SELECTION OF LIGHTING CLASSES

a Comparative Analysis

Version 1
09-2017

1. Introduction

In the European standard EN 13201-2:2015 "Road lighting - Part 2: Performance requirements" [1] a lighting class is defined by a set of photometric requirements aiming at the visual needs of certain road users in certain types of road areas under specified environmental conditions. In this European standard [1] which has to be implemented by the national standards organizations of the participating countries there are basically three different sets of lighting classes described: M classes for areas intended for motorized traffic, C classes for conflict areas, and P classes for pedestrian and low speed areas. Guidelines on the selection of an appropriate lighting class are given in the Technical Report CEN/TR 13201-1:2014 [2], but national standards organizations are not bound to implement CEN technical reports. The national standards organizations of four countries participating in this Interreg project, i.e. Croatia, Czech Republic, Slovakia, and Slovenia, have adopted the Technical Report CEN/TR 13201-1:2014 "Road lighting - Part 1: Guidelines on selection of lighting classes" [2] as national recommendation without specifying which of the two methods described in the report are to be applied. In the other three countries participating in this Interreg project the national standards organizations have elaborated or are elaborating national standards on the selection of lighting classes; namely in Italy the standard UNI 11248 "Illuminazione stradale - Selezione delle categorie illuminotecniche" [3] has been published in November 2016, in Austria the standard O 1055:2017 "Straßenbeleuchtung - Auswahl der Beleuchtungsklassen" [4] has been published in August 2017, and in Germany a standard DIN 13201-1 "Straßenbeleuchtung - Teil 1: Auswahl der Beleuchtungsklassen" [5] is expected to be published in 2018.

Different fixed or (over time) variable parameters which are considered in the various selection processes could lead to deviating lighting classes for in principle the same type of road. Possibilities and limits associated with the different selection procedures will be described and discussed in view of a conceivable harmonization in the future taking into account normal and adaptive / dynamic lighting.

2. Selection of Lighting Classes

2.1. Selection of Lighting Classes according to CEN/TR 13201-1

In the Technical Report CEN/TR 13201-1:2014 "Road lighting - Part 1: Guidelines on selection of lighting classes" [2] two methods are presented for the selection of an appropriate lighting class, i.e. one method based on the Technical Report CIE 115:2010 "Lighting of roads for motor and pedestrian traffic" [6] given in the main text, and an alternative method proposed by the French standards organization included in an informative annex. The national standards organizations in Croatia, Czech Republic, Slovakia, and Slovenia have adopted the CEN Report [2] without giving guidance on the preferred application of one or the other method for the selection of a lighting class.

For the selection of a lighting class M for motorized traffic - following the method based on Technical Report CIE 115:2010 [6] - eight parameters are considered: design speed, traffic volume and traffic composition, separation of carriageways and junction density, parked vehicles, ambient luminance, and difficulty of navigational task. The same parameters, except junction density, are taken into account for the selection of a lighting class C for conflict areas. For the selection of a lighting class P for pedestrian and low speed areas in general five parameters are considered, i.e. travel speed, use intensity, traffic composition, parked vehicles and ambient luminance, and in addition, if necessary, facial recognition. For the determination of the lighting class M, C, or P to be applied to a given situation the appropriate weighting values associated with the options for the different parameters have to be selected and added. The sum of the weighting values leads to the number of the lighting class M, C, or P to be applied.

The alternative method for the selection of a lighting class, described in the informative annex B of the Technical Report CEN/TR 13201-1:2014 [2], is based on a functional or administrative classification of roads. For lighting classes M and C road designation ranges from interurban motorways (speed limit less equal 130 km/h) to dangerous sections of urban roads (speed limit less equal 30 km/h), for lighting classes P from low speed roads (speed limit less equal 40 km/h) to walkways and bicycle tracks. The five parameters considered, besides the road type, are in all cases the speed limit, the traffic composition and traffic volume, the ambient light, and the mental task load. For a given road category, from the multiplication of the five coefficients associated with the selected options per parameter results an overall coefficient. Transferring the overall coefficient on to the appropriate graphic presentation leads to an average luminance (for lighting classes M) or illuminance (for lighting classes C or P) to be applied to the given lighting situation.

2.2. Selection of Lighting Classes according to UNI 11248

In the Italian Standard UNI 11248:2016 “Illuminazione stradale - Selezione delle categorie illuminotecniche” [3] roads are categorized based on current legislation. The types of road classified range from interurban motorways to local urban streets predominantly used by pedestrians. For any type of road, associated with a given speed limit and traffic flow (in vehicles per hour), a lighting class M, C, or P as described in the European standard EN 13201-2:2015 [1] is specified as a starting point for the selection of an appropriate lighting class. Before a lighting class can be applied a risk analysis has to be carried out taking into account the parameters: normal complexity of the visual field, low density of conflict areas, and high conspicuity of traffic signs in conflict areas, presence of traffic lights, and lack of crime risk. Careful evaluation of these parameters for a given situation leads to a maximum reduction of two steps in term of the lighting class (M, C, or P) to be applied.

2.3. Selection of Lighting Classes according to O 1055

The selection of lighting classes M and P in the Austrian standard O 1055:2017 “Straßenbeleuchtung - Auswahl der Beleuchtungsklassen” [4] is based on the method described in the Technical Report CEN/TR 13201-1:2014 [2]. For the selection of a lighting class M for motorized traffic eight parameters are considered: substantial speed, substantial traffic volume (vehicles per day) and traffic composition, separation of carriageways and junction density, parked vehicles, ambient luminance, and difficulty of driving task. For the selection of a lighting class P for pedestrian and low speed areas in general five parameters are considered, i.e. speed, traffic flow, traffic composition, parked vehicles and ambient luminance, and in addition, if necessary, facial recognition. For the determination of the lighting classes M or P to be applied to a given situation the appropriate weighting values associated with the options for the different parameters have to be selected and added. The sum of the weighting values leads to the number of the lighting class M or P to be applied. For the selection of a lighting C for conflict areas the different Austrian standard O 1051 “Straßenbeleuchtung - Beleuchtung von Konfliktzonen” [7] has to be applied.

2.4. Selection of Lighting Classes according to E DIN 13201-1

In the draft German standard (still under discussion) E DIN 13201-1:2017 “Straßenbeleuchtung - Teil 1: Auswahl der Beleuchtungsklassen” [5] roads are categorized based on common designations. For the selection of a lighting class M for motorized traffic different parameters are considered dependent on the road category, e.g. only speed, junction density, and luminance of environment for motorways. For major roads additional parameters like separation of carriageways, traffic flow and traffic composition, parked vehicles and/or increased demands (e.g. due to difficulty of driving task) are taken into account. For the selection of a lighting class P further parameters are considered, i.e. traffic flow pedestrians, traffic flow cyclists and in addition, if necessary, facial recognition. For the determination of the lighting class M or P to be applied to a given situation the appropriate weighting values associated with the options for the different parameters have to be selected and added. The sum of the weighting values leads to the number of the lighting class M or P to be applied. The selection of a lighting C for conflict areas is linked to the lighting level of the roads leading to the conflict area using a table of comparable lighting levels for different values of the average luminance coefficient of the road surface or of the diffuse reflectance of the pavement of the area.

3. Adaptive / Dynamic Road Lighting

According to the Technical Report CEN/TR 13201-1:2014 [2] the normal lighting class is defined as the class with the maximum value of luminance or illuminance at any period of operation, adaptive lighting is defined as temporal controlled changes in luminance or illuminance in relation to traffic volume, time, weather or other parameters. A more comprehensive working definition has been discussed by the partners of this Interreg project: Dynamic lighting is adaptive lighting, i.e. it is being provided where and when it is needed depending on different variable conditions, such as travelling speed, traffic volume and/or composition, ambient luminances, weathers and other exterior factors in a way that it reduces light pollution as well as energy consumption; beyond that it recognizes varying human and social needs, such as aesthetics or feeling of safety.

The adapted, usually reduced lighting level or levels should be average luminance or illuminance from a class or classes of the same type (M, C, or P) from which the normal lighting class has been selected [2] [6]. When applying adaptive lighting it is important that the changes in the average lighting level do not affect the other quality criteria outside the limits given in the system of lighting classes M, C, and P in the European standard EN 13201-2:2015 [1]. Reducing the light output from every light source by the same amount using dimming techniques will not affect the luminance or illuminance uniformity, diversity, or the object contrast, but the threshold contrast will increase. Reducing the average lighting level by switching off some luminaires will decrease uniformity while increasing glare, and will not fulfil the quality requirements and is therefore not recommended [2] [6]. The use of adaptive lighting can provide significant reduction in energy consumption, compared with operating the normal lighting class throughout the hours of darkness. Where the pattern of variation in parameter values is well known, such as from records of traffic counts on traffic routes, or can be reasonably assumed, as in many residential areas, a simple time based control system may appropriate. In other situations an interactive control system linked to real-time data may be preferred. Such a system would permit the normal lighting class to be activated in the case of e.g. roads works, serious accidents, bad weather or poor visibility [2] [6].

4. Application of Adaptive Road Lighting

In all technical reports [2] [6] and standards [3] [4] [5] considered here the application of adaptive road lighting is described and recommended as a possibility to reduce energy consumption while keeping road safety and security at an appropriate level.

4.1. Adaptive Road Lighting according to CEN/TR 13201-1

In that part of the Technical Report CEN/TR 13201-1:2014 [2] which is based on the Technical Report CIE 115:2010 [6], all parameters considered in the selection process of a lighting class M, C, or P are regarded as time dependent. Re-determination of the lighting classes to be applied using different options associated with the parameters will result in different lighting levels per time interval. In the alternative method described in the informative annex B of the Technical Report CEN/TR 13201-1:2014 [2] the only parameter which is considered as time dependent for all road categories is the traffic volume. For lighting classes M or C (for some road designations), and for lighting classes P (for all road designations) also the parameters ambient luminance and mental task load are regarded as time dependent.

4.2. Adaptive Road Lighting according to UNI 11248

In the Italian Standard UNI 11248:2016 [3] adaptive lighting is linked predominantly with traffic volume/flow. The categorized roads are associated not only with a design speed but also with a maximum traffic flow (in vehicles per hour). The comparison of the current traffic flow (measured real time) with the maximum traffic flow results in a reduction of the lighting level in one or two steps. The allowable reduction of the lighting level depends also on the outcome of the risk analysis carried out during the selection process for the normal lighting class.

4.3. Adaptive Road Lighting according to O 1055

The application of adaptive lighting as describe in the Austrian standard O 1055:2017 [4] follows closely the method given in the Technical Report CEN/TR 13201-1:2014 [2]. All parameters are considered as possibly time dependent, but the parameters substantial traffic volume and ambient luminance are regarded most important.

4.4. Adaptive Road Lighting according to E DIN 13201-1

In the draft German standard (still under discussion) E DIN 13201-1:2017 [5] not only roads are categorized but also parameters, as fixed or variable over time. In general the parameters speed, junction density, and separation of carriageways are regarded as fixed. The other variable parameters could lead (when re-evaluated) to different lighting levels per time interval considered. No guidance is given how to link the traffic flow with an appropriate lighting level. The decision has to be taken from experience and knowledge.

.

5. Comparison of Individual Parameters considered

For the selection of an appropriate lighting class as well as for the application of adaptive lighting a number of various parameters are considered In the different technical reports [2] [6] or standards [3] [4] [5]. These parameters are generally related to the geometry of the area under consideration, to the traffic use of the area, or to the influence of the surrounding environment. The most comprehensive number of parameters to be taken into account, covering the lighting classes M for motorized traffic, C for conflict areas and P for pedestrian and low speed areas, can be found in the technical reports [2] [6]. In the standards [3] [4] [5] usually only a sub-set of these parameters is considered, in some cases with different names for the same influence.

5.1. Parameter Separation of Carriageways

The separation of carriageways is regarded as an effective safety measure, in particular in form of a central reserve of not less then three metres in width with guardrails for ‘high’ and ‘very high’ speed roads [2] [6]. As an intrinsic property of a road layout this parameter is not regarded as time dependent in the technical reports [2] [6] or in the Austrian standard [4]. In the Italian standard [3] and in the draft

German standard [5] this parameter is considered indirectly by the categorization of the roads. In all documents the importance of a central reserve is acknowledged, and the existence of a central reserve allows reducing the lighting level by one step.

If, from long term observations of the traffic volume profiles, it is known that during certain hours of darkness one of the carriageways is carrying considerably less traffic than the other, adaptive lighting could be used to provide different adequate lighting levels for the two carriageways.

If only one carriageway is used temporarily, e.g. during road works, the higher risk without separation could be counterbalanced with a speed reduction. This is reflected for example in the selection process for M and C lighting classes in the technical reports [2] [6]. An appropriate choice of the options for the parameters ‘speed’ and ‘separation of carriageways’ will result in an unchanged weighting value, i.e. in unaltered lighting requirements.

5.2. Parameter Junction Density

According to the Technical Report CEN/TR 13201-1:2014 [2], to the Austrian standard O 1055:2017 [4] and to the draft German standard E DIN 13201-1:2017 [5] the junction density (predominantly for lighting classes) is considered as ‘high’ if there are more than three intersections per kilometre, else it is rated as ‘moderate’. The intersection is defined as the general area where two or more roads join or cross at the same level, within which are included the carriageway and the roadside facilities for traffic movements [2]. The limit of three intersections per kilometre is in line with general assumptions concerning the application of the luminance concept; i.e. a more or less straight section of the road of a length not less than 20 to 22 times the mounting height, and the evaluation of disability glare taking into account all luminaires up to a distance of 500 m in front of the road user [8].

In a similar way the junction density is considered as ‘moderate’ for interchange spacings - or distances between bridges respectively - greater than three kilometres, else it is rated as ‘high’ [2]. Here the interchange is defined as a grade-separated junction with one or more turning ramps for travel between the through roads [2].

The intersection density is an intrinsic property of the overall road layout (counting for one step in terms of lighting requirements). Under these circumstances the application of adaptive lighting is not adequate unless it is foreseen that in the not too distant future the number of junctions will be increased considerably, and at the same time leading to an increased traffic volume. In such cases adaptive lighting could be used at an appropriately reduced lighting level until the road is in full operation.

5.3. Parameter Parked Vehicles

Parked vehicles are regarded as obstacles on the road, increasing the general risk and causing some obstruction to the driver’s view. Therefore the parameter ‘parked vehicles’ with the options ‘present’ and not present’ is considered to be important for all lighting classes M, C, and P in the Technical Report CEN/TR 13021-1:2014 as well as in the draft German standard E DIN 13201-1:2017 [5] and for the lighting classes M and P in the Austrian standard O 1055:2017 [4].

The presence of parked vehicles could be restricted to certain hours of a day or to certain days of a week. For example on single or dual carriageways (lighting classes M and C) parked vehicles on the carriageway may not be allowed during rush hours, in some pedestrian areas (lighting classes P) motorized traffic is restricted generally.

If the hours of darkness coincide to some extend with the hours of restricted parking, the option for the parameter parked vehicles could be changed from ‘present’ to ‘not present’, resulting in one step reduced lighting requirements. At the same time, e.g. during rush hours on a single or dual carriageway, an increased traffic volume could be expected, possibly demanding a higher lighting level. Depending on specific circumstances adaptive lighting could be applied, but decisions have to be taken with great care.

5.4. Parameter Speed

In the Technical Report CEN/TR 13201-1:2014 [2] and in the Austrian standard O 1055:2017 [3] there are five options given for the (design) speed), across the different lighting classes. The option 'very high' (e.g. more than 100 km/h) would apply to motorways (lighting classes M) and to associated interchanges (lighting classes C). The option 'high' (e.g. between 70 km/h and 100 km/h) would apply primarily to inter-urban single and dual carriageways, but also to urban principal roads between primary destinations (lighting classes M and C). In urban areas speed limits are about 50 km/h on average, ranging from 40 km/h to 70 km/h (e.g. on major distributor roads). The option 'moderate' is related to this speed (lighting classes M and C). In residential areas with or without geometric measures for traffic calming in many cases the speed limit is set to 40 km/h or less. Here the option 'low' would be the appropriate choice (lighting classes C or P). For areas where pedestrians are considered as main users the speed option 'very low', i.e. walking speed, often limited between 5 km/h and 7 km/h, should be applied (lighting classes P).

In the informative annex of the Technical Report CEN/TR 13201-1:2014 [2] and in the Italian standard UNI 11248 [3] the speed limit is associated with any one type of road described, ranging from 5 km/h (walking speed in pedestrian areas) to 130 km/h or even 150 km/h on motorways. In the draft German standard E DIN 13201-1:2017 [5] different design speed options are linked with the categorized roads (limiting values to select from are 100 km/h, 80 km/h, 50 km/h, 30 km/h, and walking speed).

From the road safety point of view the relationship between speed and stopping distance is one of the most important aspects. The stopping distance is the sum of two stretches, i.e. the distance covered during the reaction time and the distance covered during the breaking time. A simplified method, assuming a constant friction coefficient, for the evaluation of stopping distances is described in the CEN Technical Report CR 14380:2002 'Tunnel lighting' [9]. For known friction coefficients the stopping distance is a function of speed, and can be calculated for a given slope of the road assuming a certain reaction time. In recommendations and regulations across Europe the specified reaction time varies between 1 s and 2 s, and friction coefficients for dry and wet conditions are not harmonized at all. Figure 1 shows the relationships between design speed and stopping distance as given in different European recommendations and regulations on road and tunnel lighting [10]. For the relevant speeds between 30 km/h and 100 km/h the resulting absolute stopping distances differ by a factor of almost two, but in all cases the decrease of the stopping distance as a function of speed is significant. As an example, the stopping distance for a speed of 30 km/h (option 'low') is on average shorter by a factor of two compared to the stopping distance for a speed of 50 km/h (option 'moderate').

At a speed of 30 km/h the length of the area in front of a car lit by its own vehicle headlights is approximately equivalent to the stopping distance. In this case road lighting should be provided predominantly for all non-motorized road users, usually moving at a lower speed. It can be concluded that the reduction of the lighting level as function of speed as indicated by the weighting values for the different lighting classes is appropriate. In particular in urban areas the reduction of the speed from 50 km/h to 30 km/h during certain hours of darkness, e.g. between 11 p.m. and 5 a.m. also as a measure against noise, would allow to use adaptive lighting, i.e. to reduce the average lighting level.

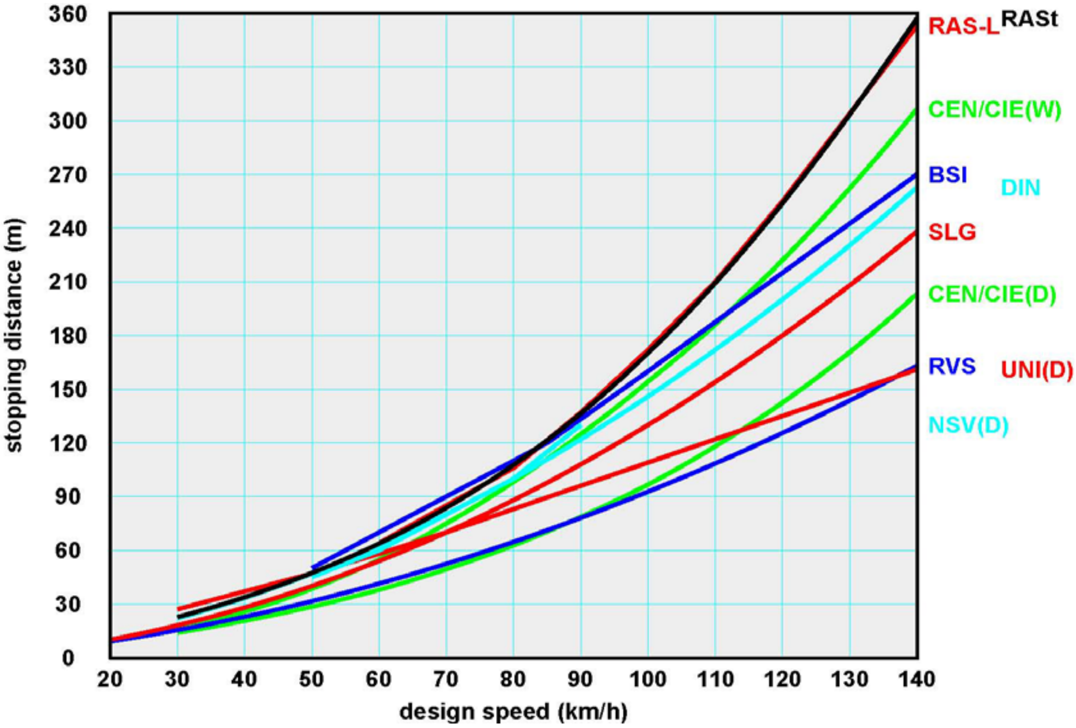

Figure 1: Stopping distance as function of design speed according to different national and international regulations [10]

5.5. Parameter Traffic Volume

When designing a new road or re-designing an existing road the traffic volume to be expected in the near future, i.e. in the next 10 to 15 years, is one of the main design criteria. In this respect the parameter 'traffic volume' (lighting classes M or C) is linked to the absolute values of the average daily traffic (ADT) or to the flow of vehicles, cyclists or pedestrians (lighting classes P).

In the Technical Report CEN/TR 13201-1:2014 [2] the parameter 'traffic volume' is considered in terms of the (relative) actual traffic volume in comparison to the design value of maximum capacity, the selection of the option could be modified at a second stage (for temporal reasons). The traffic volume of motorways or multilane routes is regarded as 'high' if the actual traffic volume is higher than 65 % of the maximum capacity, as 'moderate' if the actual traffic volume is between 35 % and 65 % of the maximum capacity, and as 'low' if the actual traffic volume is smaller than 35 % of the maximum capacity. For two lane routes the respective values are more than 45 % (for 'high'), between 15 % and 45 % (for 'moderate') and less than 15 % (for 'low').

A similar approach is described in the Austrian standard O 1055:2017 [4], but is based on the substantial traffic volume expressed in terms of the average daily traffic (ADT). The substantial traffic volume of motorways or multilane routes is regarded as 'high' if ADT is higher than 45000, as 'moderate' if ADT is between 25000 and 45000, and as 'low' if ADT is smaller than 25000. For two lane routes the respective values of ADT are more than 7000 (for 'high'), between 2000 and 7000 (for 'moderate') and less than 2000 (for 'low').

In the Italian standard UNI 11248 [3], the traffic volume expressed as design values (vehicles per hour) is associated with the type of road. In the draft German standard E DIN 13201-1:2017 [5] the traffic volume, indirectly linked with the type of road considered, is regarded as 'normal', with no limiting values specified.

It is generally accepted that the risk increases with the driving speed and to a certain extent with the traffic volume. In this respect the knowledge of the actual/substantial traffic volume in comparison to the traffic volume considered at the design stage of the road offers the opportunity to apply adaptive lighting, i.e. to adjust the lighting level in accordance with the appropriate lighting class linked to the sum of the weighting values [2] [4].

In the Austrian standard O 1055:2017 [4] as well as in the Italian standard UNI 11248:2016 [3] the possible reduction of the lighting level is based on the in principle measured actual/substantial traffic volume expressed as average hourly traffic (AHT). For motorways and multilane routes specified (absolute) limiting values of AHT allow a reduction of up to two steps, for two lane routes up to steps are possible following the Austrian standard [4]. In the Italian standard [3] the actual AHT in relation (as percentage) to the design value is used as an indicator for a possible reduction of the lighting level of up to two steps.

The draft German standard E DIN 13201-1:2017 [5] offers for most types of road the possibility to reduce the lighting level by one step during the hours of a traffic volume which is regarded as 'low'. The actual traffic volume is not considered as being measured continuously, but as known (as far as possible or assumed) from daily, weekly, monthly, or seasonal profiles of the traffic flow in general.

5.6. Parameter Traffic Composition

The parameter 'traffic composition' has been introduced to consider the influence of different users of a certain traffic area on the resulting risk caused e.g. by differences in the speed of movement and/or changes of the visual conditions. In the Technical Report CEN/TR 13201-1:2014 [2] and in a similar way in the Austrian standard 0 1055:2017 [4] the influence of the amount of non-motorized users on roads predominantly intended motorized traffic (lighting classes M and C) is taken into account by the options 'mixed with high percentage of non-motorized', 'mixed', and 'motorized only'. In a similar way the option 'mixed' could be interpreted as a mixture of cars and (a higher percentage) of trucks. For lighting classes P, predominantly intended of pedestrian and low speed traffic, the parameter 'traffic composition' allows to take into account the different users of a traffic area; pedestrians, cyclists, and motorized vehicles, (separate or together) at a certain moment [2] [4]. In the Italian standard UNI 11248:2016 [3] and in the draft German standard E DIN 13201-1:2017 [5] the traffic composition is in principle associated with the type of road under consideration. However, in the draft German standard [5] for some types of road the same options, as described in CEN/TR 13201:2014 [2], are considered as time dependent variables.

If during certain hours of darkness, e.g. between 11 p.m. and 5 a.m., the number of non-motorized users is (assumed or known to be) low, the option for the parameter traffic composition could be changed from 'mixed with high percentage of non-motorized' to 'mixed' (for lighting classes M and C). In pedestrian and low speed areas (lighting classes P) the access for motorized vehicles and/or cycles is quite often restricted to certain hours of a day and/or to certain days of a week. If these time frames coincide with some hours of darkness the option for the parameter traffic composition may be reconsidered and adjusted (e.g. no motorized vehicles, no cyclists). In all these cases the temporal change of the traffic composition could result in reduced lighting requirements, i.e. adaptive lighting could be applied to provide the appropriate lighting levels, accounting for up to two steps in terms of the lighting classes.

5.7. Parameter Ambient Luminance

The parameter ambient luminance is used to take into account the ambient brightness level (in the visual field) which is defined as the assessed luminance level of the surroundings [2]. In the Technical Report CEN/TR 13201-1:2014 [2] as well as in the Austrian standard 0 1055:2017 [4] the ambient luminance (sometimes named luminosity) is regarded as one of the parameters for which significant variations may apply at different periods of the hours of darkness. The option 'high' is associated with shop windows, advertisement signs, sports fields, station or storage areas in the visual field, the options 'moderate' is regarded as normal, and the option 'low' should be applied to intrinsically dark areas [2] [4]. In the draft German standard E DIN 13201-1:2017 [5] the level of the ambient luminance is considered in a similar way as 'high', 'average', or 'low', in all documents accounting for up to two steps in terms of the lighting classes.

The luminance (brightness) distribution in the visual field controls the adaptation level of the eyes. The higher the adaptation level of the visual system, the more sensitive it is to low contrasts, and less sensitive it is to glare [11]. The adaptation luminance is usually approximated by the average road surface luminance in front of the road user created by the road lighting installation. If the surroundings, in particular the (vertical) facades of buildings, provide some additional lighting of the road, e.g. by reflecting light from the road lighting installation, without causing a proportional increase of the illuminance at the observer's eye (i.e. of the veiling luminance responsible for disability glare), the visual conditions will improve. In this case the ratio R of the veiling luminance to the adaptation luminance will decrease, and in consequence the threshold increment TI will be lower, as shown in figure 2. The option 'moderate' or 'low' for the parameter ambient luminance would be the appropriate choice.

If parts of the surroundings, e.g. shop windows, displays, advertisement signs, are so bright that a significant increase of the veiling luminance is to be expected, a higher adaptation luminance, approximated by the average road surface luminance, has to be provided to keep the visual conditions, here expressed in terms of the threshold increment TI, at the required level. Depending on the original lighting level and on the expected (or calculated for critical situations foreseen) change of the ratio R of veiling luminance to adaptation luminance the option for the parameter ambient luminance has to be changed appropriately to 'high'. This could lead to an increase of the required lighting level by a factor of up to two. In extreme cases, e.g. using video walls with average luminances of several hundred cd/m^2, it is not realistic to counterbalance the possible glare by increasing the lighting level; dimming of such 'glare' sources during the hours of darkness would be the obvious choice.

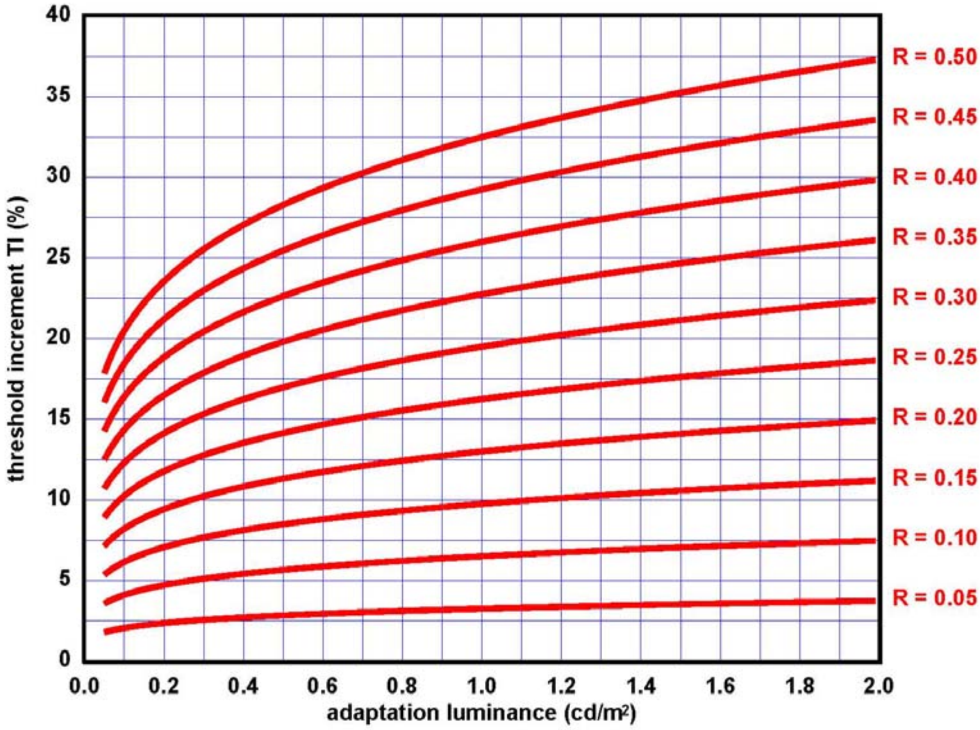

Figure 2: Threshold increment as function of adaptation luminance for different ratios R of veiling luminance to adaptation luminance

Some of the glare sources will be regarded as obtrusive light which is defined as light giving rise to annoyance, discomfort, distraction or a reduction in the ability to see essential information [12]. For the control of obtrusive lighting in general stricter requirements apply during certain periods of the night (curfew), usually fixed by local authorities [12]. If the time frame is given adaptive lighting could be applied to reduce the lighting level accordingly, offering some energy consumption savings without impairing the road safety. It should be noted hat the reduction of the average lighting level by dimming has no negative effect on the threshold increment (figure 2), but switching off e.g. every second luminaire will increase the ratio R causing the resulting threshold increment to exceed the limits permitted in most cases.

5.8. Parameter Difficulty of Navigational Task

The difficulty of the navigational task is defined as the degree of effort necessary by the road user, as a result of the information presented, to select route and lane and to maintain or change speed and position on the carriageway [2]. The execution of guidance manoeuvres is assisted by traffic safety devices, like road surface markings, delineators, and/or signs. A similar parameter 'visual guidance' is used to take account of the existence of such devices and/or of the difficulty to recognize them at adverse weather conditions [6]. Traffic signs or traffic lights, considered as parameter 'traffic control' [6], could help to reduce the overall risk.

in the Technical Report CEN/TR 13201-1:2014 [2] as well as in the Austrian standard 0 1055:2017 [4] there are three options given for the parameter difficulty of navigational task; these are 'very difficult', 'difficult' and 'easy', accounting for up to two steps in lighting classes. In the Italian standard UNI 11248:2016 [3] the parameter 'complexity of the visual field' is used in a similar way; allowing a reduction by one step if the given situation is less complex. In the draft German standard E DIN 13201-1:2017 [5] a parameter named 'increased demand' with the options 'present' or 'not present' is considered in situations of e.g. difficult navigation, poor visual guidance, or complex road layout.

The option to be selected for the given situation could have a significant influence on the lighting requirements. If the lighting installation has been designed to fulfil the requirements for 'very difficult' conditions, e.g. for adverse (winter) weather conditions, adaptive lighting could be applied to reduce the lighting level during periods of 'easy' conditions, e.g. during the dry summer. The decision to change the lighting level for a longer period of time should be based principally on long term observation/experience. A dynamic adaptation requires probably quite sophisticated (and more expensive) measuring equipment which may not be justified by the (relatively small) amount of possible energy savings.

The provision of traffic lights, in particular in conflict areas, could allow to change the option for the parameter 'traffic control' from 'poor' to 'good' and to adjust the lighting requirements accordingly [6]. (In some cases the conflict area will not be a conflict area any longer.) However, if the surroundings are intrinsically dark, and the option for the parameter 'ambient luminance' is selected as 'low', traffic lights could become a glare source, thus requiring a higher lighting level. Switching off the traffic lights during certain hours of darkness could increase the overall risk which could be compensated by an increase of the (adaptive) lighting level. In such situations adaptive lighting cannot really contribute to energy consumption savings.

5.9. Parameter Facial Recognition

The parameter 'facial recognition' is considered only for lighting classes P, intended predominantly for pedestrian and low speed areas [2] [4] [5]. The recognition of another pedestrian's face at a certain distance requires some vertical lighting at a height of about 1.5 m above the ground. According to the lighting requirements for pedestrian and low speed areas as specified in Technical Report CIE 115:2010 [6] and in the European standard EN 13201-2:2015 [1] (values have still to be corrected) the level of the vertical illuminance should be about one third, the level of the semi-cylindrical illuminance about one fifth of the horizontal illuminance. If this is accomplished with increased lighting or even better with additional lighting using more appropriate (possibly two or even three) intensity distributions, adaptive lighting could be applied to adjust the lighting during certain hours of darkness dependent on the expected or actual traffic flow of pedestrians.

5.10. Other Parameters

In the first edition of the Technical Report CEN/TR 13201-1:2004 [13] there were further specific parameters listed for consideration. For moderate and low speed traffic areas (lighting classes M and C) special attention is given to the (geometry related) parameter ‘measures for traffic calming’. Generally only in the area of traffic calming the higher lighting requirements of the lighting class numbered one step lower have to be fulfilled [13]. This is equivalent to the consideration of an area of traffic calming as a conflict area.

The judgement of the parameter ‘crime risk’, i.e. the crime risk in the considered traffic area compared to the crime risk in a larger area, would require the knowledge of the objective relation between lighting and crime statistics, but experience indicates that a truly objective approach is very difficult [13]. Where ‘crime risk’ is rated ‘higher than normal’ it is always linked to the requirement of facial recognition which in turn leads to a required higher level of the horizontal illuminance on the ground [13]. But for the purpose of facial recognition the additional requirement of vertical or semi-cylindrical illuminances at a certain height above ground is much more appropriate. In the Italian standard UNI 11248:2016 [3] this parameter is still considered; the ‘absence of a crime risk’ allows to reduce the lighting level by one step.

The (environment related) parameter ‘complexity of the visual field’, defined as the amount of lighting and other visual elements existing in the visual field of the road user which mislead, distract, disturb, or annoy the road user, is predominantly taken into account for traffic areas for motorized traffic at ‘moderate’ speed [13]. In the Technical Report CEN/TR 13201-1:2004 [13] it is noted that although visual guidance provided by the road and the environment may be adequate, such elements may cause problems in detecting high priority objects such as traffic lights and other road user’s changing direction. Examples may include advertisements, lighting columns, lighted buildings, and sports lighting installations. In the more recent European standards EN 12193:2007 ‘Light and lighting - Sports lighting’ [14] and EN 12464-2:2014 ‘Light and Lighting - Lighting of work places - Part 2: Outdoor work places’ [15] the effects of obtrusive lighting are described in a similar way as in the Technical Report CIE 150:2003 [12]. In these standards [14] [15] limits are specified e.g. for the average luminances of facades and signs as well as for the veiling luminances at the road user’s eye caused by luminaires (glares sources) not providing the road lighting. If the given limits are observed the ‘complexity of the visual field’ is unlikely to be higher than normal, i.e. a particular consideration of this special parameter is not necessary. The general influence of the surroundings is taken into account of by the parameter ‘ambient luminance’. Finally, for traffic areas for motorized traffic (lighting classes M) the ‘main weather type’ is considered as a special parameter. In the European standard EN 13201-2:2015 [1] the overall uniformity for wet conditions is the only additional requirement to be applied if the road surfaces are rated ‘wet’ for an expected substantial part of the hours of darkness and appropriate road surface data are available. Therefore the ‘main weather type’ has not to be regarded as a special parameter as long as the associated lighting requirements are applied.

All in all the parameters discussed in this chapter do not offer a substantial extension beyond the parameters used for the selection of an appropriate lighting class M (for motorized traffic), C (for conflict areas), or P (for pedestrian and low speed areas), and they do not show a particular relevance for the application of adaptive lighting.

6. Need for Harmonization

For the selection of an appropriate lighting class as well as for the application of adaptive lighting a number of parameters are considered which are generally related to the geometry of the traffic area under consideration, to the traffic use of the area, or to the influence of the surrounding environment. In different national regulations all or only some of the various parameters are regarded as fixed or time dependent. In certain regulations the roads are categorized and some of the parameters are associated intrinsically with the different types of road and not considered further. In cases of given limiting values linked to the selectable options, e.g. for design speed or for average daily or hourly traffic, these values differ from regulation to regulation. All in all this could lead to different lighting requirements in terms of the selected lighting class for a given road traffic situation. To keep the road safety and security at the same appropriate level for road users travelling through Europe, it is desirable to harmonize the selection procedures across the different national regulations. This could be achieved probably by the regularly recurring revision of the European standards on road lighting.

7. References

[1] EN 13201-2:2015 “Road lighting - Part 2: Performance requirements”

[2] CEN/TR 13201-1:2014 “Road lighting - Part 1: Guidelines on selection of lighting classes”

[3] UNI 11248 “Illuminazione stradale - Selezione delle categorie illuminotecniche”, 2016

[4] O 1055 “Straßenbeleuchtung - Auswahl der Beleuchtungsklassen”, 2017

[5] E DIN 13201-1: “Straßenbeleuchtung - Teil 1: Auswahl der Beleuchtungsklassen”, 2017

[6] Technical report CIE 115:2010 “Lighting of roads for motor and pedestrian traffic”

[7] O 1051 “Straßenbeleuchtung - Beleuchtung von Konfliktzonen”, 2007

[8] EN 13201-3:2015 “Road lighting - Part 3: Calculation of performance”

[9] CEN CR 14380:2002 “Tunnel lighting”

[10] Stockmar, A. “Tunnel lighting - Recommendations and regulations”, Proceedings “Seminar om utendørsbelysning”, Lyskultur, Oslo, 2010-10-07

[11] “Fundamentals of the visual task of night driving”, Technical Report CIE 100:1992, Vienna

[12] “Guide on the limitation of the effects of obtrusive light from outdoor lighting installations”, Technical Report CIE 150:2003, Vienna

[13] CEN/TR 13201-1:2004 “Road lighting - Part 1: Selection of lighting classes”

[14] EN 12193:2007 “Light and lighting - Sports lighting”

[15] EN 12464-2:2014 “Light and lighting - Lighting of work places - Part 2: Outdoor work places”