



BSI Standards Publication

Lighting applications — Tunnel lighting

National foreword

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Eclairagisme - Eclairage des tunnels

Angewandte Lichttechnik - Tunnelbeleuchtung

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European foreword

This document (CEN/TR 14380:2024) has been prepared by Technical Committee CEN/TC 169 “Light and Lighting”, the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes CEN CR 14380:2003.

In comparison with the previous edition, the following modifications have been made:

- The whole content has been rewritten to comply with the CEN/CENELEC Internal Regulations part 3 rules applying to Technical Reports (informative document);
- The definitions have been updated following EN 12665:2024, as closely as possible;
- A new Clause 5 (“Dimensioning rules for the lighting of road tunnels”) replaces the previous subclause 4.2 (“Distinction between long and short tunnels”), Clause 5 (“Lighting of long tunnels”) and Clause 6 (“Artificial lighting of short tunnels and underpasses”);
- The clause “Emergency lighting” has been renamed “Lighting in emergency conditions”;
- The term “Standby lighting” has been replaced by “Safety lighting”;
- In Clause 6 “Lighting in emergency conditions”, a Note has been added on the requirement of safety lighting in tunnels concerned by the European Directive 2004/54/EC 12/2022;
- The previous Clause “Traffic signals” has been removed;
- In Annex A and Annex B, the levels of daytime luminance in the interior zone have been adapted in accordance with the latest developments at CIE;
- A new Annex C has been added: “The CIE perceived contrast methodology”;
- Limited adaptations in Annex D “The space and time adaptation method as used in France”;
- A new Annex E has been added: “An energy saving approach: practice from Italy”;
- The previous Annex “Veiling Luminance Method As Used In The Netherlands” has been removed;
- The term “electric lighting” replaces “artificial lighting”;
- The following figures have been updated: Figures 3, Figures A.1, A.2, A.3, Figures C.1, C.2, Figures D.1, D.2, D.3 to D.8, Figures F.1, F.4, F.5, Figures G.1 and G.2.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

Introduction

The aim of tunnel lighting is to ensure that users, both during the day and by night, can approach, pass through, and exit the tunnel without changing direction or speed with the degree of safety commensurate to that on the approach road.

To achieve safe passage through a road tunnel, it is necessary that all users have sufficient information regarding the course of the road ahead, possible obstacles and the presence and actions of other users. Furthermore, it is necessary that users, particularly drivers of motor vehicles, have at least an equal sense of security to that experienced on the approach roads.

Principal characteristics that describe the quality of tunnel lighting are:

- the luminance of the road surface,
- the luminance of the walls up to 2 m in height above the road surface,
- the uniformity of the luminance distribution on the road and walls,
- the control of induced glare,
- the avoidance of critical flicker frequencies.

In some cases, the illuminance of the road surface is used.

All photometric quantities are based on photopic photometry.

1 Scope

This document describes the current practice in the design of the lighting of road tunnels and underpasses for motorized and mixed traffic. This concerns arrangements, levels and other parameters including daylight, which are related only to traffic safety. Aspects concerning visual comfort are generally chosen in agreement with national rules. The information in this report concerns any tunnel or underpass where the decision to provide lighting has been taken by any authority working within national legislation or other constraints. The design is based on photometric considerations, and all values of luminance or illuminance are maintained values.

The main body of the report covers the common aspects of Tunnel Lighting, and the various methods currently used in Europe are detailed in the annexes. No single method is recommended.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12665, *Light and lighting — Basic terms and criteria for specifying lighting requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12665 and the following apply. ISO, IEC and CIE maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp/>
- IEC Electropedia: available at <https://www.electropedia.org/>
- e-ILV International Lighting Vocabulary: available at <https://cie.co.at/e-ilv>

3.1 Tunnel related zones

3.1.1

entrance portal

<of a road tunnel> part of a road tunnel construction that corresponds to the beginning of the covered part of the road tunnel or, when open sun screens are used, to the beginning of the sun screens

[SOURCE: EN 12665:2024, 3.5.41]

3.1.2

exit portal

<of a road tunnel> part of a road tunnel construction that corresponds to the end of the covered part of the road tunnel or, when open sun screens are used, to the end of the sun screens

[SOURCE: EN 12665:2024, 3.5.45]

3.1.3

access zone

<of a road tunnel> part of the open road immediately outside (in front of) the entrance portal, covering the distance over which an approaching driver must be able to see into a road tunnel

Note 1 to entry: The access zone begins at the stopping distance point ahead of the entrance portal and it ends at the entrance portal.

[SOURCE: EN 12665:2024, 3.5.24]

3.1.4

access zone length

<tunnel lighting> length of the access zone that begins at the stopping distance point ahead of the portal and ends at the portal

Note 1 to entry: Access zone length is expressed in metres (m).

Note 2 to entry: Generally, for curved roads, the access zone is considered to begin from where the driver can see the whole tunnel entrance portal, at least on his/her driving lane.

[SOURCE: EN 12665:2024, 3.5.25, modified – Note 2 to entry added]

3.1.5

threshold zone

<of a road tunnel> first part of a road tunnel, directly after the entrance portal

Note 1 to entry: The threshold zone starts either at the beginning of the road tunnel or at the beginning of the sun screen when a sun screen is installed. The length of the threshold zone is at least equal to the stopping distance.

[SOURCE: EN 12665:2024, 3.5.78]

3.1.6

transition zone

<of a road tunnel> part of a road tunnel that follows directly after the threshold zone and ends at the beginning of the interior zone

Note 1 to entry: In the transition zone, the lighting level is decreasing from the level at the end of the threshold zone to the level of the interior zone.

[SOURCE: EN 12665:2024, 3.5.86]

3.1.7

entrance zone

<of a road tunnel> combination of the threshold zone and the transition zone

Note 1 to entry: Entrance zone refers to the tunnel section where the eye's adaptation passes from the external light level to the interior zone lighting.

Note 2 to entry: In some countries the term entrance zone is also known as reinforcement zone.

[SOURCE: EN 12665:2024, 3.5.42, modified – Notes 1 and 2 to entry added]

3.1.8**interior zone**

<of a road tunnel> part of a road tunnel directly following the transition zone that stretches from the end of the transition zone to the beginning of the exit zone

[SOURCE: EN 12665:2024, 3.5.52]

3.1.9**exit zone**

<of a road tunnel> part of a road tunnel where, during daytime, the vision of a driver approaching the exit is predominantly influenced by the brightness outside the road tunnel

Note 1 to entry: The exit zone begins at the end of the interior zone. It ends at the exit portal of the road tunnel.

[SOURCE: EN 12665:2024, 3.5.46]

3.1.10**parting zone**

<of a road tunnel> first part of the open road directly after the exit portal of a road tunnel

Note 1 to entry: The parting zone is not a part of the road tunnel, but it is closely related to the road tunnel lighting. The parting zone begins at the exit portal. It is advised that the length of the parting zone is equal to 2 times the stopping distance. A length of more than 200 m is not necessary.

[SOURCE: EN 12665:2024, 3.5.66]

3.2 Lighting**3.2.1****visual guidance**

optical and geometrical means that ensure that motorists are given adequate information on the course of the road in the tunnel

3.2.2**threshold zone lighting**

lighting of the threshold zone of the tunnel which allows drivers to see into the tunnel whilst in the access zone

[SOURCE: EN 12665:2024, 3.5.79]

3.2.3**transition zone lighting**

lighting of the transition zone which helps drivers to adapt to the lighting level in the zones ahead

[SOURCE: EN 12665:2024, 3.5.87]

3.2.4**interior zone lighting**

lighting of the interior zone of the tunnel which provides adequate visibility in the interior of the tunnel

Note 1 to entry: At certain moments of the day, the interior zone lighting extends from the entrance portal to the exit portal.

[SOURCE: EN 12665:2024, 3.5.53, modified – removed “irrespective of the use of vehicle headlights”, Note 1 to entry added]

3.2.5

exit zone lighting

<of a road tunnel> lighting that provides the visual contact for the driver still in a road tunnel with the open road beyond the road tunnel

Note 1 to entry: It is assumed that visual contact will provide adaptation to the external condition.

[SOURCE: EN 12665:2024, 3.5.47]

3.2.6

safety lighting

<of a road tunnel> lighting provided to ensure a minimum visibility for tunnel users to evacuate the tunnel in the event of a breakdown of the main power supply

Note 1 to entry: Safety lighting is usually a part of the normal lighting installation.

3.2.7

daylight screen

daylight louvre

<tunnel lighting> device that transmits part of the ambient daylight

Note 1 to entry: Screens or louvres may be applied for the lighting of the threshold zone and/or the entrance zone of a tunnel

[SOURCE: EN 12665:2024, 3.4.10, modified – “part of” without brackets, Note to entry reworded]

3.2.8

sun-tight screen

<tunnel lighting> screen that is constructed in such a fashion that direct sunlight can never reach the road or wall surface under the screen

[SOURCE: EN 12665:2024, 3.4.11]

3.3 Luminance, illuminance

3.3.1

access zone luminance

eye adaptation luminance in the access zone

Note 1 to entry: Access zone luminance is expressed in candelas per square metre ($\text{cd} \cdot \text{m}^{-2}$)

[SOURCE: EN 12665:2024, 3.2.38]

3.3.2

L_{20} access luminance

L_{20}

<of a road tunnel> average luminance contained in a conical field of view, subtending an angle of 20° with the apex at the position of the eye of an approaching driver and aimed at the tunnel mouth

Note 1 to entry: L_{20} access luminance is assessed from a point at a distance equal to the stopping distance from the tunnel portal at the middle of the relevant carriageway or traffic lane.

Note 2 to entry: L_{20} access luminance is expressed in candelas per square metre ($\text{cd} \cdot \text{m}^{-2}$).

Note 3 to entry: If there is no national definition of the aiming, the definition of CIE 88:2004 can be used (i.e. aimed towards a centred point at a height equal to one quarter of the height of the tunnel entrance portal).

[SOURCE: EN 12665:2024, 3.2.44, modified – “the centre of” removed, Symbol added, Note 3 to entry added]

3.3.3

equivalent veiling luminance

L_{seq}

luminance that, when added by superposition to the luminance of both the adapting background and the object, makes the luminance threshold or the luminance difference threshold the same under the two following conditions: (1) glare present, but no additional luminance; (2) additional luminance present, but no glare

Note 1 to entry: Equivalent veiling luminance is expressed in candela per square metre ($\text{cd}\cdot\text{m}^{-2}$).

[SOURCE: EN 12665:2024, 3.2.41, modified – different Symbol used]

3.3.4

atmospheric luminance

L_{atm}

light veil as a result of the scatter in the atmosphere expressed as a luminance

Note 1 to entry: Atmospheric luminance is expressed in candela per square metre ($\text{cd}\cdot\text{m}^{-2}$).

[SOURCE: EN 12665:2024, 3.4.9]

3.3.5

windscreen luminance

L_{ws}

light veil as a result of the scatter in the vehicle windscreen expressed as a luminance

Note 1 to entry: Windscreen luminance is expressed in candela per square metre ($\text{cd}\cdot\text{m}^{-2}$).

[SOURCE: EN 12665:2024, 3.2.52, modified – Symbol changed]

3.3.6

threshold zone luminance

$\bar{L}_{\text{th}}$

average road surface luminance of a transverse strip at a given location in the threshold zone of the tunnel (as a function of the measurements grid)

Note 1 to entry: Threshold luminance is expressed in candela per square metre ($\text{cd}\cdot\text{m}^{-2}$).

[SOURCE: EN 12665:2024, 3.2.48]

3.3.7

transition zone luminance

$\bar{L}_{\text{tr}}$

average road surface luminance of a transverse strip at a given location in the transition zone of the tunnel (as a function of the measurement grid)

Note 1 to entry: Transition zone luminance is expressed in candela per square metre ($\text{cd}\cdot\text{m}^{-2}$).

[SOURCE: EN 12665:2024, 3.2.50]

3.3.8

interior zone luminance

$\bar{L}_{in}$

<of a road tunnel> average road surface luminance of a transverse strip at a given location in the interior zone of the tunnel (as a function of the measurement grid)

Note 1 to entry: Interior zone luminance is expressed in candela per square metre ($\text{cd} \cdot \text{m}^{-2}$).

[SOURCE: EN 12665:2024, 3.2.43]

3.3.9

vertical illuminance

E_v

illuminance on a vertical plane

Note 1 to entry: Vertical illuminance is expressed in lux (lx).

[SOURCE: EN 12665:2024, 3.2.59, modified – symbol E_v selected]

3.3.10

contrast revealing coefficient

q_c

<of a tunnel lighting installation> quotient of the luminance, L , of a road surface and the vertical illuminance, E_v , at a specific location in a tunnel

$$q_c = \frac{L}{E_v}$$

Note 1 to entry: Contrast revealing coefficient is expressed in candelas per square metre per lux ($\text{cd} \cdot \text{m}^{-2} \cdot \text{lx}^{-1}$) which may be simplified to steradian to the power minus one (sr^{-1}).

Note 2 to entry: E_v is the illuminance at a particular location at a height of normally 0,1 m above the road surface, in a plane facing the direction of oncoming traffic. The height of 0,1 m above the road surface is meant to represent the centre of an object of 0,2 m $\times$ 0,2 m. This orientation is an acceptable approximation of the real situation.

[SOURCE: EN 12665:2024, 3.2.39, modified – index of L and E_v adapted, Note 2 to entry added]

3.3.11

threshold luminance ratio

k

ratio between the threshold zone luminance $\bar{L}_{th}$ and the access luminance L

$$k = \frac{\bar{L}_{th}}{L}$$

where

$\bar{L}_{th}$ is the threshold zone luminance

L is the luminance in the access zone

Note 1 to entry: L is evaluated according to the methodology considered, e.g. L_{20} access luminance, L_v veiling luminance, etc. According to the methodology considered to obtain L , the corresponding subscript is added to k , e.g. k_v , k_{20} .

Note 2 to entry: In the L_{20} methodology, L_{th} is considered in the first part of the threshold zone.

3.3.12

luminance uniformity

overall uniformity (of road surface luminance, of wall surface luminance)

U_o

quotient of minimum luminance and average luminance of a surface

Note 1 to entry: Luminance uniformity has the unit one.

Note 2 to entry: Can apply to the reference field of calculation or measurement.

[SOURCE: EN 12665:2024, 3.2.54, modified – “overall uniformity (of road surface luminance, of wall surface luminance)” added, Note 2 to entry added]

3.3.13

longitudinal uniformity

U_l

<of road surface luminance of a carriageway> lowest of the ratios determined for each driving lane of the carriageway as the ratio of the lowest to the highest road surface luminance found in a line in the centre along the driving lane

Note 1 to entry: The longitudinal uniformity is considered for each driving lane.

Note 2 to entry: Can apply to the reference field of calculation or measurement.

Note 3 to entry: In tunnels longitudinal uniformity is used only in zones where the average luminance is constant.

Note 4 to entry: Longitudinal uniformity has the unit one.

[SOURCE: EN 12665:2024, 3.2.45, modified – Notes to entry added]

3.3.14

veiling luminance

L_v

luminance that superimposes on the retinal image and reduces the contrast

Note 1 to entry: Veiling luminance is expressed in candela per square metre ($\text{cd}\cdot\text{m}^{-2}$).

3.4 Traffic related concepts

3.4.1

carriageway

part of the road normally used by vehicular traffic

[SOURCE: EN12665:2024, 3.5.29]

3.4.2

traffic lane

strip of carriageway intended to accommodate a single line of moving vehicles

[SOURCE: EN12665:2024, 3.5.85]

3.4.3

emergency lane

hard shoulder

lane parallel to the traffic lane(s), provided for emergency and/or broken-down vehicles only

Note 1 to entry: The emergency lane is not part of the carriageway.

[SOURCE: EN12665:2024, 3.5.38, modified – Note 1 to entry added]

3.4.4

traffic flow

traffic volume

number of vehicles passing a specific point in a stated time in stated direction(s)

Note 1 to entry: In tunnel design, peak hour traffic per lane is used, expressed in vehicles per hour per lane.

[SOURCE: EN12665:2024, 3.5.88, modified – admitted terms added]

3.4.5

peak hour traffic

traffic volume during the one-hour period during which the greatest volume of traffic uses the road section

Note 1 to entry: Peak hour traffic is expressed in vehicles per hour per lane.

3.4.6

speed limit

maximum legally allowed speed

Note 1 to entry: Speed limit is expressed in kilometres per hour ($\text{km}\cdot\text{h}^{-1}$).

[SOURCE: EN 12665:2024, 3.5.72]

3.4.7

design speed

speed adopted for a particular stated purpose in designing a road

Note 1 to entry: Design speed is expressed in kilometres per hour ($\text{km}\cdot\text{h}^{-1}$)

[SOURCE: EN 12665:2024, 3.5.34]

3.4.8

reaction time

minimum time interval between the occurrence of an event demanding immediate action by the driver and the response to the event

Note 1 to entry: The reaction time includes the time needed for perception, taking a decision and acting.

Note 2 to entry: Reaction time is expressed in seconds (s).

[SOURCE: EN 12665:2024, 3.1.13, modified – “by the driver” added]

3.4.9

stopping distance

SD

d_s

distance needed to bring a vehicle, driving at design speed, to a complete standstill

Note 1 to entry: The stopping distance is usually defined in national legislation or regulation.

Note 2 to entry: The stopping distance includes both the distance covered while reacting and the distance covered while braking.

Note 3 to entry: Stopping distance is expressed in metres (m).

Note 4 to entry: The concept “Safe stopping distance” is not used in this Technical Report.

[SOURCE: EN 12665:2024, 3.5.75, modified – Abbreviation and symbol added, Note 4 to entry added]

3.4.10

mixed traffic

traffic that consists of motor vehicles, cyclists, pedestrians, etc

[SOURCE: EN 12665:2024, 3.5.60]

3.4.11

motor traffic

motorized traffic

traffic that consists of motorized vehicles only

Note 1 to entry: It depends on national legislation which vehicle types are included in this classification.

Note 2 to entry: In some countries it only includes vehicles which are capable of maintaining a minimum speed. In others, mopeds are not considered as motorized traffic.

[SOURCE: EN 12665:2024, 3.5.61]

3.5 Symbols and abbreviations

Table 1 — Symbols and abbreviations

Symbol	Abbreviation	Name or description	Unit
d_s	SD	Stopping distance	m
E_v	-	Vertical illuminance	lux
$\bar{L}_r$	-	Average road surface luminance	$\text{cd}\cdot\text{m}^{-2}$
$\bar{L}_w$	-	Average wall surface luminance	$\text{cd}\cdot\text{m}^{-2}$
k	-	Threshold luminance ratio	1
q_c	-	Contrast revealing coefficient	$\text{cd}\cdot\text{m}^{-2}\cdot\text{lx}^{-1}$
L_v	-	Veiling luminance	$\text{cd}\cdot\text{m}^{-2}$
L_{atm}	-	Atmospheric luminance	$\text{cd}\cdot\text{m}^{-2}$
L_{ws}	-	Windscreen luminance	$\text{cd}\cdot\text{m}^{-2}$
L_{seq}	-	Equivalent veiling luminance	$\text{cd}\cdot\text{m}^{-2}$
L_{20}	-	L_{20} access luminance	$\text{cd}\cdot\text{m}^{-2}$
$\bar{L}_{\text{th}}$	-	Threshold zone luminance	$\text{cd}\cdot\text{m}^{-2}$
$\bar{L}_{\text{tr}}$	-	Transition zone luminance	$\text{cd}\cdot\text{m}^{-2}$
$\bar{L}_{\text{in}}$	-	Interior zone luminance	$\text{cd}\cdot\text{m}^{-2}$
U_o	-	Overall uniformity	1
U_l	-	Longitudinal uniformity	1
f_m	-	Maintenance factor	1
f_{TI}	-	Threshold increment	%
-	LTP	Look through percentage	%
-	AADT	Average daily traffic at peak hour	vehicles per hour per lane
-	CBL	Counter-beam lighting	-
-	SYM	Symmetric lighting	-

Table 2 — Symbols used in Annex C – The perceived contrast methodology

Symbols used in the perceived contrast methodology		
Symbol	Name or description	Unit
C_i	Intrinsic contrast of the reference object	1
$C_{p,m}$	Minimum required perceived contrast of the reference object	1
C_p	Perceived contrast of the reference object	1
$L_{o,i}$	Intrinsic luminance of the reference object	$\text{cd}\cdot\text{m}^{-2}$
$L_{r,i}$	Intrinsic luminance of the road surface near the reference object	$\text{cd}\cdot\text{m}^{-2}$
$L_{o,p}$	Perceived luminance of the reference object	$\text{cd}\cdot\text{m}^{-2}$
$L_{r,p}$	Perceived luminance of the road surface near the reference object	$\text{cd}\cdot\text{m}^{-2}$
$L_{v,d}$	Design value of the veiling luminance	$\text{cd}\cdot\text{m}^{-2}$
τ_{atm}	Atmospheric transmittance	1
τ_{ws}	Windscreen transmittance	1
ρ	Reflectance of the reference object	1
k	Coefficient that evaluates the influence of the driver's age	$\text{cd}\cdot\text{m}^{-2}$
$k_{i,j}$	Weight factor that considers the area of the i, j section of the Adrian diagram	1
θ	Angle between the direction of origin of the light and the foveal direction of view	degree
θ	Solid angle of integration	degree
dE	Elementary contribution of the illuminance	lx
x	Longitudinal coordinate	m
δ	Angle between the direction of origin of the light and the foveal direction of view	degree

4 General aspects of tunnel lighting

4.1 Tunnel conditions

4.1.1 General

Road and traffic conditions in tunnels may differ considerably from those that prevail on the open road. The design of tunnel lighting installations takes these different conditions into account, with regard to the traffic safety aspects.

Measurements of the tunnel lighting installation are taken after completion to ensure that the design requirements have been met. Advice on measurement is given in Clause 7.

4.1.2 Stopping distance

Important parameters for the design of tunnel lighting installations include the speed, volume and composition of traffic flow entering, and passing through.

There is a strong, but nonlinear relationship between the traffic flow and the accident risk: higher volumes show a higher accident risk (except for very low or very high traffic volumes). The extra risk can be counteracted, at least in part, by increasing the light level. This relationship is established for many types of open roads, and it is assumed that it also holds for tunnels.

One of the most important factors is speed. In practice, road and tunnel designs are such that speed and flow are usually interrelated, as a high design speed is selected for roads for which a high flow is expected. High speeds require better visibility and therefore generally a higher luminance level.

When not defined in national standard or legislation, the stopping distance (SD) can be calculated following the method described in Annex G.

4.1.3 The purpose of tunnel lighting

The lighting of a tunnel is necessary:

- to avoid the 'black hole effect' when a driver is unable to see into the tunnel,
- to reduce the likelihood of a collision with another tunnel user,
- to enable a driver to react and stop within the stopping distance (SD) if an unexpected hazard appears.

4.1.4 Traffic composition

The traffic composition is relevant for the tunnel lighting in several aspects:

- the percentage of trucks,
- the presence/absence of pedal bicycles and/or mopeds,
- the presence/absence of pedestrians (non-emergency conditions),
- the presence/absence of authorization to allow the transit of hazardous material.

The lighting is adapted to these circumstances. Higher levels or better-quality lighting for the walls or the road are necessary for the visual task when the conditions are more difficult or more hazardous.

4.1.5 Road and tunnel conditions

Driving comfort is an important aspect of the quality of the lighting installations of road traffic tunnels. Good design prevents tunnels, constructed to overcome traffic obstructions, from becoming a traffic obstruction in themselves: the traffic flow in and through the tunnel will be just as fluid as on the open road. As a result of feelings of anxiety, drivers are likely to slow down near the tunnel entrance. Sudden drops in speed reduce the traffic capacity and might lead to traffic jams and even to accidents. So, good lighting that helps to overcome any feeling of anxiety is not only a matter of driving comfort but also a matter of road capacity and of traffic safety.

This can be explained as follows. Driving a car safely is mainly a matter of attention. On long stretches of motorway, attention can waver and the level of arousal is low. Drivers are not well prepared to cope with emergencies if they occur unexpectedly. Near tunnels, the attention must be higher to cope with additional hazard factors. Tunnels, being low and narrow, might cause concern or even fear, but also will lead to an increase in arousal. The fear and the arousal are likely to cancel out each other to a large extent, so that the more dangerous tunnel entrance need not lead to more accidents.

A tunnel is a confined environment that makes any accidents more critical. The object of installing lighting in a road tunnel is to enable the traffic to pass through with the same or better degree of safety and comfort, as is customary on the open road, and with an acceptable speed. The difficulty of the driving task when approaching and passing through a tunnel is mainly influenced by the speed, the traffic volume (flow) and the composition of the traffic and by the layout of the road and the tunnel and their immediate surroundings. To enable a road user to drive safely when a tunnel is on his/her route, it is pertinent to give them adequate and relevant information, which allows the driver to situate themselves in space and time, to foresee a possible obstacle on the way.

When making the lighting design for a tunnel, it is important to consider the following aspects:

a) Altered perception:

The walls can generate a “wall shyness effect” which tends to make drivers keep further away. Drivers’ visual performance can be considerably lower, especially regarding visual acuity, the perception of contrast and distances, peripheral vision and the discrimination of colours. Time perception can change: the perceived duration seems to be about twice as long as the actual time span. And finally, some drivers can be affected by sensations such as claustrophobia.

b) Overall perception:

1) Before entering a tunnel:

- relevant signs show that one is approaching the tunnel,
- dark portals reduce the access zone luminance,
- black asphalt surface for the road up to the portal helps to adapt the driver to the lower luminances inside the tunnel.

2) Entering the tunnel:

- East-West orientations can cause more problems than North-South orientations,
- green surfaces in the immediate surround of the entrance portal reduce the access luminance around the portal,
- trees or other screens to avoid direct glare from the sun.

3) Inside the tunnel:

- discontinuities, ramps, and intersections in the geometric design, are treated by an ad hoc lighting system,
- diffusing light-coloured road surfaces are better for symmetric lighting; specular surfaces help in counter-beam lighting,
- adopting and maintaining markings, delineators etc. along the road provide good guiding facilities.

4) At the exit:

- a glaring situation can be expected outside the exit; civil engineering works or planting that will screen off the direct sunlight are important.

4.2 Lighting systems and contrast rendition methods

4.2.1 Electric lighting systems

The contrasts of objects can be negative or positive, depending on the reflection properties of the surface of the object and on the lighting system used. There are two electric lighting systems in common use in lighting design: the symmetric lighting system and the counter-beam lighting system. A third one, pro-beam lighting, is seldom used and will not be described in this Technical Report. The symmetric and counter-beam terms refer to the luminous intensity distribution of the luminaires that are used.

In a counter-beam lighting system (CBL), luminaires are used where the maximum luminous intensity is aimed against the direction of the traffic and with a low luminous intensity in the direction of the traffic so that the luminous intensity distribution is strongly asymmetric, as illustrated on Figure 1. The terms refer only to the direction of normal traffic.

The symmetric lighting system is a system where the luminaires show a luminous intensity distribution that is symmetric in relation to the 90°/270° C-plane (the plane usually normal to the direction of the traffic), as illustrated on Figure 2.

The luminous intensity distribution is not sufficient to quantify the effect of the installation, because the effect of the lighting is determined by the contrasts. The effect of the lighting is characterized by the value of the contrast revealing coefficient q_c . CBL systems can be used to increase the contrast, typically to a value of L/E_v above 0,6.

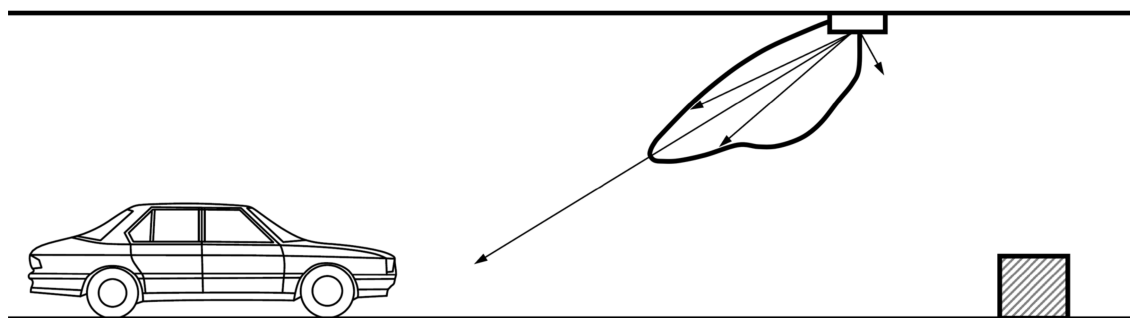


Figure 1 — Counter-beam lighting system

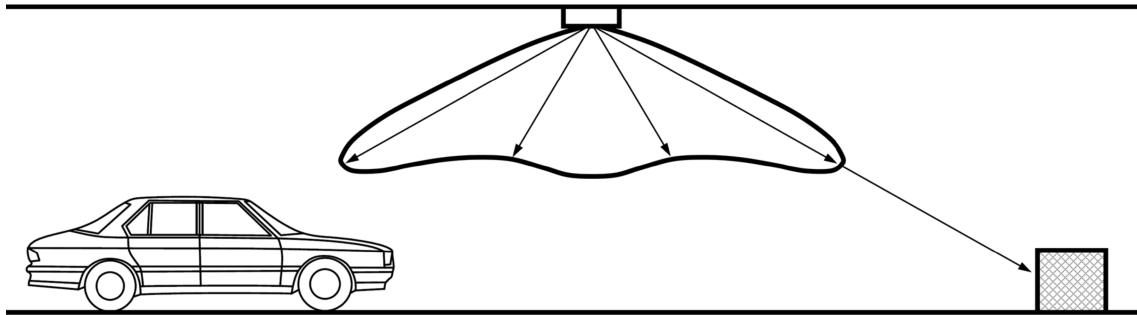


Figure 2 — Symmetric lighting system

The counter-beam lighting system comprises luminaires with a luminous intensity distribution that is aimed against the direction of the traffic. It usually produces a higher negative contrast for objects on the road, because the illuminance on the planes that are facing the approaching drivers is low. When specular road surfaces are used (ex. R3, R4, C2), the luminance yield usually is significantly higher than with symmetric lighting. The counter-beam lighting system will normally create greater contrast between objects and the background (e.g. road surfaces and walls).

However, the counter-beam lighting system:

- can give some increase in the “black hole” effect, because in some design methods the threshold luminance may be lowered, so that drivers’ guidance could be reduced,
- could not be appropriate for a tunnel entrance with high daylight penetration,
- can prove to be less effective for tunnels with very high traffic flows or for tunnels with a high percentage of heavy goods vehicles,
- can be less effective in revealing road markings that show a diffuse reflection.

4.2.2 Screened daylight systems

Daylight, controlled by screens, is sometimes used as an alternative light source for tunnel entrances. As regards to luminance and illuminance levels, the same minimum requirements apply to daylight and electric light. However, the road surface luminance under the screens is generally higher than the minimum required. This holds for the different tunnel lighting design methods described in this document. The contrast revealing coefficient q_c is determined in the same way as for electric light.

Daylight screens are either sun-tight or non-sun-tight. Sun-tight screens over the roadway serve to realize the threshold zone luminance and sometimes part of the transition zone luminance in much the same way as electric lighting. Non-sun-tight screens over the roadway serve primarily to screen the bright sky directly over the tunnel entrance from direct view. Non-sun-tight screens can cause unwanted flicker effects (see 4.3.1). When open daylight screens are used in situations where heavy snowfall is common, blocks of snow can fall on the carriageway, causing a serious danger for the users.

4.3 Aspects common to various design methods

4.3.1 Flicker

Flicker sensations are experienced when driving through spatially periodic changes in luminance, such as those produced by louvres in the tunnel walls or ceiling, or by incorrectly spaced luminaires (with high rate of change in their luminous intensity distribution). The visual discomfort experienced due to flicker depends upon:

- a) the number of luminance changes per second (flicker frequency),

- b) the total duration of the flicker persistence,
- c) the rate of change from light to dark in a single cycle,
- d) the ratio of peak (light) to trough (dark) luminance within each period (luminance modulation depth).

The influences of points (a), (b) and (c) depend upon vehicle speed and luminaire spacing; points (c) and (d) also depend on the optical characteristics and spacing of the luminaires.

When the distance between the ends of adjacent luminaires is less than the length of the flashed area of a single luminaire, the fourth point (d) is typically minimized, and perceived flicker rendered negligible – at least with respect to the electric lighting.

To calculate the flicker frequency within a stretch of tunnel, divide the velocity ($\text{m}\cdot\text{s}^{-1}$) by the luminaire spacing (m). For example:

- If velocity = $60 \text{ km}\cdot\text{h}^{-1} = 16,6 \text{ m}\cdot\text{s}^{-1}$ and luminaire spacing = 4 m, then flicker frequency = $16,6/4 \approx 4,2 \text{ Hz}$.

In general, the flicker effect is negligible at frequencies below 2,5 Hz and above 15 Hz. When the frequency is between 4 Hz and 11 Hz, and has a duration of more than 20 s, discomfort can arise provided no other measures are taken.

This is valid for all tunnel zones, including for non-sun-tight daylight louvres at the entrance and/or the exit. For large size luminaires with low gradients in the luminous intensity distribution, the flicker effects are lower. Compact light sources with a high gradient in the luminous intensity distribution are a higher concern.

Non-sun-tight louvres can also cause a flicker effect perceived by the driver.

4.3.2 Glare restriction

As glare reduces visibility, it is important to minimize its effects. In tunnel lighting, physiological (disability) glare is considered. Disability glare effects are quantified by the threshold increment f_{TI} as described in CIE 31 and in EN 13201-3:2015, 8.5, where formulae are given for its calculation.

NOTE 1 Some national standards or legislation give maximum values for the threshold increment f_{TI} .

Generally, a maximum value of threshold increment up to 15 % is applied for the interior zone of the tunnel during daytime, and for all tunnel zones during the night. For the exit zone during daytime no restriction is given.

NOTE 2 Some European countries currently apply lower limit values of threshold increment.

The following formulae are used to calculate f_{TI} :

$$f_{TI} = 65 L_v / (\bar{L}_{r,i})^{0,8} \text{ if } \bar{L}_{r,i} \leq 5 \text{ cd} \cdot \text{m}^{-2} \quad (1)$$

$$f_{TI} = 95 L_v / (\bar{L}_{r,i})^{1,05} \text{ if } \bar{L}_{r,i} > 5 \text{ cd} \cdot \text{m}^{-2} \quad (2)$$

where

$\bar{L}_{r,i}$ is the average initial road surface luminance (in $\text{cd} \cdot \text{m}^{-2}$);

L_v is the equivalent initial veiling luminance (in $\text{cd} \cdot \text{m}^{-2}$), created by all luminaires in the field of view where the axis of fixation is 1° down from the horizontal at the relevant location.

The calculations are made on the base of the initial values, and include only the luminaires under a screening plane which is inclined at 20° to the horizontal, and which passes through the observer's eye.

NOTE 3 Formula (1) comes from EN 13201-3:2015 and Formula (2) comes from CIE 88:2004 and is being challenged in some countries and replaced by other methods.

In case of variable luminances, as in the second part of the threshold zone or in the transition zone, f_{TI} can be calculated with the above formulae, where $\bar{L}_{r,i}$ is considered to be the initial luminance of the transversal road section at a distance of 86 m from the observer. Higher values of f_{TI} (up to 30 %) are acceptable in these zones of variable luminance with this calculation method.

4.3.3 Lighting control

The access zone luminance varies with changes in daylight conditions. During the day, the luminance levels in the threshold and transition zones are adjusted to the variations of luminance in the access zone by automatic control of the electric lighting.

For adequate light control the access zone luminance is monitored continuously by a luminance meter and consequently the entrance zone luminance is adjusted. Generally, the control is done by continuously adjusting the light output or switching on or off groups of luminaires/light sources.

The luminance meter is ideally centred on the tunnel portal and positioned at the stopping distance (SD) in front of the tunnel portal. For practical reasons like the presence of vehicles in the camera field of view, the luminance meter is mounted at a greater height than the driver's eye position. Therefore, the instrument orientation is adjusted at its installation position, and its reading is corrected.

The switching of light sources can be done in steps to switch various luminaires/light sources on or off. This has a time delay of several minutes to avoid unnecessary switching owing to transient variation in the local lighting level caused by brief transient light conditions.

Studies have shown that continuous adaptive lighting can result in considerable financial savings.

Further variables can be included such as traffic density, traffic speed and/or actual luminance achieved inside the tunnel. The base lighting can also be adapted during daytime and night-time based upon high- and low traffic densities and the approach road lighting class.

Frequent maintenance and cleaning of the control equipment is important to ensure proper operation.

4.3.4 Maintenance

To maintain the design performance of the lighting installation, cleaning is particularly important: walls and luminaires are put under specific programs of washing or cleanliness, the cleaning cycle being related to the maintenance factor used in the calculations of the lighting levels.

The maintenance factor also refers to the depreciation in the photometric performance of a luminaire from its state when new to its worst acceptable state in service.

The lighting scheme is designed taking into account an overall maintenance factor (f_m) calculated for the selected lighting equipment, environment and specified maintenance schedule for the tunnel according to ISO/CIE TS 22012.

The designer:

- states f_m and list all assumptions made in the derivation of the value;
- specifies lighting equipment suitable for the application environment; and
- prepares a maintenance schedule to include e.g. frequency of light source replacement, luminaire and surface cleaning intervals.

The maintenance factor f_m has a large impact on energy efficiency. The assumptions made in the derivation of the f_m are intended to be both realistically achievable and optimized in a way that leads to a high value.

NOTE Guidance on the determination of the maintenance factor can be found in ISO/CIE TS 22012 and further information on the derivation of f_m for electric outdoor lighting systems can be found in CIE 154. Aspects of tunnel maintenance are further developed in the relevant chapter of CIE 88.

In practice, the luminance of the walls will decrease faster than that of the road surface. This is usually considered at the design stage by assigning a maintenance factor to the wall initial reflectance.

Using the recommended maintenance cycles ensures that the luminance does not fall below the target value or that failed light sources give unacceptable uniformity.

The maintenance of the access zone luminance meters / photometers regarding alignment and calibration is critical for energy consumption and safety of the users.

5 Dimensioning rules for the lighting of road tunnels

5.1 Distinction between long and short tunnels

Tunnels are generally divided into two main categories, long tunnels and short tunnels.

The lighting requirements for long and short tunnels differ according to the degree to which the approaching motorist can see through the tunnel as seen from a point at a distance equal to the stopping distance in front of the tunnel portal. The ability to see through the tunnel depends primarily on the length of the tunnel but also on other design parameters (width, height, horizontal and/or vertical curvatures, etc.).

Tunnels shorter than 25 m do not need daytime lighting. For tunnels of length between 25 m and 200 m, methods to determine a possible need of daytime lighting are given in Annex F. Tunnels longer than 200 m are considered as long tunnels. The length is typically measured along the tunnel axis.

5.2 Lighting of long tunnels

It is essential to know the luminance in the access zone to determine the luminance levels that are required at the tunnel entrance. Alternative methods of assessing the entrance luminance are given in Annexes A to E. The value of the entrance luminance that is used for the lighting design and/or the lighting control is determined in one of two ways: it is either the maximum access zone luminance occurring during the year, or it is that value which is only exceeded for a certain proportion of a year decided by national agreement.

- a) The L20 method is described in Annex A. It covers daytime lighting of the threshold, transition and interior zones and night-time lighting of the whole tunnel.
- b) A traffic-weighted adaptation of the L20 method is described in Annex B. It classifies tunnels into classes, using parameters related to the traffic and visual conditions. It covers daytime lighting of the threshold, transition, interior and exit zones, with guidance on the parting zone where appropriate and night-time lighting of the whole tunnel.
- c) The CIE perceived contrast methodology is described in Annex C.
- d) An alternative method of assessing the adaptation luminance is described in Annex D.
- e) An alternative method of assessing the luminance in the threshold zone and energy savings aspects is described in Annex E.

Values of daytime luminance in the interior zone depend on several parameters and tunnel conditions. Several methods are provided in Annexes.

5.3 Lighting of short tunnels and underpasses

The need for electric lighting during daytime is determined by the degree in which other road users or objects are visible for a driver from the beginning of the access zone against the scene behind the exit portal.

When the exit portal is a large part of the scene visible through the entrance from the access zone, other road users and objects can easily be seen as dark against the lighter scene of the exit portal. On the other hand, electric lighting is needed when the exit is in a relatively large dark frame, in which objects can be obscured. This can happen when the short tunnel is relatively “long”, or when the short tunnel is curved in such a way that only a part of the exit can be seen or when the exit cannot be seen at all.

So, the critical factor is whether approaching drivers can see vehicles, other road users or obstacles when their distance from the entrance portal is equal to the stopping distance.

Usually, when daytime electric lighting is needed in a short tunnel, the lighting levels can easily be derived from the requirements of long tunnels.

Part-time daytime lighting can be provided during periods when the daylight penetration does not provide a background of sufficiently high luminance to enable the silhouette effect to operate. Such conditions can arise after dawn, prior to dusk and on overcast days.

Different methods used to determine the need of daytime electric lighting in short tunnels are presented in annexes.

One of the methods for determining the need of daytime electric lighting in short tunnels is the “Look Through” method, detailed in Annex F. The “Look Through” is defined as the ratio between the visible