the number of different types of luminaires. In any case, the sample controls should adequately represent the entire installation being controlled.

Samples should be taken during installation by the group of luminaires to be installed on-site and no factory sample should be selected for inspection.

Measurements should be carried out by a body accredited for the respective measurement which shall have the appropriate infrastructure and calibrated equipment. Measurements should be performed in accordance with one of the standards EN 13032, CIE S025 or IES LM79.

The characteristics to be controlled, as a minimum, on each sample are shown in Table 20. The controlled characteristics shall be compared with those provided by the manufacturer and the deviations shall not exceed the corresponding percentage as indicated in the same table.

Table 20 – Characteristics measured during laboratory testing of luminaires.

Controlled characteristic	Maximum deviation from manufacturer's declaration
Operating voltage	-
Total luminaire current	-
Total luminaire power	+ 10%
Luminaire power factor at full load	- 0.05
Harmonic distortion of luminaire current up to the 30th harmonic	+ 2%
Total luminous flux of luminaire	- 10%
Luminous intensity distribution of luminaire	-
Correlated colour temperature (CCT) measured at C0-C330 levels at 60^o and in angles c=0 to c=180^o at 30^o).	± 200K
Power variation relative to luminous flux for luminaires with adjustable luminous flux between 100 % and 0 % of the luminous flux with 10 % adjustment percentage.	-
Light flicker of luminaire (PstLM, SVM) in nominal operating conditions and at each luminous flux control level.	+ 5%

6.3 On-site measurements

6.3.1 Categories of on-site measurements

On-site measurements concern the control of the overall performance of a road lighting installation (luminaires, installation, geometric characteristics, etc.). The GCCI shall define that control is to be carried out in the following cases (as described in the relevant Technical Guideline of the Technical Chamber of Greece (TGTCG) "Design and Control of Road Lighting Facilities", 2018):

a. **Measurements before delivery of the installation (Type 1 – T1)**
   Provision should be made for measurements to be carried out during the final delivery phase of the work and the process of commissioning the road lighting system. Compliance with the applicable specifications and/or the results of the lighting studies shall be controlled.

b. **Measurements during the lifetime of the installation (Type 2 – T2)**
   Provision should be made for measurements at regular and predetermined operation intervals of the road lighting system. These measurements check the degradation rate of the installation, identify any operational problems and adjust maintenance and re-inspection intervals.

c. **Adaptive lighting measurements (Type 3 – T3)**
   It concerns a series of measurements to be carried out for the control and adjustment of road lighting installations with adjustable luminous flux. These measurements check or adjust accordingly the achieved levels of adaptive lighting. They are performed in combination with T1 or T2 measurements.

d. Measurements to investigate deviations (Type 4 – T4)

Provision should be made for measurements to be carried out in cases where deviations of the achieved lighting levels from the lighting studies or project specifications are investigated due to equipment, installation method, asphalt properties, environmental or other factors.

The measurements are carried out by properly trained personnel and according to ELOT EN13021-4 standard. Additional control requirements may be provided for by the work designer. Instruments for measuring photometric, geometric and electrical characteristics should be suitable for the intended use, have valid calibration certificates during the measurement period and cover the measurement range of each characteristic expected to be measured on-site.

The reports on the measurements should be provided in detail with the indication of the individual measurements, the calculation of the quality indicators (where necessary), the geometric and electrical characteristics of the installation, the weather conditions, etc. according to ELOT EN13021-4 standard.

6.3.2 Definition of on-site measurement areas

On-site measurements are performed on standard grids according to ELOT EN13021-4. Standard cases of measurement areas are presented in Figure 8.

A measuring grid is defined between two continuous lighting poles (on the same road side) as shown in Figures 9 and 10. In each standard geometry tested (pole spacing, road heights/widths, type of luminaire, etc.) at least 2 grids should be measured.

In any case, the area(s) of measurement shall be carefully selected so as be representative of the concerned road or installation in general.

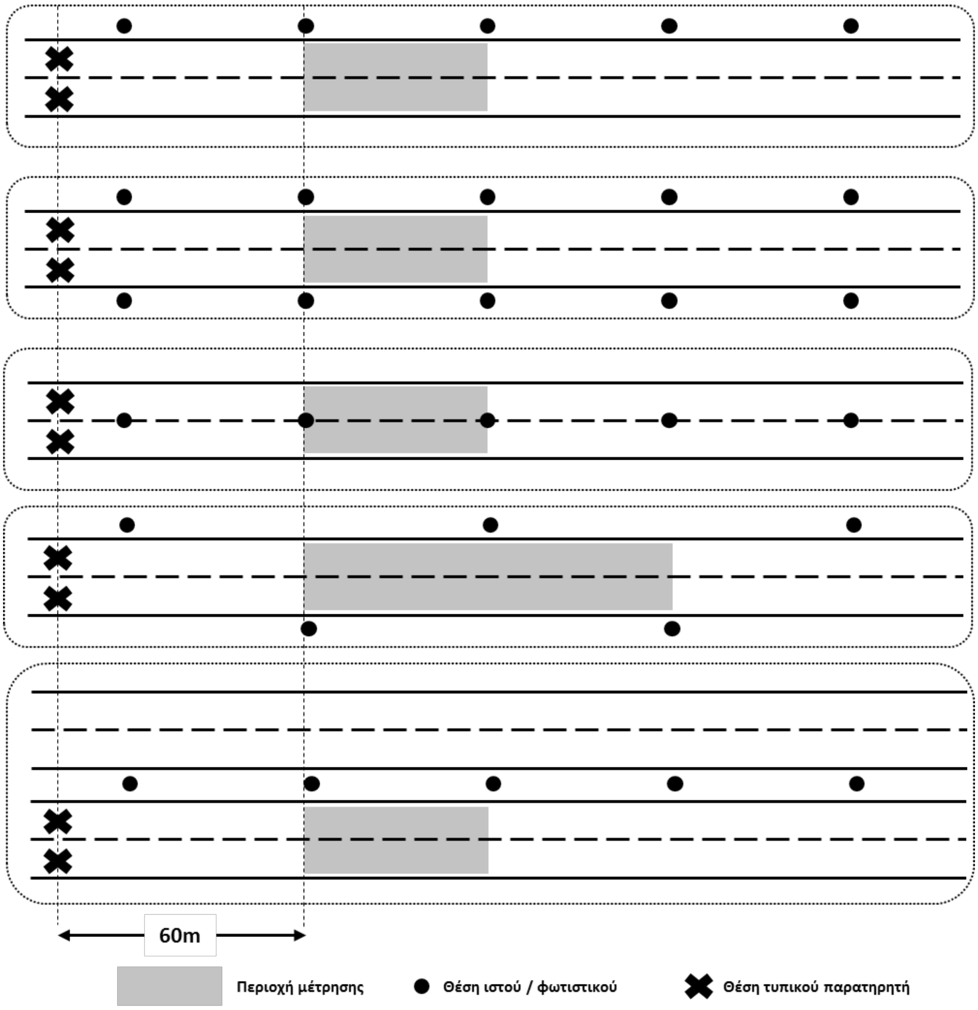


Figure 8 – Standard measurement areas of photometric road lighting characteristics according to ELOT EN 13201-3 (source: TGTCG, 2018).

Περιοχή μέτρησης	Measurement area
Θέση ιστού/φωτιστικού	Location of pole/luminaire
Θέση τυπικού παρατηρητή	Standard observer position

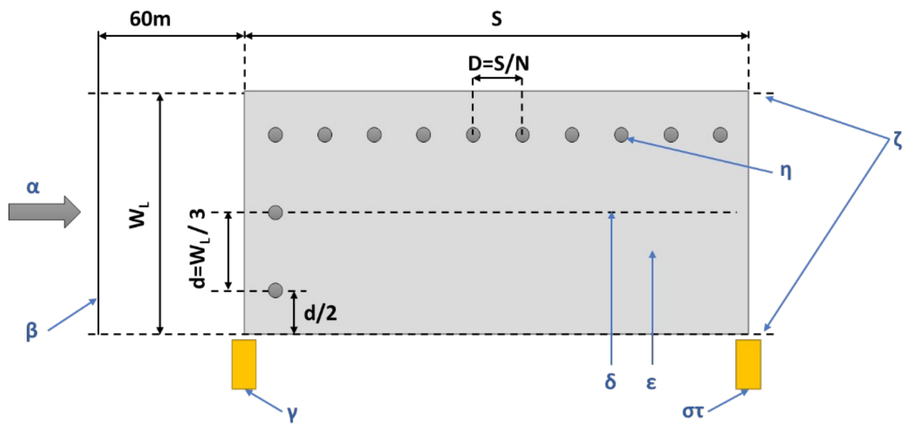


Figure 9 – Standard grid for luminance or illuminance measurement according to ELOT EN 13201-3 (source: TGTCG, 2018).

The characteristics of Figure 9 are the following:

- ***α*** : Observer direction
- ***β*** : Longitudinal observer position
- ***γ*** : First luminaire in the measurement area
- ***δ*** : Centreline of the traffic lane
- ***ε*** : Measurement area
- ***στ*** : Last luminaire in the measurement area
- ***ζ*** **:** Traffic lane limits
- ***η*** **:** Measuring points
- W_L : Traffic lane width
- ***S*** : Distance between luminaires
- ***D*** : Longitudinal distance between measuring points (D=S/N)
- ***N*** : Required number of measuring points along the road
  For S<30m, N=10.
  For S> 30 m, N equals the minimum integer resulting in D≤3m

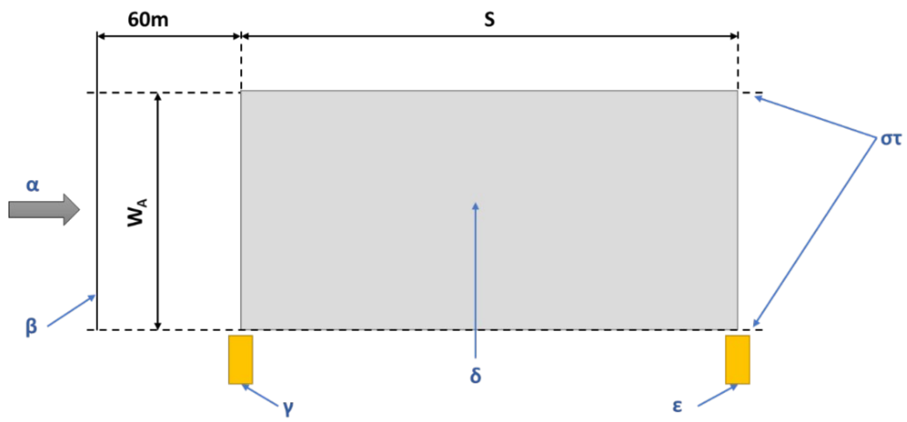


Figure 10 – Taking into account the whole measurement area for the measurement of luminance with an ILMD device according to ELOT EN 13201-3 (source: TGTCG, 2018).

The characteristics of Figure 10 are the following:

- ***α*** : Observer direction
- ***β*** : Longitudinal observer position
- ***γ*** : First luminaire in the measurement area
- ***δ*** : Measurement area
- ***ε*** : Last luminaire in the measurement area
- ***στ*** : Traffic lane limits
- $\boldsymbol{W_A}$: The width of the measuring area
- ***S*** : Distance between luminaires

In each grid, the lighting characteristics corresponding to the class (luminance or illuminance) are measured and the corresponding qualitative and quantitative indicators are calculated.

6.3.3 On-site measuring instruments

Instruments for measuring the photometric, geometric and electrical characteristics of a road lighting installation shall be designed for the intended use, have valid calibration certificates, and cover the measurement range of each measured characteristic expected to be measured on-site. Table 21 shows the indicative requirements of the measuring instruments.

Table 21 – Indicative requirements of measuring instruments for road lighting installations (source: TGTCG, 2018).

Measuring type	Characteristic	Requirement
Illuminance *(portable instrument)*	Measurement range	0.1 – 10 000 lx or wider
	Accuracy	± 3 % ± 1 digit
	Repeatability	± 1 % ± 1 digit
	Filter accuracy V(L)	f1' <6%
	Cosine correction	f2 < 3%
	Spectral correction	Yes
Luminance *(portable analogue measuring instrument)*	Measurement range	0.01 – 10 000 cd/m^2 or wider
	Field of vision	2' of an angular degree in length 20' of an angular degree in width
	Filter accuracy V(L)	f1' <6%
	Spectral correction	Yes
	Accuracy	± 3 % ± 1 digit
	Repeatability	± 1 % ± 1 digit
Luminance *(ILMD device)*	Measurement range	0.001 – 10 000 cd/m^2 or wider
	Image resolution	640x480 pixels or more
	Field of vision	> 20^O horizontally > 10^O vertically
	Filter accuracy V(L)	f1' <6%
	Spectral correction	Yes
	Accuracy	± 3 % ± 1 digit
	Lens shading correction	YES
	Noise correction	YES
Colour spectrum/temperature *(portable spectrometer or colorimeter)*	Spectral response range of instrument	380-780 nm or wider
	Measurement analysis (spectrometer)	1 nm or less
	Colour temperature calculation (T)	YES
	Ra Calculation	Desired
Electrical characteristics *(portable power analyser)*	Voltage measurement (V)	YES
	Current measurement (I)	YES
	Power measurement (VA, W, Var)	YES
	Power factor measurement (L)	YES
	Harmonic distortion measurement (THD)	YES
Distance measurement *(distance meter or tape)*	Measurement range	0 – 100 m or wider
	Distance meter accuracy	± 3 % ± 1 digit
	Tape measurement accuracy	0.1 or better
Environmental characteristics (portable thermometer)	Temperature measurement	YES
	Relative humidity measurement	YES
	Storage of measurement time series	YES

6.3.4 Luminance measurements (M light classes)

The compliance control of M class road lighting installations shall be carried out by measuring road luminance. Measurements shall be carried out in accordance with ELOT EN13201-4 in a grid shown in Figures 9 or 10. The measuring grids should be selected from 2 consecutive luminaires located within a group of at least 4 similar luminaires on a similar installation. A luminance measuring device as described above shall be used for measurements.

Measurements shall be carried out from a distance of 60 m from the beginning of the grid and from a height of 1.5 m above the ground. If the distance of 60 m is not feasible, measurements may be carried out from a smaller height and a shorter distance, but in any case the relative angle of the measuring position from the beginning of the grid should be about 1 degree.

Measurements shall be carried out on dry and moisture-free carriageway which is free of foreign objects, such as parked vehicles, building materials, and other obstacles on the grid. In any case, stray light, if any, shall be removed by means of an additional measurement with the luminaires switched off, if possible. If the section to be measured contains asphalt sections of different quality and paving date or alterations due to use, an alternative measuring grid shall be selected. Otherwise, this shall be clearly indicated in the measurements report. In the case of a new installation, the condition of the asphalt and its age shall be indicated.

6.3.5 Illuminance measurements (C and P lighting classes)

The compliance control of C and P class road lighting installations shall be carried out by measuring the illuminance on the road surface concerned. The measurements shall be performed according to the ELOT EN13201-4 standard in a grid shown in Figure 9. The measuring grids shall be selected from 2 consecutive luminaires located within a group of at least 4 similar luminaires on similar installation. An illuminance measuring instrument as described above shall be used for measurements.

Measurements shall be performed at each point on the grid in contact with the ground in a horizontal position. The illuminance value of each point shall be recorded when the instrument reading is stabilised. In any case, stray light, if any, shall be removed by means of an additional measurement with the luminaires switched off (if possible). Particular attention shall be paid to the creation of shadows in the instrument sensor by the instrument body, by the instrument operator or by various obstacles around and within the measuring grid.

6.3.6 Measurement of geometrical and electrical characteristics

In addition to the measured photometric characteristics, the following characteristics shall also be recorded.

- Road width
- Width of each traffic lane
- Emergency lane width
- Pole spacing in the measurement area, plus one pole before and pole after.
- Height of luminaires in the measuring area, plus one luminaire before and one luminaire after.
- Distance of each luminaire from the beginning of the nearest lane
- Angle of the luminaire in relation to the horizontal level
- Carriageway cant
- Type of each luminaire.

Where electrical measurements are possible, they shall be carried out on each luminaire separately or on a specified number of similar luminaires.

The change in temperature and relative humidity shall be recorded throughout the measurements.

7. International and European technical guidelines for tunnel lighting

The standards and technical references governing tunnel lighting are mainly the following three.

7.1 CIE 88 – Guide for the Lighting of Road Tunnels and Underpasses

CIE 88 technical report is the main source of information on tunnel lighting design both in Europe and internationally. This report has also been the basis for the most recent European Technical Report CEN CR 14380 described below. These two technical reports share the same information for the most part, while differences are found only in selected parts.

The latest version of CIE 88 was published in 2004 (2nd version) and it has been under review since 2017. The new version is expected to be published in 2023 or 2024.

CIE 88 report contains instructions for class selection, lighting requirements and lighting design methods in tunnels and underground passages. Some of the main sections are the following:

- Separation between long and short tunnels
- Tunnel lighting zones
- Parameters for the selection of class and requirements
- Calculation of external luminance of the tunnel mouth (L_{20} ή L_{seq})
- Definition of luminance variation curve along the tunnel
- Emergency lighting
- Maintenance and operation issues
- Other design proposals and guidelines

Most lighting studies in Greece and globally are based on CIE 88. Specific software has been developed to take into account the recommendations and parameters for selecting the lighting requirements described in this technical report.

7.2 CIE 189 – Calculation of tunnel lighting quality criteria

The CIE 189 Technical Report was published by the International Commission on Illumination in 2010 with the aim to determine the parameters for calculating photometric characteristics for tunnel lighting. It is the most accepted source of information for the development of software for photometric tunnel lighting calculations. All software for such studies has adopted the calculation methodology described in CIE 189.

7.3 CEN CR 14380 - Lighting applications - Tunnel lighting

The CEN CR 14380 Technical Report was published in 2003 and adopted by ELOT in 2004 as ELOT CR 14389. It essentially concerns the European version of CIE 88 on tunnel lighting with some additions and variations. This report has been adopted mainly by European countries and in most of them it is either used in combination with CIE 88 or has informally replaced it. In Greece it is also used in combination with CIE 88. The content of this report is similar to CIE 88 as mentioned in §7.1.

8. Tunnel lighting requirements

This Regulation draws on the methodologies described in CEN CR14380 Technical Report. In the event that a new version of CEN CR 14380 or CIE 88 is published (whichever is the latest), this Regulation will be updated if it is deemed that the provisions of these new versions introduce significant changes.

Among the proposed methodologies for a work designer to choose, the following is suggested by way of example:

8.1 Separation of tunnels into long and short tunnels

Tunnels or underground passages should be equipped with a daily lighting system if their length above 200 m. Tunnels less than 25 m in length do not require daily lighting and tunnels with intermediate lengths should be considered using the LTP method (see §8.2). Table 22 summarises the above.

In any case, the construction characteristics of the tunnels should be thoroughly examined and where appropriate, tunnels shorter than 25m may be illuminated during the day for special safety reasons.

Table 22: Need to use daily tunnel lighting

Tunnel length	Need for daily lighting
> 200m	Yes
Between 25 m and 200 m	Investigation by LTP method
< 25m	No

8.2 Investigation of the need to use daily lighting (LTP method)

For tunnels with a total length between 25 m and 200 m, the need for a daylighting system shall be investigated by calculating the LTP indicator. This indicator refers to the percentage of visibility of the tunnel exit relative to the entrance of the tunnel (Look Through Percentage – LTP) and is defined by Equation (9).

$$LTP = 100 \cdot (\text{ΕΣΤΖΗ surface}) / (\text{ΑΒΓΔ surface}) \qquad (9)$$

The surfaces listed in Equation (9) are defined in the generalised drawing in Figure 11. The LTP is calculated either based on the drawing of the tunnel or on a photograph thereof. In any case, the field of vision is defined by the image/drawing when the observer is:

- at the safe stopping distance from the tunnel mouth
- at a height of 1.2 m above the ground
- in the centre of each lane

In the case of e.g. 3 lanes, 3 images or 3 drawings are taken and the LTP is calculated for each lane

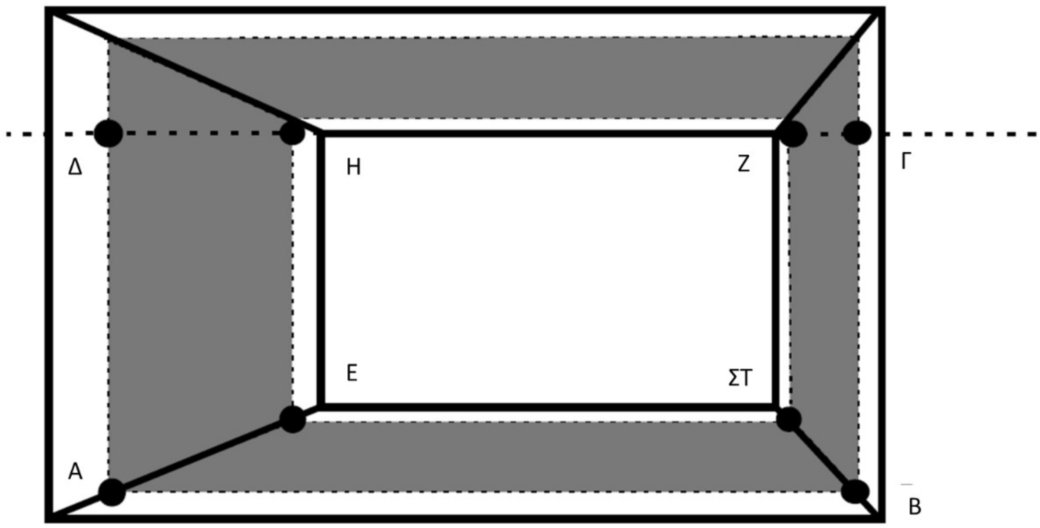


Figure 11: Generalised implementation plan for LTP method.

According to Figure 11, the roof of the tunnel is not taken into account. Also, due to the influx of natural light into the tunnel (entry and exit) a post-entry section (~5m) and a pre-exit section (~10m) are not taken into account for the LTP calculation.

In the case of tunnels or crossings with curvature in both the horizontal and vertical levels, it is preferable that the control is carried out based on the drawings and the LTP calculated using Equation (10). The corresponding angles of Equation (10) are shown in the generalised drawing of Figure 12.

$$LTP = 100 \cdot (\beta_u / \beta_i) \cdot (\alpha_u / \alpha_i) \quad (10)$$

The decision to use daily lighting according to LTP is presented in Table 23.

Table 23: Use of daily tunnel lighting in relation to LTP

LTP value	Need for daily lighting
< 20%	Yes
> 50%	No
Between 20 % and 50 %	Investigation of vehicles/pedestrians/cyclists visibility

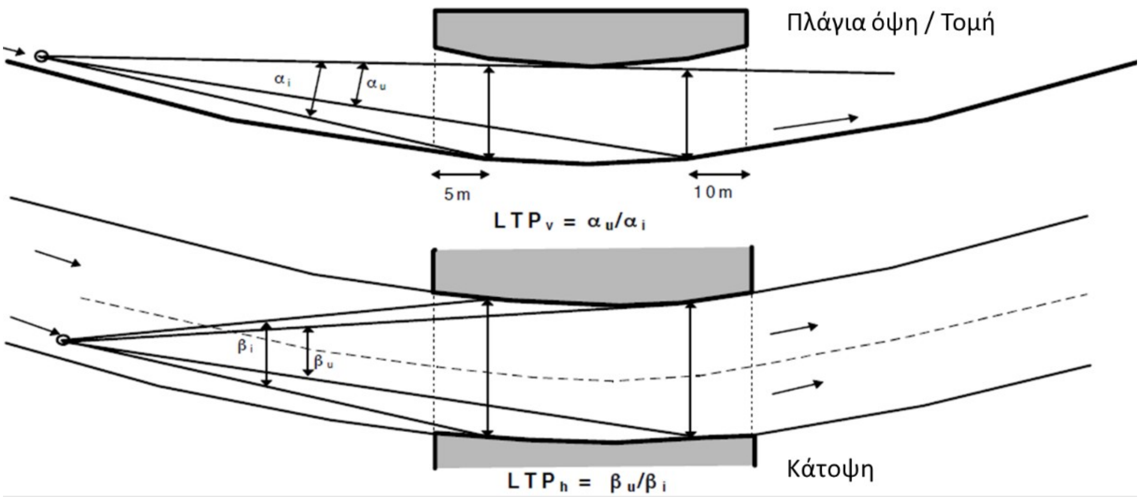


Figure 12: Generalised implementation plan for LTP method to tunnels with curvature

Πλάγια όψη/Τομή	Side view/Section
Κάτοψη	Floor plan

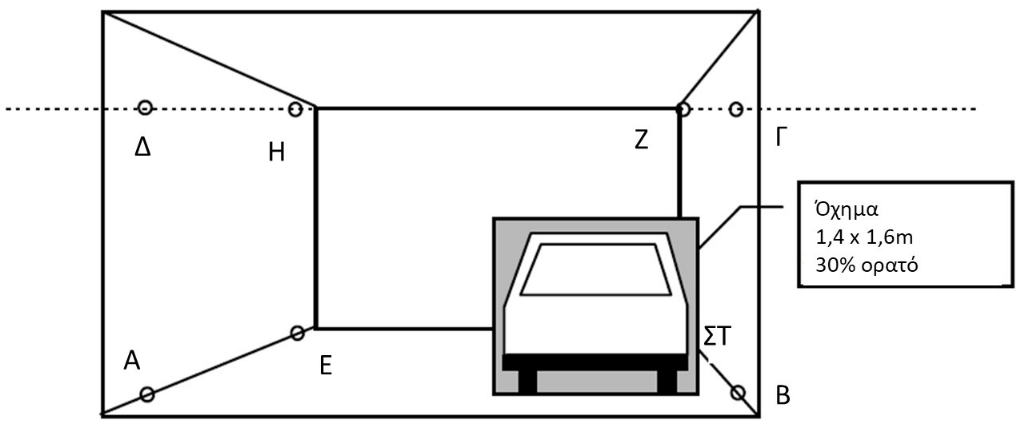
In cases where the LTP is estimated to be between 20 % and 50 %, a target detection investigation according to Figures 13 (for tunnels with only motor vehicles) and 14 (for mixed-use tunnels by pedestrians and cyclists) shall be carried out. In each case, a virtual car or pedestrian obstacle shall be placed in the centre of the lane to be controlled and the percentage of the visible obstacle shall be calculated compared to the tunnel exit.

The standard vehicle obstacle shall measure 1.4 m x 1.6 m.

The standard pedestrian/cyclist obstacle shall measure 0.5 m x 1.8 m.

The use of daily lighting is necessary when:

- More than 30 % of the standard vehicle barrier is not visible in relation to the tunnel exit
- More than 30 % of the standard pedestrian/bicycle barrier is not visible in relation to the tunnel exit



Όχημα	Όχημα
30% ορατό	30% ορατό

Figure 13: A generalised plan for the application of LTP method with a vehicle barrier (example).

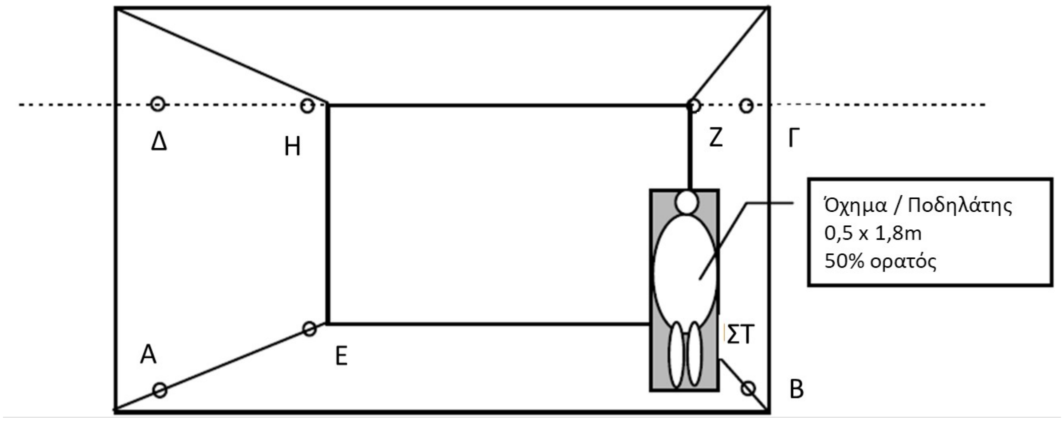


Figure 14: A generalised plan for the application of LTP method with a pedestrian or cyclist obstacle (example).

Όχημα/Ποδηλάτης	Vehicle/Cyclist
50% ορατός	50 % visible

8.3 Calculation of maximum external luminance L_{20}

The calculation of the maximum external luminance L_{20} of the tunnel shall be carried out using a drawing or photograph of the tunnel mouth from the safe stopping distance. Figure 15 shows the drawing of a typical tunnel from the safe stopping distance.

The L_{20} luminance is calculated using Equation (11):

$$L_{20} = \gamma L_c + \rho L_R + \varepsilon L_E + \tau L_{th} \quad \text{with: } \gamma + \rho + \varepsilon + \tau = 1 \text{ (cd/m}^2\text{)} \qquad (11)$$

where: L_C is the sky luminance, γ the sky coverage rate, L_R the road luminance, ρ the road coverage rate, L_E the surrounding area luminance, ε the coverage rate of the surrounding area, L_{th} the threshold luminance (or the luminance of the tunnel mouth) and τ the coverage rate of the tunnel mouth. All of the above are defined for the field of vision of 20^O.

The perspective of the drawing used or the photograph taken shall have an observation/taking position as follows:

- At the safe stopping distance from the tunnel mouth
- At a height of 1.2 m above the ground
- From the centre of the total width of the carriageway
- Direction towards the centre of the tunnel mouth

  In Equation (11), the tunnel mouth luminance $(L)_{th}$ is unknown and is the aim of the tunnel design. For a safe stopping distance of more than 100 m, τ is considered to be low (less than 10 %) and the tunnel threshold/mouth luminance L_{th} is significantly lower than the rest of L_{20} luminance values. Thus the contribution of the L_{th} factor can be omitted. Therefore:

$$L_{20} = \gamma L_c + \rho L_R + \varepsilon L_E \qquad (cd/m^2) \tag{12}$$

with:

$$\gamma + \rho + \varepsilon < 1 \tag{13}$$

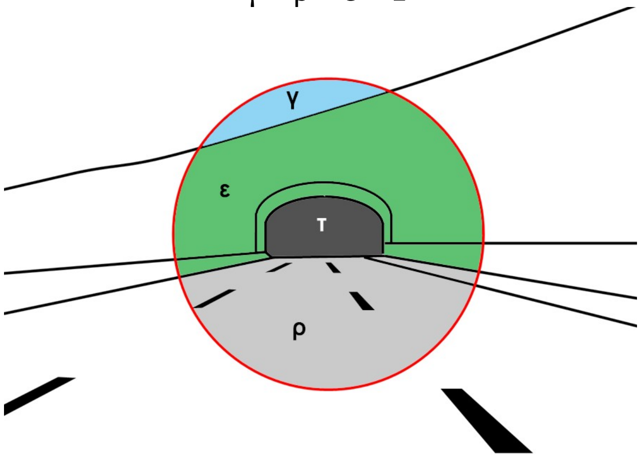


Figure 15: Example of a tunnel design from the safe stopping distance for the calculation of L_{20} luminance

The maximum L20 luminance shall be calculated according to the values in Table 24 and the coverage rates shall be calculated based on the photograph or the corresponding drawing.

Table 24: Luminance values of individual L_{20} factors for each type and orientation.

Driving direction	L_c (sky) kcd/m^2	L_R (carriageway) kcd/m^2	L_E (environment) kcd/m^2			
			Rock	Buildings	Snow	Plants
North	8	3	3	8	15 (V/O)	2
East West	12	4	2	6	10 (V) 15 (H)	2
South	16	5	1	4	5 (V) 15 (H)	2
(V) Vertical surfaces, (H) Horizontal surfaces						

8.4 Selection of lighting class and k factor

For long tunnels and for those requiring daily lighting, the appropriate tunnel class and the coefficient k according to Tables 4-6 shall be selected in order to calculate the threshold luminance L_{th}. The L_{th} luminance is calculated using the Equation (14) and is the required luminance of the tunnel entrance zone.

$$L_{th} = k \cdot L_{20} \qquad (cd/m^2) \tag{14}$$

Traffic data (estimated over a 10-year horizon) shall be used to determine the tunnel class and if no such data are available, safe assumptions shall be made.

Tunnels are divided into two main categories according to the type of users:

- Motor vehicles only (A)
- Mixed use including pedestrians/cyclists (M)

Table 25 is used to select which of the 4 categories the tunnel belongs to, based on traffic load and type of users and Table 26 lists the categories of traffic load in vehicles per hour and lane.

Table 25: Selection of tunnel class

Traffic load	High		Medium		Low	
Type of users	M	A	M	A	M	A
Tunnel class	4	3	3	2	2	1

Table 26: Traffic load in relation to traffic flow

Traffic load	One-way tunnels (flow in vehicles/h · lane)	Two-way tunnels (flow in vehicles/h · lane)
High	> 1500	> 400
Medium	500 – 1500	100 – 400
Low	< 500	< 100

Table 27: k factor values in relation to safe stopping distance

	Safe stopping distance (m)		
Tunnel class	60	100	160
4	0.05	0.06	0.10
3	0.04	0.05	0.07
2	0.03	0.04	0.05
1	Only guidance lighting is necessary		

The safe stopping distance required to use Table 27 and to determine the length of the tunnel lighting zones (see §8.5) is calculated using Equation (15).

$$SD = u \cdot t_o + \frac{u^2}{2 \cdot g \cdot (f \pm s)} \quad (m) \qquad (15)$$

where:

u: design speed

t_o: reaction time (usually 1sec)

f: coefficient of friction

g: acceleration of gravity

s: the angle of the carriageway (+) uphill, (−) downhill

If the coefficient of friction is not known, it can be estimated based on the diagram in Figure 16.

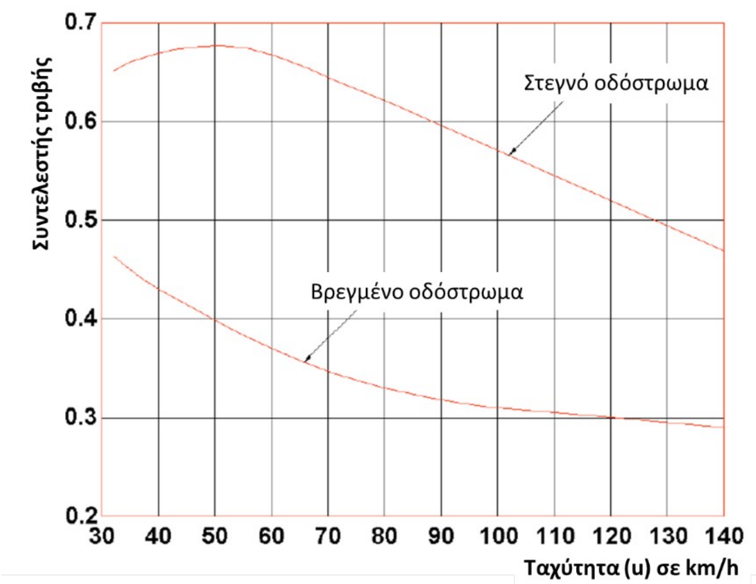


Figure 16: Graphical calculation of the f coefficient of friction.

Συντελεστής τριβής	Coefficient of friction
Στεγνό οδόστρωμα	Dry carriageway
Βρεγμένο οδόστρωμα	Wet carriageway
Ταχύτητα (u) σε km/h	Speed (u) in km/h

8.5 Day and night tunnel lighting requirements

Long tunnels and those requiring daily lighting are divided into the following lighting zones:

1. **Access zone**
   It is the section of the open road construction before the tunnel entrance.
2. **Threshold zone**
   It is the first zone of the tunnel. Starting at the tunnel mouth and ending at a length equal to the safe stopping distance.
3. **Transition zone**
   Starting after the threshold zone and ending before the internal zone
4. **Interior zone**
   Runs through the whole length of the tunnel between the end of the transition zone and the exit zone, if available, or the tunnel mouth
5. **Exit zone**
   It is an optional lighting zone and, if available, starts after the end of the interior zone and ends at the tunnel mouth.
6. **Parting zone**
   It is the part of the open road construction after the end of the tunnel.

The graphic representation of the lighting zones of a tunnel is shown in Figure 17. The same image shows the standard variation of road luminance along the tunnel and in each lighting zone.

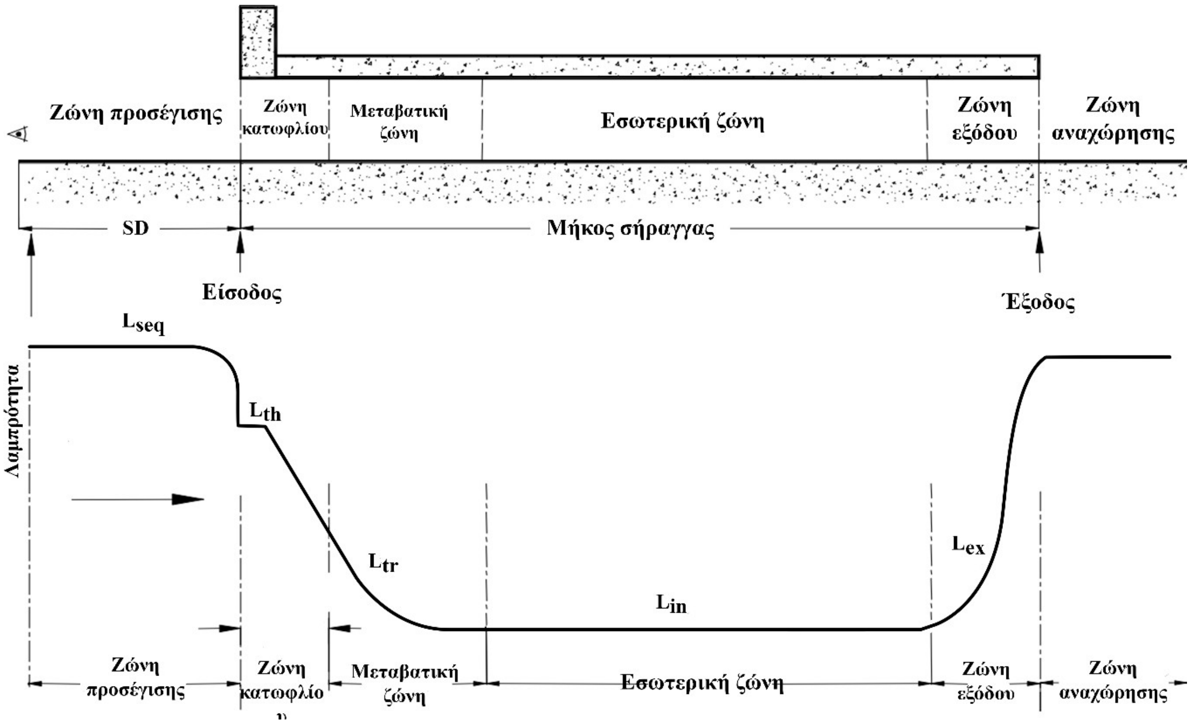


Figure 17: Tunnel lighting zones and standard variation of road surface luminance.

Ζώνη προσέγγισης	Access zone
Ζώνη κατωφλίου	Threshold zone
Μεταβατική ζώνη	Transition zone
Εσωτερική ζώνη	Interior zone
Ζώνη εξόδου	Exit zone
Ζώνη αναχώρησης	Parting zone
Είσοδος	Entrance
Μήκος σήραγγας	Tunnel length
Έξοδος	Exit
Λαμπρότητα	Luminance

The lighting requirements of each zone are set out in the following sections. Figure 18 shows the standard curve of luminance variation along the tunnel for the lighting zones on the time scale.

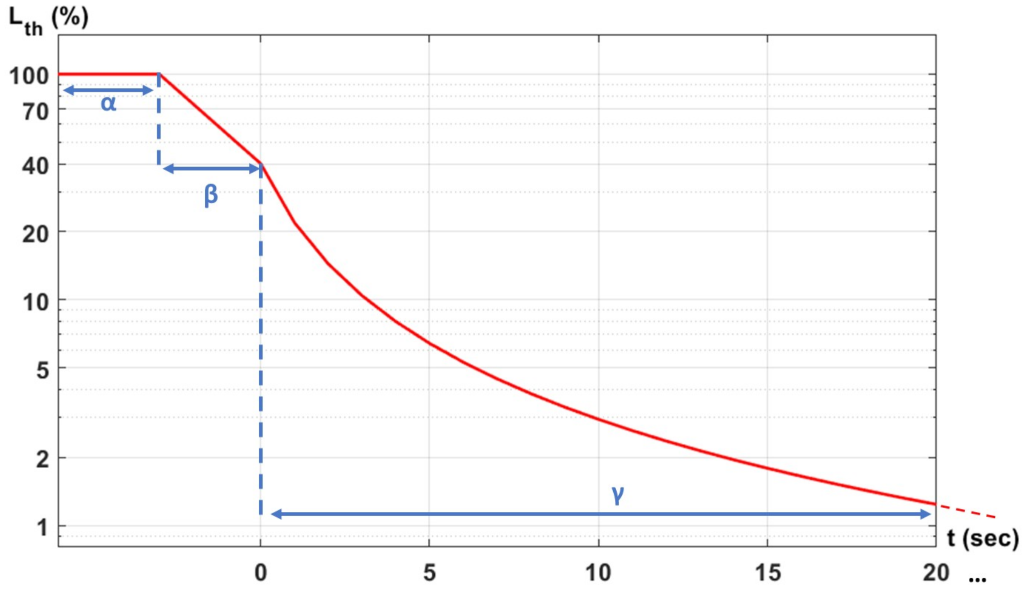


Figure 18: Standard variation of the mean luminance of a tunnel road surface. a) fixed section of the threshold zone, b) linear reduction of threshold zone luminance, c) transition zone.

8.5.1 Threshold zone

The threshold zone shall be at least equal to the safe stopping distance calculated using Equation (15). In the middle of the threshold zone, the average road surface luminance shall be at least equal to the threshold luminance L_{th} (Figure 18, section a) as calculated using Equation (14). For the remainder of the threshold zone, luminance shall be reduced linearly to 40 % of L_{th} (Figure 18, section b). This reduction may take place gradually, as long as luminance does not fall below the values corresponding to the linear reduction.

The required mean luminance shall be calculated over the entire width of the road surface (lanes and emergency lane if applicable).

8.5.2 Transition zone

Transition zone luminance L_{TR} changes according to Equation (16).

$$L_{tr} = L_{th} \cdot (1.9 + t)^{-1.423} \quad \text{cd/m}^2 \tag{16}$$

In Equation (16), time t starts at the end of the threshold zone (t=0). The shape of the luminance variation curve is shown in Figure 18, section c. This change may take place gradually as long as luminance does not fall below the values of this imaginary curve. In this case, the luminance steps shall not exceed 3:1. At the same time, the transition from threshold zone to transition zone shall not have a luminance step greater than 1.5:1.

The end of the interior zone is defined as the point where luminance L_{TR} is twice the value of the interior zone L_{in} luminance.

The required average luminance shall be calculated for all lanes (including the emergency lane, if applicable).

8.5.3 Interior zone

The tunnel interior zone luminance L_{in} shall be fixed throughout this zone and selected on the basis of the tunnel class and the design speed according to Table 28.

Table 28: Luminance values of interior zone L_{in}

	Safe stopping distance (m)		
Tunnel class	60	100	160
4	3.0	6.0	10.0
3	2.0	4.0	6.0
2	1.5	2.0	4.0
1	0.5	0.5	1.5

These values refer to the luminance of the zone during the day and are calculated for the overall width of the lanes, except for the emergency lane (if any). The emergency lane shall have an average luminance at least equal to the average lane luminance for class 4 tunnels or at least 50 % of the average lane luminance for class 3 and class 2 tunnels.

8.5.4 Exit zone

The exit zone is optional but can be used when:

- The geometry, location and orientation of the tunnel combined with the environment at the tunnel exit disproportionately increase the level of external luminance resulting in glare while driving.
- In very long class 4 tunnels (>1 000 m).

In this case the exit zone luminance shall increase linearly before exiting the safe stopping distance from the Lin level to level $5 \cdot L_{in}$ 20m before the exit.

8.5.5 Access and parting zone and tunnel night lighting

The tunnel lighting during the night shall be at least equal to the open road lighting before and after the tunnel. Therefore, the lighting level follows that of the tunnel access and parting zone but is not less than 1 cd/m^2 for class 2 tunnels and not less than 1.5 cd/m^2 for class 3 and 4 tunnels. Night lighting concerns both long tunnels and covered road sections (> 200 m of length) and shorter covered road sections (top/bottom crossings, etc.) which lie within a road-lit section, even if they do not require daily lighting.

8.5.6 Luminance uniformity

The total and longitudinal uniformity of the tunnel road surface shall be determined according to its class based on Table 29. Uniformity requirements (total and longitudinal) do not apply to the transit zone of tunnels.

Table 29: Minimum required luminance uniformity of road surface.

Tunnel class	Total uniformity U_o	Longitudinal uniformity U_l
4	0.4	0.7

3	0.4	0.6
2	0.3	0.5
1	-	-

8.5.7 Wall lighting

Wall lighting shall be sufficient to contribute to visual contrast when detecting possible obstacles within the tunnel. The average wall luminance is calculated for the corresponding calculated point in the tunnel where the average road surface luminance is calculated. The requirements are the following:

- In class 4 tunnels, the average wall luminance at a height of up to 2 m shall be at least equal to the average road surface luminance at the same point.
- In class 3 and 2 tunnels, the average wall luminance up to 2 m shall be at least equal to 60 % of the average road surface luminance at the same point.
- There is no requirement for class 1 tunnels, but it is proposed that the average wall luminance up to 2 m shall be at least equal to 25 % of the average road surface luminance at the same point.

8.5.8 Limiting light flicker and glare

Light flicker is caused by the frequent alternation between bright and dark background. In tunnels this is due to the succession of luminaires. For this purpose, the luminaires shall be positioned at such a distance that, depending on the speed of passage, the light flicker is less than 2.5 Hz or more than 15 Hz.

The glare is calculated using the TI (Threshold Increment) indicator. The TI value shall in any case be <15. Particular attention shall be paid when using LED luminaires where the TI calculation requires high accuracy in photometric records of luminaires.

9. Tunnel lighting equipment specifications

9.1 Minimum technical specifications for tunnel lighting luminaires

Tunnel luminaires shall have the following minimum technical characteristics and certifications. It is noted that each contracting authority has the possibility to require additional specifications to the following, as well as to incorporate the specifications of each applicable HTS.

The luminaires shall be of standard construction, with a specially protected housing for tunnel installations. They shall be designed from the outset for exclusive use in tunnels and no luminaires shall be permitted that have been converted from headlamps or luminaires of other uses.

9.1.1 Constructional characteristics of a luminaire

The luminaire body shall be made of suitable material for the relevant operating conditions and requirements at the discretion of the contracting authority. In cases where lighting equipment is close to a seaside environment, it shall withstand the seaside environment. The construction of the luminaire body will ensure the removal of the heat produced for both the optical source section and the electrical parts section. The luminaire shall also be equipped with adaptation and protective fittings suitable for the installations within the tunnel as required.

In the case of luminaires where the electrical instruments are in a separate housing from the optical unit, they shall be locked in an appropriate frame for their proper operation and shall be accompanied by the appropriate wiring to the optical unit.

9.1.2 Protective cover

The protective cover is designed to protect the optical unit from the external environment. The protective cover shall be made of tempered glass which protects the optical source and the light diffusion lenses or reflectors as a whole. The cover may be clear or translucent (Frosted type).

9.1.3 Optical unit materials

Diffusion is achieved by aluminium lenses or reflectors. Lenses may be made of PMMA or silicone or other equivalent temperature resistance material. Reflectors shall be made of anodised aluminium or other material of higher reflectance.

9.2 Operating characteristics

9.2.1 Photometric data

Photometric data are obtained at a Ta 25°C temperature. Photometric data are obtained according to EN13032 or IES LM 79 (their newest versions).

Power and luminous flux of the luminaires are selected based on the lighting needs of each application. In addition, in the case of use of LED luminaires, the correlated colour temperature (CCT) shall not exceed 4000 K. The combination of CCT & CRI shall be expressed in colour codes according to IEC 62717 e.g. 740 (CRI 70, 4000K), 730 (CRI 70, 3000K) etc.

The luminous intensity distribution of the luminaire shall be selected by the work designer according to the requirements.

9.2.2 Electrical characteristics

The luminaire must have the following minimum electrical characteristics

- Operation on a network with a nominal operating voltage of 230V AC 50Hz and tolerance to fluctuation on the nominal operating value of at least 220-240V.

- Protection against overvoltage of at least 10 kV (according to ELOT EN 61000-4-5, test class X)
- Electrical shock protection class I or II (according to EN 60598-1)
- Power factor of at least 0.9 in full load mode of the luminaire. In cases where the luminaire is also operating under dimming conditions, the work designer shall ensure that the power factor is kept as high as possible and as close as possible to the above value.

- Light flicker control (PstLM, SVM according to IEC TR 61547-1:2020 and IEC TR 63158:2018)

9.2.3 Degrees of protection against external influences

The luminaire shall be watertight and dust-tight of at least IP66 category and shall have shock resistance of at least IK08.

The luminaire shall be suitable for operation in an external environment between -20 °C and +30ºC. Given the criticality of the high temperature in the functionality of luminaires, the upper temperature limit is checked against EN/IEC 60598. In particular, each luminaire shall be able to operate at a temperature of up to Ta 30ºC or greater, depending on the external environment conditions.

9.2.4 Connectivity

LED luminaires shall have a luminous flux dimming function. For this purpose, their power supply units shall be able to receive appropriate commands via DALI or 1-10V (0-10V) or PWM or other type depending on the technological advances.

All internal connections of the luminaire shall be implemented during its production and the future installation of a controller shall be as simple as possible.

9.2.5 Maintenance of luminous flux

The maintenance of the luminous flux of LED sources is expressed through IES LM-80 and IES TM-21 technical report. Luminaires shall be equipped with LED sources having a minimum value of L80 calculated at 50 000 hours at an outdoor ambient temperature of at least 25ºC. The LM 80 report shall be used as evidence for this statement, which shall contain one or more representative datasets of the luminaire function, i.e. combinations of driving current (If-mA) & temperature Ts (or Tsp).

It is noted that if a declaration of luminous flux maintenance is requested, with a Byy coefficient other than B50, then IEC 62717 may also be used for the calculation.

9.2.6 Certifications

Luminaires shall have at least the following certifications.

1. Manufacturer’s declaration of conformity according to CE. The declaration shall include compliance with the Directives and their corresponding harmonisation standards as applicable.
    a. Low Voltage Directive (LVD) 2014/35/EU
    b. Electromagnetic Compatibility Directive (EMC) 2014/30/EU
    c. Eco Design Directive 2009/125/EC
    d. Regulation (EU) 2017/1369 as supplemented by Regulation (EU) 2019/2015

   e. ATEX 2014/34/EU for products intended for use in potentially explosive atmospheres, where appropriate and if the study provides for the creation of such conditions in the places where the products are to be placed
   f. Rohs Directive 2011/65/EU

2. The manufacturer of luminaires shall have an active quality management system ISO 9001:2015 and environmental management system ISO 14001:2015. The certification shall include the manufacture and placing on the market of lighting products.
3. ENEC or other equivalent ISO Type 5 certificate which meets the requirements of the low voltage standards (EN 60598-1, EN 60598 2-3)
4. Optional – ENEC+ type certificate or other equivalent ISO Type 5 certificate relevant to the application of EPRS 003 (application of EN/IEC 62722-2-1).
5. The photometric data shall be obtained from an ISO 17025-accredited laboratory of an EA-MLA or IAF/ILAC body. The Contracting Authority may also require, in addition to an accredited laboratory, that the laboratory of the photometric data be alternatively Approved/Recognized by an accredited body according to ISO 17025. In this case a laboratory declaration shall be submitted that the photometric data originate from the laboratory. Evidence of the origin of photometric data may be a statement from the issuing laboratory or the manufacturer's laboratory if available.
6. It is noted that the work designer is given the opportunity to require the accreditation of the photometric laboratory by an EA-MLA body (and not generally by IAF/ILAC), since only European bodies belong to this group of accreditation bodies.
7. The luminous flux maintenance data according to LM-80 shall be obtained from a laboratory accredited by an EA-MLA or IAF / ILAC body according to ISO 17025.

Finally, it is necessary to provide additional information material, photographs, installation manuals and other technical material proving compliance with the specifications.

10. Additional tunnel lighting requirements

10.1 Lighting of lay-by recesses

Where tunnels have lay-by recesses, the lighting shall meet the requirements of P1 class according to ELOT EN13201-2. These recesses may have a separate lighting system which shall operate 24/7. It is proposed to use luminaires with a higher colour temperature to facilitate the identification of the area, if its identification is not assisted by other means (paint, marking, etc.).

10.2 Emergency lighting

Provision shall be made in the tunnel lighting system to maintain a minimum lighting level in emergency situations, such as power supply failure. The minimum level of safety may be maintained by using luminaires connected to an uninterruptible power supply system. Also, for the same purpose, part of the luminous flux of specific luminaires may be used where necessary, e.g. one of the lamps in luminaires with more than one lamp, individual LED units in luminaires supporting it, etc.

In any case, the lighting system shall in emergency situations achieve an average illuminance of 10 lx with a minimum value of 2 lx at any point of the tunnel including the road surface and sidewalks, if available. This requirement does not apply to wall lighting.

In the event of power failure and until the Stand-By Generating Set is operational, the Uninterruptible Power Supply (UPS) system will supply, among others, the tunnel emergency lighting system (all night lighting) and the light signals (roads and escape route signs, etc.). Then the Stand-By Generating Set will also supply part of the tunnel system. The traffic control system, with the use of traffic control signs before and inside the tunnel, will determine the new speed at which vehicles will pass before and through the tunnel. This limit shall be calculated and correspond to the lighting level of the threshold and transition zones resulting from the predetermined number of luminaires which are electrified by the Stand-By Generating Set in these zones.

10.3 Evacuation lighting

In the event of a fire, the lighting level of the tunnel is reduced due to smoke, so that the routes and escape routes are not always sufficiently visible. Therefore, each section of the tunnel shall be equipped with luminaires indicating the routes and orientating towards the escape routes. Escape routes shall be marked with signs and clearly illuminated. This lighting which serves for the orientation and assistance of the evacuation is required for all tunnels of ≥ 500 m length.

a. Illuminated signs indicating the nearest escape routes

These signs shall be‑ placed on the side of the tunnel where the escape routes are located, embedded in the tunnel wall, at ≤ 25 m intervals and in such a way that they clearly indicate the route and provide orientation. They shall be permanently illuminated and include a pictogram with an escape symbol (“running man” icon directed towards the nearest escape route), combined with arrows per escape direction and with an indication above or below the distance from the nearest escape route or the nearest tunnel exit. In order to quickly understand the above distance information, the numbers are rounded to the nearest ten meters (10 m). The pictogram of these signs shall be green and white (the colour of symbols shall be white on green background).

In order to allow for side view of the above illuminated signs, they should protrude 2 to 3 cm from the tunnel wall and maximum 6 cm. They shall have side guidance lighting in the form of vertical green stripe with minimum dimensions (WxH) 20 mm x 300 mm and of LED technology. They shall also be designed in such a way that they do not cause injury to escaping users. If the construction of the tunnel does not allow the embedded mounting of this illuminated sign, flat, shallow wall-mounted illuminated signs shall be used alternatively.

The illuminated signs indicating the nearest escape routes shall meet the following requirements:

- Minimum pictogram dimensions 300 mm x 300 mm.
- Average pictogram luminance of at least 200 cd/m^2
- Side surfaces of green colour, average luminance of not less than 75 cd/m^2
- Protection/watertightness class of illuminated signs: IP 65 and IK 08

- Protection class: I
- Installation height: The lower edge of the illuminated sign shall be at a height of 1.00 to 1.20 m above the escape route level
- Power supply: This illuminated sign shall be powered by a UPS. The distribution of distribution lines on the illuminated signs shall be determined by the risk assessment of the tunnel. In any case, successive luminaires will be powered by a different phase (R,S,T).

These illuminated signs, at the bottom, will have an integrated (may also be located externally) white-coloured luminaire for the (downwards) illumination of the escape route along the pavement and powered by a UPS. This will only be activated in the event of a fire or other emergency, automatically via the fire detection system or manually from the tunnel surveillance centre. The luminaire shall be of LED technology, I(α) at least 25 cd, where the α angle shall be within the range of: -87 ° < α <+ 87° _at the horizontal level and -60o ° < α <+ 20° at the vertical level. The overlapping of the illuminated sign indicating the nearest escape routes should be avoided by reducing the glare of this luminaire located at the bottom of the illuminated sign. If an individual luminaire is placed outside the illuminated sign, its characteristics shall be the same as that of the luminaire incorporated in the illuminated sign.

b. Signs indicating escape routes

Escape routes shall be clearly indicated by an internally permanently illuminated double-sided sign mounted vertically to the traffic direction, powered by a UPS. A green flashing lamp shall be mounted above the illuminated signs, which shall also be powered by a UPS and activated only in the event of a fire or other emergency, automatically via the fire detection system or manually from the tunnel surveillance centre. These escape route luminaires shall be of protection category IP 65, IK 08 and protection class: I.

c. Lighting indicating the escape routes

Escape routes shall also be indicated by a LED tape placed around them, powered by a UPS and permanently switched on in order to indicate their position. They may be installed on either side of the escape route in the form of illuminated columns approximately 2.5 m high. Alternatively, the desired optical result may be achieved by installing a sufficient number (3-5) of two-sided illuminated indicators vertically arranged on either side of the exit. The lighting is of green colour, LED technology and controlled by the automation system in order to achieve a luminance of 30 cd/m^2 under normal tunnel operation and 100 cd/m^2 in the event of an evacuation alert.

The luminaires shall be designed to provide adequate illumination on the transverse axis, making it easy for users moving within the tunnel to locate and identify the emergency exit. They shall have IP65, IK 08 protection and a design such that there is no risk of injury to passing pedestrians (sides at an angle).

10.4 Painting of walls, asphalt and mouth of the tunnel

In order to enhance the luminance of the walls and reduce the required installed power of the lighting system, it is proposed that the tunnel walls are painted in light grey colour with a total reflectance of ≥ 50 % at a height of at least 3 m.

At the same time, it may be possible to investigate the use of light-coloured asphalt coating to increase the luminance of the road surface. In this case, knowledge of the reflective properties of the coating is required and all quality lighting characteristics (uniformities, wall /asphalt luminance ratio) should be ensured.

In order to reduce the luminance of the tunnel mouth, and thus reduce the required luminance in the tunnel during the day, it is proposed to paint the structural elements of the tunnel mouth with dark paint. The planting of the surrounding area with plants or the use of dark-coloured materials also contributes to reducing the luminance of the tunnel mouth. In any case, interventions at the tunnel mouth shall reduce the overall L20 luminance of the standard driver's field of vision.

11. Preparation of tunnel lighting studies

11.1 General requirements

The purpose of a tunnel lighting study is to meet the lighting needs of the tunnel along its length and during day and night. The lighting system shall achieve the appropriate levels of road luminance along the tunnel as calculated based on the diagram in Figure 18 (§8.5). At the same time, the lighting requirements for the walls and the required uniformities shall be met. Tunnel lighting studies shall be carried out using specific software suitable for tunnel lighting studies. Software shall incorporate calculation methodologies in accordance with applicable standards such as CIE 189 Technical Report. The lighting design shall take into account the actual geometrical data of the tunnel as well as the determination of other data relating to the location and operation of the tunnel.

11.2 Maintenance factor

The maintenance factor of a tunnel lighting system shall be calculated as in the case of road lighting and described in §3.2. In the case of tunnels, the deterioration over time of the reflective properties of these walls shall be taken into account in the calculations with the use of the specialised software of these lighting studies, in conjunction with the cleaning programme for the walls of the road work in question, as provided for in the maintenance manuals.

11.3 Positioning of luminaires within the tunnel

The positions of the luminaires are determined based on the results of the lighting studies of a tunnel. Lighting positions shall ensure the safe operation of luminaires and shall meet the safety requirements of electromechanical installations. The usual configuration of luminaires is as follows:

1. Roof mounting on special supports, in the centre or near the centre of the tunnel next to the electric cables channels, at a distance from the centre to facilitate maintenance. This configuration may consist of one or more sets of luminaires depending on the width of the tunnel or the photometric requirements. For tunnels with 3 or more lanes, luminaires shall be distributed to positions ensuring optimal utilisation of the light emission of luminaires.
2. Mounting on the tunnel walls at an appropriate height indicated by the relevant safety specifications and lighting studies.

In any case, the required lighting levels on the walls and on the road surface of the tunnel shall be ensured.

The distance between the luminaires shall be calculated during the lighting study and may be either variable along the tunnel or fixed per group of a given number of luminaires. In the first case, a smooth change of luminance is achieved along the tunnel, while in the second case, the levels of luminance are achieved in distinct steps. Whichever method is followed, the luminance levels defined by the diagram in Figure 18 (§8.5) shall be met.

11.4 Lighting circuits and adaptive lighting

The lighting needs of a tunnel vary during the day. The luminance of the access zone changes and is directly correlated with the sky luminance, the luminance of the tunnel mouth surroundings or the weather conditions. As a result, L20 luminance changes and thus the required threshold zone luminance Lth. There is therefore a clear need for automatic adaptation of the lighting of the threshold zone and the transition zone in relation to the external luminance. To this end, luminaires covering the illumination of the threshold, transition, interior and exit zones (if any) should be adjusted accordingly to achieve the desired lighting levels.

Tunnel lighting control systems shall manage luminaires using one of the following methods:

1. **Grouping of luminaires and switching ON/OFF**
   This is the case mostly in existing installations, given the dominance of conventional lighting sources before the emergence of LED luminaires and their additional control options. With this method the luminaires are divided into circuit groups, one or more per lighting degree. These circuits manage the switching on/off of the circuits and achieve the various distinct levels of tunnel lighting. The ON/OFF method may be used with any luminaire technology. The number of control circuits and therefore the corresponding illumination levels shall be at least 5 without taking into account the night lighting level e.g. 100 %, 80 %, 60 %, 40 % and 20 % of the luminance Lth plus the night light level.

2. **Grouping of luminaires and adjusting the luminous flux to two levels and switching ON/OFF**.
   This method is similar to the 1st one but combines the possibility of using bi-power luminaires. In this case the luminous flux of the luminaires can be adjusted to two distinct levels e.g. 100 % and 50 % of the rated luminous flux. This achieves twice as much lighting as the 1st method or may correspondingly reduce by half the required number of circuits while achieving the same number of lighting levels. For example, in the 1st case with 4 luminaire circuits 4 lighting levels are achieved, while in the 2nd case with 2 luminaire circuits and 2 luminous flux levels per luminaire 4 lighting levels are also achieved. The number of control circuits and therefore the corresponding lighting levels shall be at least 5 without taking into account the night lighting level.

3. **Grouping of luminaires, continuous adjustment of luminous flux to a lower level and switching ON/OFF**.
   This method is similar to the 2nd method except that the luminous flux of luminaires can be adjusted to continuous levels up to a threshold e.g. 50 %, 30 %, etc. With the appropriate distribution of luminaires in circuits, a combination of multiple discrete lighting levels is achieved, as in the 1st and 2nd method, but the transition from one level to the next is done by continuously adjusting the luminous flux before certain luminaires are switched off. This combination method is proposed in cases where the operation of luminaires at low luminous flux levels is contraindicated for reasons of power quality and lifetime of light sources.

4. **Addressing of luminaires and method of continuous adjustment of luminous flux throughout the operating range**
   This method is the new generation of two-way communication and management systems through which the addressing of each luminaire or groups of luminaires takes place, so that they perform specific commands for ON/OF switching or luminous flux adjustment at every possible level (0-100 %). In this case it is possible to create lighting scenarios with luminance change accuracy. Each illumination level is composed of a specific luminous flux level of the luminaires. The method usually leads to less wiring than other methods.

11.5 Dynamic control via external and internal measuring devices

The illumination of a road tunnel shall be adjusted appropriately to follow changes in the outer luminance of the tunnel mouth. For this purpose, a luminance measurement device shall be installed at the safe stopping distance which shall continuously measure the L20 or Lseq luminance value. For practical reasons, the luminance measuring device shall be positioned at a height higher than that of the standard driver's seat and off the road (right or left). In order to avoid incorrect readings, it is recommended to optimise the field of vision of the luminance measuring device by means of an appropriate target, so that the luminance measuring field has surrounding, sky and road proportions equivalent to the field of vision of the standard observer (standard driver). If optimisation is not possible, the measuring instrument shall aim at the centre of the tunnel mouth.

The level of tunnel lighting shall be adjusted according to the indication of the external instrument and according to the assignment of lighting class resulting from the lighting study.

11.6 Two-way tunnel lighting

In permanent two-way tunnels, lighting is designed for both traffic directions, i.e. for each entrance mouth on either side of the tunnel. The lighting requirements for threshold, transition and interior zones are based on the outer L20 luminance of the tunnel mouth. Indoor lighting and night lighting are common to the entire tunnel. In any case, the minimum requirements for each standard observer shall be met. When the tunnel is relatively short and the enhanced lighting zones overlap inside the tunnel, then the enhanced lighting of each direction stops at the starting point of the overlap.

11.7 Optimisation of tunnel lighting design

The work designer shall optimise the tunnel lighting design according to the optimisation of the road lighting design. In any case, the aim of the work designer is to find the technical solution that requires the least possible installed capacity per lighting level and the lowest possible annual energy consumption. This may be combined with various economic criteria.

In the case of tunnel lighting, the work designer may use the qualitative indicators of §3.4 to compare alternative technical solutions and opt for the most advantageous. In these indicators (where required) the lighting surface will be taken as the surface of the carriageway, the sidewalks (if any) and the walls up to 2 meters high.

In addition, it is recommended that the work designer calculates the q_c factor defined in Equation (17):

$$q_c = \frac{L}{E_V} \quad (17)$$

where:
q_c : contrast factor
L : road surface luminance at the calculation point
E_v : vertical lighting intensity at the calculation point

The minimum value of the qc factor per type of luminaire used is:

- Highly asymmetrical beam luminaires: q_c greater than or equal to 0.60
- Symmetrical or almost symmetrical beam luminaires: q_c approximately equal to 0.15
- Luminaires of other distribution: (no requirement)

12. Compliance control of tunnel lighting

12.1 Introduction

Road lighting studies stipulate that a specific chapter should be included, i.e. "Guidelines for Compliance Control during Implementation (GCCI)", describing the procedures to be followed for compliance control during the implementation phase of the study.

The compliance control relates to the qualitative and quantitative checks to be carried out in road tunnels both after the system has been installed or upgraded and at regular intervals.

The control aims at confirmation, by sampling, of the results obtained, whether on the equipment itself (luminaires, control system, etc.) or the installation as a whole (lighting performance on-site).

Compliance control shall not in any case replace the controls resulting from the certificates of conformity provided for in the Technical Specifications nor shall it certify the production process of the equipment.

The controls to be provided for in the GCCI, particularly with regard to luminaires and their performance after integration into the tunnel lighting installation, shall include laboratory measurements of the equipment and on-site controls of the lighting installation.

12.2 Laboratory measurements

Sample checks of the equipment should be provided for each new installation of luminaires in a road tunnel or upgrade of an existing one. The number of samples to be checked depends on the number of different types of luminaires used. In any case, the sample checks shall adequately represent the entire installation being checked.

Samples should be taken during installation by the group of luminaires to be installed on-site and shall not be factory samples to be checked.

Measurements should be carried out by a body accredited for the respective measurement, which will have the appropriate infrastructure and calibrated equipment. Measurements should be performed in accordance with one of the standards EN 13032, CIE S025 or IES LM79.

The characteristics to be controlled, as a minimum, on each sample are shown in Table 30. The controlled characteristics shall be compared with those provided by the manufacturer and the deviations shall not exceed the corresponding percentage as indicated in the same table.

Table 30 – Characteristics measured during laboratory testing of luminaires.

Controlled characteristic	Maximum deviation from manufacturer's declaration
Operating voltage	-
Total luminaire current	-
Total luminaire power	+ 10%
Luminaire power factor at full load	- 0.05
Harmonic distortion of luminaire current up to the 30th harmonic	+ 2%
Total luminous flux of luminaire	- 10%
Luminous intensity distribution of luminaire	-
Correlated colour temperature (CCT) measured at C0-C330 levels at 60^o and in angles c=0 to c=180^o at 30^o).	± 200K
Power variation relative to luminous flux for luminaires with adjustable luminous flux between 100 % and 0 % of luminous flux with 10 % adjustment	-
Light flicker of luminaire (PstLM, SVM) in nominal operating conditions and at each luminous flux control level.	+ 5%

12.3 On-site measurements

12.3.1 Categories of on-site measurements

The categories of on-site measurements should be provided for in the GCCI similarly to those in §6.3.1.

The measurements shall be carried out by appropriately trained personnel and in accordance with CEN/CR 14380 Technical Report. Additional control requirements may be provided for by the work designer.

The reports on the measurements shall be provided in detail with the indication of the individual measurements, the calculation of the quality indicators, where necessary, the geometric and electrical characteristics of the installation, the weather conditions, etc.

12.3.2 Definition of on-site measurement areas

On-site measurements in road tunnels shall be carried out on representative grids in all individual lighting zones. Each grid is defined as the area between two consecutive luminaires of the night lighting circuit according to CEN/CR 14380 Technical Report. The minimum number of measuring grids is set out in Table 31.

Table 31 – Minimum number of measuring grids per tunnel lighting zone.

Lighting zone	Minimum number of grids
Entrance zone (segment of fixed luminance)	2
Entrance zone (section of linear reduction of luminance)	2
Transition zone	6
Interior zone	2
Exit zone	2

The minimum number of grids shall apply as long as each zone is available and its length allows the definition of the minimum number of grids. If this is not the case, the representative grids may be defined in the tunnel.

The measurement grids shall be selected so as to ensure a correct assessment of the luminance variation curve along the tunnel.

The minimum number of grids may be reduced by half for measurements carried out for maintenance reasons.

12.3.3 On-site measuring instruments

Instruments for measuring the photometric, geometric and electrical characteristics of a tunnel lighting installation shall be designed for the intended use, have valid calibration certificates, and cover the measurement range of each measured characteristic expected to be measured on-site. Indicative requirements for measuring instruments are given in Table 21 of §6.3.3

12.3.4 Luminance measurements

The compliance control of M class tunnel lighting installations shall be carried out by measuring the luminance of the road surface and the walls. The measurements shall be carried out in accordance with CEN/CR 14380 Technical Report on the selected grids along the tunnel. A luminance measuring device as described above shall be used for measurements. The measurements shall be repeated for all predetermined levels of tunnel lighting on the same grids.

Measurements shall be made from a distance of 60 m from the beginning of each grid and from a height of 1.5 m above the ground. If the distance of 60 m is not feasible, measurements shall be carried out from a lower height and a shorter distance, but in any case the relative angle of the measuring position from the beginning of the grid is about 1 degree. In order to minimise traffic disturbance and enhance safety, a system may be used for measuring luminance on a moving vehicle.

Measurements shall be carried out on dry and moisture-free carriageway which is free of foreign objects, such as parked vehicles, building materials, and other obstacles on the grids. During measurements additional lighting sources within the tunnel shall be switched off as far as practicable. If a new installation is being controlled, the condition of the asphalt and the age shall be indicated.

For each measuring position, the mean, minimum and maximum luminance of road surface and wall up to a height of 2 m and the uniformity of brightness shall be obtained. The luminance distribution curve along the tunnel is designed based on the values of average road luminance and compared to the nominal brightness curve at the lighting level controlled.

12.3.5 Illuminance measurements

The illuminance measurements shall be carried out to check the necessary levels of illumination of the safety lighting or to evaluate the performance of the luminaires without taking into account the effect of the asphalt.

Measurements shall be carried out at each point of the selected grids in contact with the ground and in a horizontal position. In the case of measurement of the safety lighting, the luminaires of the tunnel shall be supplied by the safety power supply system. In this case, illuminance measurements shall be performed both on the road surface and on sidewalks, if any, on either side of the road and the mean and minimum illuminance value shall be obtained from all measured points.

The illuminance value of each point shall be recorded only when the instrument reading is stabilised. In any case, stray light, if any, shall be removed by means of an additional measurement with the luminaires switched off, if possible. Particular attention shall be paid to avoid shadows on the instrument sensor by the instrument body, the instrument operator or various obstacles around and within the measuring grid.

12.3.6 Measurement of geometrical and electrical characteristics

As part of on-site measurements, the following geometrical characteristics shall be recorded:

- Maximum width and maximum height of the tunnel
- Carriageway width
- Width of each traffic lane
- Emergency lane width, if any
- Width of sidewalks, if any
- Standard distance between night lighting luminaires
- Luminaire mounting height
- Vertical distance of luminaires from the centre axis of the tunnel
- Angle of the luminaire in relation to the horizontal level
- Carriageway cant
- Type of luminaires.

Where electrical measurements are possible, the supply voltage of the luminaires during the measurements shall be recorded.

The change in temperature and relative humidity shall be recorded throughout measurements.

13. Provision for the compliance of existing road lighting and tunnel lighting installations

This Regulation shall apply immediately to new lighting installations (road lighting and tunnels) and the following shall apply to existing installations.

13.1 Road lighting installations

Existing road lighting installations shall be in line with the provisions of the Regulation in the following cases:

- Equipment upgrade (luminaires or control system). It does not concern the regular maintenance of equipment by changing lamps, activation and supply devices or other maintenance on the equipment.
- Extension of the existing road lighting network
- Existence of a system for regulating the luminous flux of luminaires at levels that meet the requirements of the new lighting classes.

In every case of an existing installation, the entity concerned may determine the new lighting classes, nominal and adaptive lighting classes, as derived from the provisions of the Regulation. If necessary, the entity may design or operate the lighting system depending on the new lighting requirements.

13.2 Tunnel lighting installations

In existing tunnels, lighting requirements shall be aligned with the provisions of the Regulation in case of upgrade of equipment, luminaires and/or the control system. It does not concern the regular maintenance of equipment by changing lamps, activation and supply devices or other maintenance on the equipment.

In every case of an existing installation, the respective entity may review the tunnel lighting requirements, calculate the L20 luminance and k index and determine the new luminance variation curves along the tunnel as derived from the provisions of the Regulation. If necessary, it may design or operate the lighting system depending on the new requirements.

14. Regulation review

Renewal, correction or enhancement of the Regulation shall take place in the following cases:

- After 5 years from the last renewal according to ISO standards.
- If the integrated international standards, specifications, guidelines and common practice have changed to the extent that a renewal of the Regulation is required in less than 5 years.

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