



White Paper Luminance & Illuminance

Brief explanation of photometry
for the application of tunnel lighting control

1 General

This document gives a brief explanation of photometry, the basics of tunnel lighting and the application of photometers in controlling the lighting of tunnels.

2 Photometry

2.1 Luminance & Illuminance

Luminance is the photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle.

Luminance is often used to characterise emission or reflection from flat, diffuse surfaces. The luminance indicates how much luminous power will be detected by an eye looking at the surface from a particular angle of view. Luminance is thus an indicator of how bright the surface will appear to the human eye.

$$L_v = \frac{d^2\Phi_v}{dA d\Omega \cos \theta}$$

L_v ... Luminance in cd/m^2

Φ_v ... Luminous flux or luminous power in lm

θ ... Angle between surface normal and specified direction

A ... Area of the surface in m^2

Ω ... Solid angle in sr

Illuminance is the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception.

$$E_v = \frac{d\Phi_v}{dA}$$

E_v ... Illuminance in lx or lm/m^2

Φ_v ... Luminous flux or luminous power in lm

A ... Area of the surface in m^2

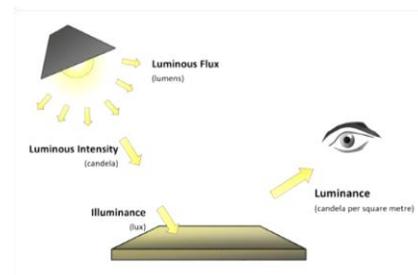


Figure 1 - Luminance & illuminance

3 Tunnel lighting

3.1 Design objectives & parameters

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 a degree of safety equal to that on the approach road.

Guidelines on how to design an appropriate tunnel lighting installation are laid out in the Technical Report CIE 88:2004 of the Commission internationale de l'éclairage (CIE) and the CEN Report CR 14380 as well as in several national standards as the Austrian RVS 09.02.41 (RVS).

The lighting requirements of a tunnel are totally different by day and by night. At night-time on lit roads the luminance levels in the tunnel simply need to be equal to those outside the tunnel.

The design of the lighting during daytime is particularly critical because of the human visual system. A driver approaching a tunnel cannot simultaneously perceive details on the road under lighting levels existing in a highly illuminated

exterior and a relatively dark interior. While the visual system can adapt to such a reduction of ambient illumination this adaptation process takes time.

The design of a tunnel lighting installation not only needs to take the different environmental lighting conditions into account. Further important parameters in the design are:

- Tunnel length
- Design speed
- Volume (flow) and composition of traffic

Generally the lighting of a tunnel entrance should be adequate

- to avoid the “black hole effect” when a driver enters the tunnel,
- to reduce the likelihood of a collision with other traffic or objects,
- to enable a driver to react and stop within the stopping distance if an unexpected hazard appears.

3.2 Tunnel related zones

A tunnel is structured into different zones to determine the longitudinal lighting level at daytime:

- **Access zone:** a part of the open road immediately in front of the tunnel portal, covering the distance over which an approaching driver must be able to see into the tunnel. The access zone begins at the stopping distance point ahead of the portal and ends at the portal.
- **Threshold zone:** the first part of the tunnel, directly after the portal. The threshold zone starts either at the beginning of the tunnel or at the beginning of the daylight sunscreens when occurring. The length of the threshold zone is at least equal to the stopping distance.
- **Transition zone:** the part of the tunnel following directly after the threshold zone. The transition zone begins at the end of the threshold zone. It ends at the beginning of the interior zone. 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.
- **Interior zone:** the part of the tunnel following directly after the transition zone. It stretches from the end of the transition zone to the beginning of the exit zone.
- **Exit zone:** the part of the tunnel where, during the day-time, the vision of a driver approaching the exit is predominantly influenced by the brightness outside the tunnel. The exit zone begins at the end of the interior zone. It ends at the exit portal of the tunnel.
- **Parting zone:** the first part of the open road directly after the exit portal of the tunnel. The parting zone is not a part of the tunnel, but it is closely related to the tunnel lighting. The parting zone begins at the exit portal. It is advised that the length of the parting zone equals two times the stopping distance. A length of more than 200 m is not necessary.

The guidelines cited above describe different nominal luminance levels for these zones which shall be achieved by an appropriate lighting of the tunnel.

3.3 Tunnel lighting control

The access zone luminance varies with changes in daylight conditions. During the day the required luminance levels in the threshold zone and transition zone are functions of the access zone luminance. Therefore it is necessary to provide automatic control of the artificial lighting in these zones. Two systems are possible: switching off (or on) groups of lamps, or dimming them. The first is most commonly applied, particularly at high luminance levels. Dimming can be considered but the actual savings need to be taken into account. Studies have shown that dimming can result in considerable financial savings. However the increased equipment cost should also be considered.

For the automatic control, the most practicable solution is to place a luminance meter with a measuring field of 20°, centred on the tunnel portal and positioned at the stopping distance (SD) in front of the tunnel portal. For practical reasons,

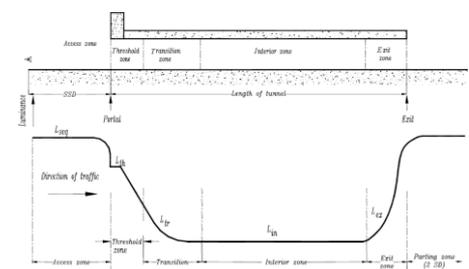


Figure 2 - Tunnel related zones and typical luminance gradient

the luminance meter usually has to be mounted at a greater height than the driver's eye position. Therefore the instrument has to be calibrated separately at the correct position.

4 Photometers in tunnel lighting control

This chapter describes requirements to photometers, their application and the use of their measured values to control the tunnel lighting. It follows the Austrian guidelines and provisions for road safety (RVS) and the recommendations of the CIE 88-2004 Guide for the Lighting of Road Tunnels and Underpasses (CIE).

Where the respective document is cited the according abbreviation appears in the headline of the subchapter.

4.1 Requirements to photometers (RVS)

Luminance photometers of common type with adapted optics and measuring ranges are to be installed to measure the luminance in the access zone L_{20} , the threshold zone L_{th} and the interior zone L_{in} . Additionally to the luminance the outside illuminance shall be measured by a lux meter.

All metal parts of the photometers shall be corrosion free and installed in an insulated housing. Protective class shall be IP 65 at minimum.

Icing and fogging of the camera windows shall be prevented by appropriate measures (e.g. an electronically controlled heating with a safety thermostat).

4.2 Typical setup

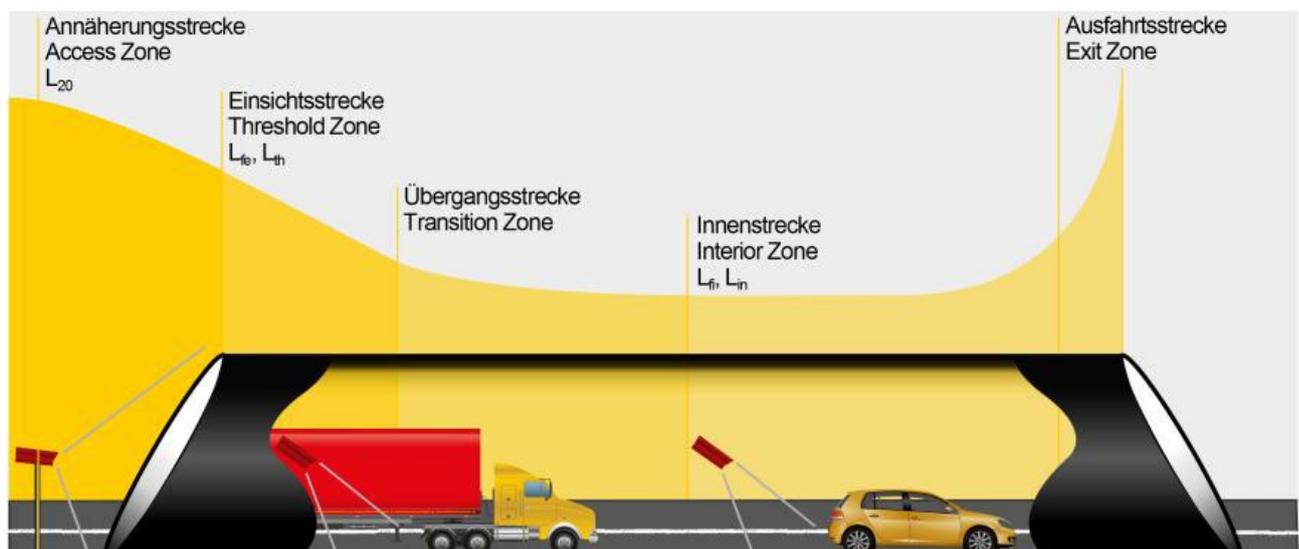


Figure 3 - Luminance gradient and zones in a tunnel with typical installation positions of luminance photometers

4.2.1 Luminance photometer L_{20} (RVS)

The luminance photometer L_{20} is used to measure the luminance in the access zone.

The measuring range is usually 1 to 6,000 cd/m^2 .

The luminance photometer L_{20} has to measure the integrated luminance of the tunnel vicinity within a field angle of 20° .

In case optics are used a zoom lens with adjustable aperture has to be used.

The luminance photometer L_{20} usually has to be mounted in stopping distance from the tunnel portal at the right kerbside in a height of approximately 3.5 m.

4.2.2 Luminance photometer L_{th} (RVS)

The luminance photometer L_{th} measures the luminance in the threshold zone with a measuring range of 1 to 500 cd/m².

The cross hairs have to be aligned in the first part of the threshold zone in driving direction to the centre of the right lane. The luminance photometer is to be mounted in a height of approximately 3.5 m.

4.2.3 Luminance photometer L_{in} (RVS)

The luminance photometer L_{in} is used to measure the luminance in the interior zone and shall have a measuring range of about the double value of L_{in} .

The luminance photometer L_{in} is mounted at the end of breakdown bays with a maximum distance of 2.0 km between two photometers or in the middle of a tunnel respectively.

The cross hairs have to be aligned to the middle between two tunnel lights of the interior zone and to the middle of the roadway.

4.2.4 Illuminance photometer E_a (RVS)

The illuminance photometer E_a is used to measure the illuminance in the vicinity of the tunnel especially to control the luminance in the interior zone throughout a day.

The measuring range usually is 1 to 500 lx.

The Illuminance photometer is mounted on the pole of the luminance photometer L_{20} .

4.3 Controlling the lighting

4.3.1 Lighting of the threshold and transition zone (RVS)

The directional lanes are to be lighted with a luminance gradient according to Figure 4. The luminance shall not fall below the illustrated curve.

In the threshold (Einsichtsstrecke) and transition zone (Übergangsstrecke) the walls shall be lighted up to 2 m above the elevated shoulder with a minimum of 50 % of the roadway surface luminance. For bidirectional tunnels this provision is only applicable to the right tunnel wall.

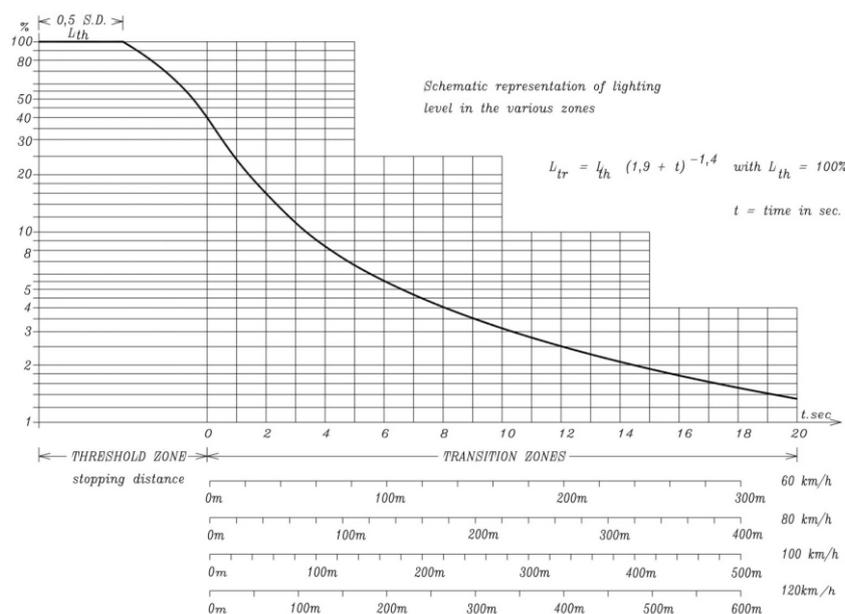


Figure 4 - Luminance gradient for the threshold and transition zone

4.3.1.1 Lighting of the threshold zone (RVS)

According to CIE the luminance after half of the threshold zone has to be reduced continuously or in steps that not exceed a rate of 1:3 to 40 % of the initial value.

The average roadway surface luminance of the first part of the threshold zone L_{th} is derived from the luminance of the access zone L_{20} and a speed dependent factor k by

$$L_{th} = k \cdot L_{20}$$

The values for k depend on the speed limit and the type of lighting.

Speed limit	k (counter beam lighting)	k (symmetrical lighting)
≤ 60 km/h	0,033	0,050
70 and 80 km/h	0,040	0,060
≥ 100 km/h	0,050	0,075

4.3.1.2 Lighting of the transition zone (RVS)

In the transition zone the luminance is to be reduced from the level at the end of the threshold zone to the level of the interior zone according Figure 4.

$$L_{tr} = L_{th} \cdot (1,9 + t)^{-1,4} \text{ with } L_{th} = 100\%$$

The luminance gradient resulting from the calculation can be approximated by variable distances between the lights or variable lamp wattages or in steps that are smaller than 3:1.

The transition zone ends as soon as the value of the roadway surface luminance ($L_{tr}+L_{in}$) becomes smaller or equal to 3 times the roadway surface luminance of the interior zone (L_{in}).

4.3.2 Lighting of the interior zone

4.3.2.1 Daytime (CIE)

The average luminance of the roadway surface in the interior zone of the tunnel is given below as a function of the stopping distance and of the traffic flow (vehicles per hour per lane). Very long tunnel's interior zone consists of two different sub zones. The first sub zone corresponds to the length which is covered in 30 seconds and should be illuminated with the "long tunnels" levels. The second sub zone corresponds to the remaining length and should be illuminated with the "very long tunnels" levels.

Stopping distance	Low traffic flow	Heavy traffic flow
160 m	6 cd/m ²	10 cd/m ²
60 m	3 cd/m ²	6 cd/m ²

L_{in} for long tunnels

Stopping distance	Low traffic flow	Heavy traffic flow
160 m	2,5 cd/m ²	4,5 cd/m ²
60 m	1 cd/m ²	2 cd/m ²

L_{in} in the second part of the interior zone for very long tunnels

For stopping distances lying between the stated figures and intermediate traffic flows (between low and heavy), linear interpolation may be used. Traffic flow used in the previous tables may be defined as follows:

Traffic flow	One way traffic	Two way traffic
Heavy	> 1500 veh./h/lane	> 400 veh./h/lane
Low	< 500 veh./h/lane	< 100 veh./h/lane

4.3.2.2 Night time (RVS)

If the tunnel is a part of an unlit road the luminance in the interior zone shall be reduced according the following formula and table.

$$L_{in}' = L_{in} \cdot k_{red}$$

Illuminance E_a	Daytime	Traffic	k_{red}
> 100 lx	—	—	1,00
≤ 100 lx	04:00 – 08:00	—	0,50
	16:00 – 22:00	—	0,50
	22:00 – 04:00	> 100 veh./h	0,25
		< 100 veh./h	0,125

Reduction factor depending on illuminance, daytime and traffic flow

If the tunnel is on a section of an illuminated road, the quality of the lighting inside the tunnel should be at least equal to the level of the access road.