REDUCING OBTRUSIVE LIGHT

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1 Introduction

All outdoor lighting is functional, its function being the enhancement of the visibility (utility lighting) and/or of the aesthetics (decorative lighting). The effectiveness of the lighting is the degree to which the function is fulfilled; the efficiency the degree to which the benefits surpass the costs. The benefits include firstly the (avoided monetary) costs of accidents, traffic jams, criminal offenses and economic losses. The beneficiaries are usually individual persons or companies. And secondly the non-monetary benefits: avoiding personal loss and grievance from traffic accidents and reducing fear for crime. The costs include firstly the direct monetary costs of the lighting equipment: installation, maintenance and energy use, and the indirect costs like the waste of energy and materials in manufacturing the equipment, the toxic waste from discarded lamps and ballasts etc. These costs are usually carried by the authorities. Further, the non-monetary costs (use of energy, scarce natural resources etc.) and the negative environmental influences, causing discomfort and annoyance. The costs and the benefits for road lighting and their mutual interrelations are described in detail in Schreuder (1998).

Good lighting design ensures that the light comes where it is needed, and does not fall elsewhere. If not, the light is 'spilled', which may cause considerable economic and environmental losses. The light, the money and the energy are simply wasted. Furthermore, spill light from outdoor lighting installations may cause disturbance and discomfort for many persons, also for those that have nothing to do with the activities for which the lighting is installed. This is obtrusive light or 'light trespass'. Light trespass has victims; one group of victims are the astronomers - both the professionals and the amateurs, but also the much larger group of persons who enjoy the darkness. Astronomers are restricted in their possibilities to make accurate observations.

This paper is based on a presentation at The 3rd National Lighting Congress held in November 2000 in Istanbul, Turkey (Schreuder, 2000).

2 The origin and effect of sky glow

2.1 The natural background radiation

Sky glow presents itself as a background luminance over the sky, against which the astronomical objects are to be observed. The interference of astronomical observations is caused by the resulting reduction in luminance contrast. The glow is caused by non-directional scatter of light by particles in space and in the atmosphere. Part of the light, and part of the particles are natural, and part is man-made. The '(natural) background radiation' is defined as the radiation (luminance) resulting from the scatter of natural light by natural particles. For earth-bound observatories, the natural background luminance is the absolute limit for observations. Further explanations may be found in Levasseur-Regourd (1994) and Leinert (1997).

2.2 The effect of sky glow on observation of contrast objects

To understand the effect of the (diffuse) sky glow, one must realise that all observations, both visual, photographic and electronic, of light emitting objects is essentially an observation of contrast. When the luminance of an object is called L_o and the luminance of its background, against which the object must be observed, is called L_b, the contrast C is conventionally defined as:

$$C = \frac{L_o - L_b}{L_b}. \qquad [1]$$

The overall stray light causes a light veil that extends over the field of observation. This veil has a luminance as well, that will be called L_v. The veiling luminance has to be added to all luminances in the field of observation. All contrasts will be reduced, as can be shown as follows:

$$C' = \frac{(L_o + L_v) - (L_b + L_v)}{(L_b + L_v)} = \frac{L_o - L_b}{L_b + L_v}. \quad [2]$$

As the nominator stays the same and the denominator always is greater, thus:

$$C' < C. \quad [3]$$

This is, of course, the way lighting engineers assess the influence of disability glare.

When the object to be observed is a star, one might suppose that its observed luminance equals the (intrinsic) luminance of its surface, and therefore is much, much higher than L_v. However, while a distant star is a close geometric approximation to a 'point source', its image in the instrument with which the observations are made is not a point at all. The image can never be smaller than a certain limiting size, even with excellent 'diffraction limited' optics. For the naked eye, which is quite far from being diffraction limited, the minimum diameter of any visual object is equivalent to almost a minute of arc. This means that for the naked eye, L_o is not very large. Thus, even for very good observers and excellent conditions the limit for detection with the naked eye is about the sixth magnitude. It should be noted that astronomers use a non-ISO unit to quantify luminances, viz. the 'magnitude per arcsec2'. The following conversion into the ISO luminances (for photopic vision) is adopted: 'a luminance of $3{,}2 \cdot 10^{-6}$ cd/m^2 corresponds to 26,33 magnitude per arcsec^2'. (CIE, 1997).

The limiting magnitude follows from the definition of (difference in) magnitude:

$$m = 2.5 \log (l_1/l_2), \quad [4]$$

where l_1 and l_2 are the luminous intensities of the two stars that are compared. See for details Sterken & Manfroid (1992). When assessing the influence of the sky glow, the smallest luminance for the most favorable conditions is L_{o1} and under sky glow conditions L_{o2}. The background luminance is L_b and L_v respectively. With $L_v = a \cdot L_b$, and according to [1] and [2], for observation at the threshold of the contrast sensitivity, C equals C':

$$C = C' = \frac{L_{o1} - L_b}{L_b} = \frac{L_{o2} - L_b}{L_b + a \cdot L_b}. \quad [5]$$

When L_b is small compared to L_{o1} and L_{o2}, L_b may be disregarded in the nominators. The formula [5] becomes:

$$(a+1) = 1/(L_{o1}/L_{o2}). \quad [6]$$

When inserting L_{o1} and L_{o2} for l_1 and l_2 in formula [4], one gets

$$m = -2{,}5 \log (a+1). \quad [7]$$

with m the increase in the threshold, or the decrease in the limiting magnitude as a result of the veiling luminance. This formula is called the 'sky glow formula' (CIE 1997).

2.3 The sources of man-made sky glow

Sky glow is the result of light that is projected upwards, and then scattered back to the surface of the Earth. Part of the stray light is projected directly upwards. Usually this results from poorly designed, or maladjusted lighting; it may, however, also occur when the light is aimed upwards on purpose. Another major contribution to the stray light is the light that is well-directed to objects, but reflected by them. Road surfaces, grass, and buildings reflect a fair amount of the incident light, and the reflected light usually goes upwards. It should be stressed in this respect that light only serves its purpose if it hits the eye of the observer. In some cases, like signalling, it is the light source itself but in almost all cases it is the light that is reflected from a surface that is 'useful'. So, the suggestion that may be heard at places, to make all surfaces black so that there is no reflected light, really is nonsense as if when doing so - even if it were possible in the first place - was to make the lighting installation useless. This is particularly true for road surfaces.

The main sources of stray light that may interfere with astronomical observations are (in random order):

- lighting of industrial sites, airports and building sites
- road and street lighting
- advertising signs
- floodlighting of buildings, discos and monuments
- lighting of billboards

- lighting of greenhouses
- lighting of sports facilities
- area lighting of sales areas, parking lots, farm yards, railroad yards etc.

It is very difficult to give a general idea about the relative importance of these sources of sky glow. The relative weight varies from place to place and is determined to a considerable extent by national or local regulations.

All sources of man-made sky glow have one thing in common: they all represent an economic loss. Crawford calculated on the basis of a number of 'rule of thumb' assumptions the loss of one billion dollars annually in the US alone (Crawford, 1991, 1997). Isobe has given similar data but then more detailed for specific towns and locations (Isobe 1999).

In spite of the fact that light trespass is a matter of major concern for the astronomers, little research about the qualitative and quantitative aspects of the interference by light for astronomical observations is reported. Most is based on the work of Walker (1973). Usually, light that interferes with astronomical observation presents itself in the form of a sky glow in the vicinity of large urban, industrial or agricultural concentrations. The luminance of the sky glow can conveniently be expressed by 'Walker's law' that can be written as:

$$Log\ p = -4{,}7 - 2{,}5\ log R + log F \qquad [8]$$

(after Anon, 1984) in which p is the ratio between the observed sky glow as measured in the direction of the source under an elevation of 45 degrees and the natural background radiation, R the distance to the source (in km) and F the total luminous flux of the outdoor lighting in the source (in lumen). In an alternative form of this 'law', the number of lumens is replaced by the per capita light output of cities. (Crawford, 1992, p.45). Garstang uses the number of 1000 lumen per capita.

It should be mentioned that there is some doubt whether the 45 angle is the most appropriate; many astronomical observations are made at 30 or even 15. The last angle is used in the Netherlands to describe the more general influence of sky glow on the experience of people in the surroundings of sky glow sources (Anon 1997a). At the other hand, astronomical observations are made seldom near the horizon. It has been suggested to consider sky glow below 150 primarily as an aesthetic problem and only the sky glow over 150 as a threat to astronomical observations.

Fellin et al. (2000) have presented a relation that allows to determine the increase of the threshold nagnitude for just visible stars as a result of lighting parameters:

$$\grave{U}M = -2.5\ log\ (1+R_n /[r(1-R_n)], \qquad [9]$$

with: $\grave{U}M$ - the increase of the threshold magnitude for just visible stars; R_n - the total upward flux of a whole town as defined further-on; r - area average of the reflection factor (after Fellin et al., 2000. eq. 9).

2.4 Increase of sky glow in recent years

In spite of the fact that urban sky glow is one of the major limiting factors for astronomical observations, very little systematic studies about the magnitude and the extent of the problem in practice have been made. Here, we will give a few examples.

In Japan, the sky glow in densely populated and heavily industrialized areas like the regions of Tokyo, Yokohama and Osaka is often more than 4 mag/arcsec² higher than in rural areas, correponding to almost a factor of 100 in luminance (Kosai et al., 1993, 1994). In the Netherlands, similar measurements have been made. The measurements have been made at about 100 locations at one moment in time. The individual values did range from 20.97 to 17.2 mag/arcsec², again corresponding to almost a factor of 100 in luminance. Details are given in Schreuder (1994). In 1997, a similar survey is made by estimating the visual borderline magnitude of stars that 'just' could be seen. Similar results have been found. See Schreuder (1999).

Almost everywhere, sky glow does increase over the years (Cinzano, 2000). A few examples. Between 1988 and 1998, measurements have been made at two major US observatories (Kitt Peak and Mount Hopkins). At Mount Hopkins, "The zenith sky brightness ... increased only modestly ... by 0.1-0.2 mag/arcsec^2". This means an increase of 10% to 20% in sky luminance.

On Kitt Peak, the increase was larger, from 0.2 to about 0.5 mag/arcsec^2 in different directions (Mice & Folz, 2000, p 572). So, even at the best protected sites in the US and probably in the world, the sky luminance increases with.

For a number of Japanese cities, the increase over recent years has been measured (Isobe & Hamamura, 1998). The result of that study is that the sky glow did increase on an average by 10% per year.

Other Japanese data are collected by means of the global method using photo cameras as described by Isobe & Kosai (1994). The measurements show in general a trend for a considerable increase in the sky brightness with a noticeable exception of the years of the Gulf War where many saving measures were taken in Japan. Photometric measurements show for the Tokyo area a dramatic increase of the sky brightness. It was 20.5 mag/arcsec^2 in 1958; 19.5 in 1978 and 17.6 in 1998 (Isobe & Kosai, 1998, pg 178). These values correspond to 0.99; 1.49 and $14.6 \cdot 10^{-3}$ cd/m² - an increase by a factor of 15 in 40 years.

2.5 Other aspects of light pollution

Until recently, it was customary to consider only human beings as 'victims' of light pollution. The majority of studies was made by astronomers and most pressure was made to protect the sites of astronomical observatories. To a lesser extent, also the public health aspects have been investigated. These seem to be relatively minor. However, many animals, like e.g. insects and birds but also sea turtles, suffer from light at night. In the Netherlands, a large number of literature studies and a number of experimental studies have been made. A compilation of the literature may be found in Van den Berg (2000), De Molenaar et al (1997, 2000). Most studies relate to the influence of motorway lighting on natural preserves and natural parks (Anon., 1997a).

2.6 The costs of light pollution

The problems from light pollution arise when the sky glow is not weak in relation to the natural background radiation of the night sky at that particular place and time. It should be noted that the search for a low and steady natural background radiation led astronomers to built their observatories at remote mountain tops near deserts where there is little air above them and where the air that still is there, is steady and clear (no turbulence, no dust). This makes the problem of light pollution more compelling, because such observatories are very expensive to built and even more to run. Light pollution leads to a reduction in the 'efficiency' of the observatory. As an example, an increase in sky glow by 20% reduces the effective aperture by 25%; for not uncommon values of the sky glow increase by a factor of 2 or 5, the loss of effective aperture is 61% or 89% (Crawford, 1992, table 2.1). This means that observatories are not used in full; this lack of efficiency can be expressed as an additional cost factor, either in the investments or in the operation of the installations. This money could be used to improve the lighting installations.

There is another approach to this. Light pollution degrades the visibility in a way similar to other disturbing factors. Is many cases this may be compensated by increasing the dimensions of the telescopes. Increasing the size of the telescope is very expensive. Murdin (1997) gives the following rule-of thumb: the costs of a telescope increase with the third power of the lens or mirror diameter - that is, with the volume of the dome! So when the light pollution reduces the effective diameter of the mirror by 5% (which seems a reasonable estimate even for weak sky glow), the economic losses are 15%. As we know that a big telescope might cost easily about US$ 100 million, fighting even that slight light pollution might mean a 'profit' of US$ 15 million. It seems reasonable to estimate that there are about 30 of those telescopes on the world, and another 500 that are a factor 10 smaller. This would lead to a total of 'hardware' of US$ 8000 million. Using the 15% estimate given earlier, this would mean that light pollution requires an extra, non-profitable investment of US$ 1200 million. As a comparison, Woltjer (1998) estimates that world-wide, per year some 4000 to 5000 million US$ are spend on astronomy. Regarding the operation of a large observatory, it was shown that an investment of

US$ 15,000 to improve the lighting around the observatory, is cost-effective if the installation can be used one hour extra per year (Schreuder, 1992).

3 Measurements of sky glow

3.1 Area surveys

For many reasons, surveys over large areas may be required. The method must be simple and cheap, and the assessments must be made by amateurs or even by lay-persons. Two systems are currently in use.

(a) *Limit star assessment*. Within a given area of the sky (e.g. between four well-known stars) the number of visible stars are counted. From the known magnitudes of the stars, the magnitude of the stars that are 'just' visible (the limit stars) can be assessed. When due account is taken, e.g. by using the well-known epidemiological data on visual acuity distribution, the method may be used on a large scale. The use of binoculars is not recommended, because the optical quality of binoculars varies considerably. Examples of the use of such measurements are given in Isobe & Kosai (1998) and Schreuder (1999).

(b) *Photographic surveys* use a large number of amateur observers making pictures with a normal (stationary) camera and with a normal slide-film of the zenith-area in their own neighborhood. The camera must have a focal length of 50-55 mm and a *F*-ratio of 2,0 or less. The exposures are made on 400 ASA colour reverse slide films at a stop of 4 with an exposure time of 80 seconds. From the relation in film density between the background and the track of known stars, the sky luminance can be assessed. Details are given by Isobe & Kosai (1998) and Kosai et al.(1994).

3.2 Continuous surveys

Continuous or quasi-continuous surveys of the sky glow can be made by monitoring the sky brightness. These surveys are often made at selected locations, often the location that is considered as the site of a major observatory. The data of a period of at least a year (to include any seasonal variations) will give adequate information regarding the suitability of that location. The survey can be done with the standard photometric equipment that is available in all major observatories. Usually, measurements of sky glow do not include elevations lower than 15 degrees. In many cases, the measurements are continued after the erection of the observatory. Presently, the data from a number of major observatories around the world are collected.

3.3 Site monitoring

In order to do accurate site monitoring at existing observatories, normal astronomical telescopes can be used with the standard equipment to perform photometry. This is done in many observatories on a routine bases. An instrument in use at the Observatory of the Canary Islands is described by Diaz-Castro (1993).

Based on many observations, it was concluded that extreme measuring accuracy seems not to be justified. It was reported that even on a 'very dark night', variations in sky glow luminance up to 30% are common. Also, the influence of air pollution may be considerable, so extreme measuring accuracy seems not to be justified (Cinzano & Diaz Castro, 1998; Diaz Castro, 1998).

On the basis of different considerations, the CIE Technical Committee TC 4.21 adopted the following procedure as a working method. This method is to measure the average luminance within a 10 degree (2·5) cone at the zenith, together with six adjoining similar areas. The minimum of these seven is considered to represent the sky glow around the zenith. Additionally, the same cone measurements may be made at 60 and 30 elevation at the eight compass directions to represent the distribution of sky glow over the sky. It should be noted that these measurements can be made with relatively simple measuring hardware (CIE, 1998).

4 The efforts to reduce obtrusive light

4.1 Policy aspects of recommendations for the reduction of obtrusive light

In most countries, the role of regulations regarding obtrusive light is to give prospective developers permission to realise their plans only if those plans are in agreement with the regulations, and prohibit the realization if that is not the case. Additionally, the regulations are used to check existing installations as to whether they comply or not. It is a matter of national legislation who takes the initiative for the checking and what happens if the lighting installations do not comply.

Regulations, if they are to be used in this way, require quantitative data of borderlines between what is permissible and what not. Usually the borderline system is described in the actual legislation, whereas the actual numerical data are included in the underlying regulations. It should be noted that there are considerable differences between countries, particularly as regards the jurisdiction and autonomy of different layers of government (municipalities, counties, provinces, states, central government etc). In all cases, the regulations to be effective, need to include, apart from the numerical, quantitative data of borderlines between what is permissible and what not, also unambiguous definitions of the quantities involved as well as certifiable measuring methods. It should be kept in mind that the question whether a specific lighting scheme complies or not, sometimes may ends in a court of justice.

4.2 General outline of the current CIE recommendations

4.2.1 The current and the proposed CIE documents

In 1997, CIE published as its Publication No. 126-1997: “Guidelines for minimizing sky glow” (CIE, 1997). This document filled a gap as it addressed a number of light-technical and photometric aspects of the reduction of sky glow. However, it did not give enough guidance for lighting designer, so a revision and extension is underway. In this section, the existing document is summarized and a brief overview of the most important proposals for additions and amendments are given. It should be stressed that these proposals are still under discussion. It will take some time before a final agreement will be reached.

4.2.2 The framework of the CIE Guidelines

The main parameter in the current CIE document is the Upward Light Output Ratio - installed (ULORinst). The values given are limiting values. Lighting designers should aim at meeting the lowest specifications for all designs unless the specific installation requires relaxation. It is proposed to add to this another parameter, the Maximum Installed Lumen per unit Area.

The recommendations are based on three principles:
* the requirements for upward light emission are related to the activities in the ‘zone’ under consideration (‘zoning’);
* the requirements for upward light emission are most stringent in the ‘night’; they may be relaxed in the ‘evening’. The ‘curfew’ is the moment in time after which the lighting shall obey different regulations as before it;
* in order to reduce the light pollution at one location, the lighting requirements in nearby zones must be taken into account (distance relations).

4.2.3 Zoning

Zoning is a well-established practice to establish a base for environmental regulations. The basic idea is that, in case the polluting activity cannot be avoided altogether, the environmental consequences of the pollution are not equally detrimental for all locations. The need to define zones follows from the fact that the world - at least most countries in it - is too small so that every-one can have its own territory where he or she can do whatever they fancy, including having all the light they want. Zoning is in essence a compromise.

The zones and the zone requirements are set up in relation to the (human and non-human) activities in these zones. Although the idea of zoning is wide-spread, its actual implementation and the way it is embedded in the legal system, particularly the juridical consequences of an areas being designated as belonging to a certain zone, vary widely from state to state and from nation to nation. Zoning does not stop environmental pollution, but it may serve as a frame of reference for anti-pollution legislation and regulation. The description of the zones as adopted by CIE is given in Table 1. In some cases, specific aspects of the design of lighting installations and for the operation of astronomical observatories calls for a more detailed zoning system, where one or more of the CIE zones are split up in sub-zones. The proposals made in this respect comply with the CIE zoning system.

Table 1 Description of the environmental zones according to the CIE Zoning System (from CIE, 1997, Table 1)

Zone	Description
E1	Areas with intrinsically dark landscapes: National Parks, Areas of outstanding natural beauty (where roads usually are unlit)
E2	Areas of 'low district brightness': generally outer urban and rural residential areas (where roads are lit to residential road standard)
E3	Areas of 'middle district brightness': generally urban residential areas (where roads are lit to traffic route standard)
E4	Areas of 'high district brightness': generally urban areas having mixed residential and commercial land use with high night-time activity

4.2.4 Curfew

Switching off the lights altogether may interfere with other important aspects of society. In most cases, the requirements change during the night; after a certain (fixed or flexible) moment in time, lighting can be reduced. The simplest way is to switch off the lights when they are not needed any more. For situations where after 'curfew' there is still some light needed, multiple source lanterns may be used. A more energy-effective solution is to use dimmers. Many local by-laws and ordinances impose time restrictions in the use of such lighting installations.

4.2.5 Upward Light Output requirements

The CIE report uses the maximum permissible value of ULORinst (the Upward Light Output Ratio - installed) as one of the major parameters in which the recommendations for the limitation of sky glow are expressed. It should be noted that the term "Upward Light Output Ratio" supersedes the earlier term of "Upward Waste Light Ratio" because the latter assumes - incorrectly - that all light emitted above the horizontal is always wasted. Considerations of many outstanding lighting installations show that this is not the case. In many cases, there is a need for light emitted above the horizon in order that the lighting installation may fulfill its functional requirements.

The recommended values are given in Table 2. They are given as the maximum permissible value of ULORinst, expressed as a percentage of the luminous flux of the luminaire) for each of the four Environmental Zones as given in Table 1. The astronomical activities indicated in Table 2 are derived from the descriptions of Murdin (1997).

Table 2 Recommendations for Upward Light Output Ratio to limit the sky glow. After CIE (1997, Table 2)

Zone rating	ULORinst (%)	Astronomical activities
E1	0	observatories of (inter)national standing
E2	0-5	postgraduate and academic studies
E3	0-15	undergraduate studies, amateur observations
E4	0-25	casual sky viewing

This limit holds for each individual luminaire in that zone. The ULORinst is used instead of the more common Upward Flux because the restrictions for sky glow do not depend on the luminaire alone; the whole installation must be taken into account. The value of ULORinst can be measured for individual luminaires only if the manufacturer or provider indicates precisely how the luminaire must be mounted.

The values in Table 2 are limiting values. Lighting designers should aim at meeting the lowest specifications for all designs unless the specific installation requires relaxation.

A number of national standards or recommendations give different but similar values. In Italy a Standard has been established (UNI, 1999, quoted by Fellin et al., 2000). Also in Spain upward flux values are prescribed that are considerably lower than the CIE values (Diaz-Castro, 2000).

4.2.6 The colour of the light

In the current CIE document, the colour of the light is treated in some detail (CIE, 1997, sec. 10). It is generally accepted that the most effective way available at present to reduce interference with astronomical observations is the use of (quasi)monochromatic light sources, more in particular the use of low-pressure sodium-vapour lamps. These lamps emit a very narrow spectral band (almost a line) in the yellow part of the spectrum. Two advantages are obvious: all other spectral regions are not involved, so that observations in other spectral regions - either photography or spectroscopy - are hardly affected (Budding, 1993; Sterken & Manfroid, 1992). Secondly, as the yellow line is close to the maximum of the sensitivity of the eye, the luminous efficacy of low pressure sodium lamps is high - they are the most efficient light sources available at present (Schreuder, 1998; Van Bommel & De Boer, 1980). On these grounds it is recommended to apply low-pressure sodium lamps for outdoor lighting near astronomical observatories.

Another aspect needs to mentioned. It is generally accepted that monochromatic light can be used safely and effectively on roads outside built-up areas that carry motorized traffic only. See e.g. De Boer, ed. (1967); Van Bommel & De Boer (1980) and Schreuder (1998). For roads and streets in residential areas the monochromatic light is not recommended. This for two reasons: first, monochromatic light is not suitable for streets with a high crime risk, both to prevent and to fight crime (Schreuder, 1998, 2000a). The second reason is more subjective. Monochromatic light is ugly and looks insecure; in other words, for amenity reasons, white light is to be preferred (Schreuder, 1989).

4.2.8 The Maximum Installed Lumen per unit Area

It is not enough to consider only the relative upward flux per luminaire. Although this is an important parameter, it does not give an indication about the actual effect of the artificial lighting on the sky glow. Even when the requirements of the upward flux are fulfilled, the size of the lamp in the luminaire and the total number of lamps that contribute to the sky glow, must be taken into account. In Table 3 a suggestion is given, based on discussions with lighting experts and with astronomers. It should be noted that these suggestions have not yet been accepted by CIE.

Table 3 Suggestions for ranges of values for the Maximum Installed Lumen per unit Area for different zones

Zone	lumen/m² before curfew	lumen/m² after curfew
E1	0.02 - 0.18	0
E2	0.75	0.15
E3	3 - 12	0.8 - 2
E4	50 - 150	20 - 30

4.3 The distance relations for zoning

The light pollution in a point in a specific zone (the ‘reference point’, e.g. astronomical observatories, natural parks etc.) is determined not only by the lighting in that zone but also by the lighting in neighboring zones, as well as by the dimensions of these zones. The lighting requirements in zones around that specific location should to be taken into account. The influence of the lighting in neighboring zones onto the overall sky glow at the reference location (reference point) depends upon the distance between the zone borderlines and the reference point.

Two aspects that seem to be conflicting, must be taken into account. At the one hand, it seems to be wise to make the zones as wide as possible. Thus, the influence of the sky glow from light sources in adjoining zones is restricted to a minimum. It this fashion, the recommended values given in Table 4 should be interpreted.

Table 4 Recommended values of the minimum distance (in km) between the zone borderlines and the reference point. After CIE (1997, table 5)

zone rating of reference point	zone rating surrounding zones recommended values of the distance (km) to borderline of surrounding zones E1-E2	E2-E3	E3-E4
E1	1	10	100
E2		1	10
E3			1
E4		no limits	

This point of view is particularly valid for countries or regions where distances are large and the population is scarce or non-existing. Those are the countries where the major international or world-class astronomical observatories are located. The values may be used in the selection process for a site for a world-class observatory. At the other hand, however, very wide zones make it difficult or even impossible to realise small-scale natural reserves, or to establish observatories with a didactical function in densely populated regions or countries. It would also mean that, because a major city – say corresponding to class E3 - is at a certain location, for wide surroundings it would be very difficult to enforce restrictions regarding obtrusive light. It would mean that amateur astronomy would have no protection at all. With this in mind, another table is added to the table from CIE (1997), designated as 'minimum permissible distance'. This additional table should be regarded as a first suggestion. As in Table 4, the corresponding values in Table 5 are given for the minimum distance between a zone borderline and the reference point (the point of the observatory). The data are derived from data that are given in the Italian standard (Fellin et al., 2000, sec. 3). The Italian standard requires that for international observatories, the first zone must be 5 km and the second zone 5, 10 or 15 km, depending on the importance of the observatory. In Table 5, the least stringent requirements from the Italian standard are used.

Table 5 Minimum permissible distance (in km) between the zone borderlines and the reference point. Based on data from UNI (1999)

zone rating of reference point	zone rating surrounding zones recommended values of the distance (km) to borderline of surrounding zones E1-E2	E2-E3	E3-E4
E1	1	5	10
E2		1	5
E3			1
E4		no limits	

5 Obtrusive light audits

The term 'audit' is a bookkeeping term; the dictionary defines it as "an official examination of accounts of a business or institution", where an account means "a record of money matters, services or goods".

Audits are a common tool in finding out in how far the aims and goals of a policy decision have been implemented. The principle is simple: one knows the goal and one knows the results. A straight-forward comparison will show the effect. And that is precisely what is done.

The policy decisions as regards outdoor lighting are made primarily by the authorities, in most cases the municipalities. Depending on the level of sophistication of the city government and its decision-making processes, the policy is founded on objective criteria in different degrees. In many cases, the goals of the lighting installations are based on general policy principles such as providing road and public safety to citizens, or to enhance the economy of the region. In most cases the goals are considered to be arrived at when the lighting agrees to norms, recommendations or standards. For road lighting, often the well-known CIE documents are accepted as guidelines (CIE 1992, 1995).

At a certain moment in time, decisions as regards outdoor lighting – at least as far as the authority of the government goes - are made. It is a matter of straight-forward management to find out whether lighting installations are made according to the plans.

It is a task of any democratically elected government to take care of the interests of the citizens as well as taking care of the more general interests of the community. Most governments extend the matter to the world: most governments feel a responsibility to protect the Earth by working according to a well-defined environmental policy plan.

Part of the policy relates to - or at least should relate to – the protection of the dark sky. So measures related to avoiding or at least reducing obtrusive light are an essential part of that policy. This implies that the requirements and the decisions as regards the outdoor lighting take the requirements of the dark sky into account. For these requirements, IAU, IDA and CIE have published documents that can be used on a national or regional level. As has been indicated earlier, many countries, regions, states and cities have already prescriptions, by-laws or ordnances that give precise information how the lighting should look - and how not.

The audit system is a tool to find out in how far the policy goals are realised - in this case as regards the dark sky. The audit involves several steps:
* to establish what are the policy goals of the government as regards the outdoor lighting;
* to establish what are the standards, ordnances etc. that have to be applied or followed;
* to establish are the photometric characteristics of the lighting installation if the policy aims and the standards are adhered to;
* to establish what has been installed in the area (viz.: the municipality in question); this involves making an inventory of the outdoor lighting.

When this is done, a comparison can be made. Based on this comparison, recommendations can be made to the government as regards the future policy (improvements etc).

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