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Recent CIE Activities on Minimizing Interference to Optical Observations

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Abstract. The paper describes the activities of CIE in the field of fighting sky glow. The most recent CIE publications are briefly discussed, as well as suggestions for further work. Modern developments in road lighting as well as alternatives to it are briefly discussed.

1. Introduction

The International Lighting Commission (Commission Internationale de l'Eclairage, or CIE) is a multi-national, professional, non-governmental, non-profit organization that monitors the whole area of lighting and visibility on a worldwide base. The structure and its way of operation are discussed by Hermann (2001) in this volume.

The relationship between CIE and IAU has a long standing. It resulted in two important documents: the CIE Document 'Statement concerning protection of sites for astronomical observatories' (CIE 1978) and the joint IAU/CIE publication 'Guide lines for minimizing urban sky glow near astronomical observatories' (IAU/CIE 1984). Again in close cooperation with IAU, more recently the 'Guidelines for minimizing sky glow; A CIE Technical Report' have been published (CIE 1997). At present, the CIE Technical Committee TC 4-21 is working at a number of additions to this Guide. A more or less parallel CIE activity involves the restriction of the more general 'obtrusive light' (CIE 1995; Pollard 2001). See also the volume edited by Isobe & Hirayama (1998).

2. Sky Glow and its Consequences

Sky glow presents itself as a background luminance over the sky, against which astronomical objects must be observed. Interference with 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 sky glow is natural and part is man-made (Levasseur-Regourd, 1994; Leinert & Mattila 1998). It is customary to express the man-made component of the sky glow as a percentage of the natural background luminance.

The sky glow is the result of light that is projected upwards and then reflected and scattered back to the surface of the earth. Even when the light

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beams are - as is good lighting design practice - downward, part of the light is scattered upwards after being 'used'. So uplight cannot be completely avoided.

The costs of light pollution are considerable. Although the costs per operating hour of an astronomical observatory cannot be defined precisely, a simple estimate suggests that, if one could use the observatory one extra hour per year, the savings in capital costs would be around US$ 15,000 and the running costs another US$ 1,500 or more. This money could be used to improve the lighting around the observatory (Schreuder 1991).

There is another approach to this. Light pollution degrades the visibility. In theory, this may be compensated by making the telescope bigger - and more expensive. The costs of a telescope increase with the third power of the lens or mirror diameter (Murdin 1997). 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%. A big telescope costs easily about US$ 100 million, so fighting light pollution might mean a 'profit' of US$ 15 million. If we assume that there are some 30 such telescopes around the world and another 500 that are a factor 10 smaller, this would lead to a total 'hardware' investment of US$ 8,000 million. Light pollution thus requires an extra, non-profitable investment of US$ 1,200 million. Over 10 years, one might save world-wide some US$ 120 million - a fair percentage of the US$ 4,000 to 5,000 million that are spent on astronomy annually (Woltjer 1998).

Finally, in many ways light may be considered on judicial grounds as a 'pollutant', just as noise, because it is a hazard to safety (i.e. for motorists); it produces ecological disturbances; it may produce environmental and visual nuisance; and it leads to energy wastage (Gray 1993). So, there are legal routes as well to combat (excessive) light pollution. See e.g. Anon (1984); Crawford (1991); IAU/CIE (1980); Murdin (1992). One way may be to include the most important observational sites in the list of World Cultural Heritage sites (see McNally 1994).

3. Lighting Design Elements

3.1. Zoning

The two key concepts in the CIE work are the zoning principle and the curfew idea. Zoning is a well-established practice to establish a base for environmental regulations. It is widely in use for describing and limiting noise, air and water pollution, vibration etc. 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 zones and the zone requirements are set up in relation to the (human and non-human) activities in these zones. Zoning does not stop environmental pollution, but it may serve as a frame of reference for anti-pollution legislation and regulation (Brouwer & Leroy 1995; Schreuder 1998). CIE has adopted four zones (CIE 1995, 1997). In some cases, when more details are needed, the ALCOR-classification for zones is used (Murdin 1997). The 'curfew' idea is that later in the night (say after midnight) the requirements may be more severe than during the evening (CIE 1995, 1997).

The quantification of the natural background radiation depends on the precise way to convert 'astronomical photometry' into 'lighting engineering photometry'. The TC 4-21 has decided to use the conversion proposed by Crawford (1997) where 26.33 mag/arcsec^2 equals 3.2×10^{-6} cd/m^2. It was also decided to use as a standard geometry for the measurements of sky glow as follows the average luminance in a cone of angular diameter 10° around the zenith, supplemented by six adjacent cone measurements around the zenith. The measurements must be made in photopic terms and the accuracy must be within 15%.

3.2. Lighting Requirements

CIE has given recommendations for the limitation of sky glow (CIE 1997). They are given as the maximum permissible value of $ULOR_{inst}$ (the Upward Light Output Ratio - installed, expressed as a percentage of the luminous flux of the luminaire) for each of the four Environmental Zones, ranging from 0 to 25%. This limit holds for each individual luminaire in that zone. For the actual lighting design, the total $ULOR_{inst}$ per zone, or the average $ULOR_{inst}$ per zone is more relevant.

Lighting designers require more than the upward flux per luminaire. They need to know what is permissible for the different zones as a whole. It is proposed to use the 'average upward flux' as a criterion. This is assessed as follows. For each zone, the maximum illuminated area as a percentage of the total area in the zone is given (roads, parking lots, industrial sites etc.). Furthermore, an 'average area illuminance' is given, which is based on the current CIE recommendations for road lighting (CIE 1995a). The proposal, currently under discussion in CIE TC 4-21, gives maximum values from 0.02 lm/m^2 for the most 'dark' zone to 150 lm/m^2 for city centres. After curfew, the values are 0 and 30 lm/m^2 respectively.

4. Environmentally-Friendly Lighting Design

4.1. Lighting Levels in Road Lighting

Although road lighting is not the only, and even not the most important contributing factor to sky glow, it is good to consider its function as an example of how lighting influences the environment. The function of road lighting is derived from the visual task of the traffic participants (the "driving task"; reaching the destination of the trip and avoiding collisions while doing so; see e.g. Schreuder 1991a, 1998). Large scale studies have established that "good" road lighting as compared with "poor" lighting may result in a reduction of about 30% in night-time injury accidents for major urban roads and for rural motorways - although the quantification of "good" and "poor" turned out not to be easy (CIE 1992; OECD 1972). For other road types, for pedestrian crossings and for tunnels, similar results have been found. Similar figures, although often much higher, were found for road lighting as a crime countermeasure (Schreuder 1994a; Painter 1998).

4.2. Sky Glow Conscious Lighting Design

Generally speaking, 'sky-glow conscious lighting design' for security and road lighting should be an easy matter, and many would simply point to the many local ordinances in the USA that simply demand full cut-off low pressure sodium luminaires. However, a low light pollution luminaire is easier to design for a high pressure discharge lamp than for a low pressure sodium lamp. It could therefore be suggested that while in the vicinity of an observatory, a low pressure sodium lamp should be used, whereas elsewhere in general the smaller and more compact lamp is better.

It has been suggested to introduce light pollution ratings, an "eco label", for luminaires, based on the actual upward flux. In order to arrive at practical limits for such an idea, data have been collected from many luminaire manufacturers of well over 100 luminaires of all different types. Whereas light pollution ratings would be of considerable help in reducing sky glow, there is one word of caution. In some cases, a small number of 'more polluting' luminaires would, over an entire scheme, be less polluting and more economical than a larger number of 'less polluting' luminaires. It must therefore be emphasised how important it is to consider the actual upward light flux of the whole installation.

Floodlighting and lighting for sports facilities usually cause more light pollution than ordinary road lighting. There are, however, national and international standards and recommendations available, such as CIE (1989, 1993). The well-known ILE Guidance Notes are published as an Annex to CIE (1997). Lighting designers usually do not like to have to use standard solutions, but for long-term environmental benefits the designers must learn to contain themselves within sensible guide lines.

This section is based on the paper given by Nigel Pollard at the CIE- Symposium "Urban sky glow, a worry for astronomy", held on 3 April 1993 in Edinburgh (see Pollard 1993).

4.3. Specific Remedial Measures

Remedial measures follow directly from the characteristic of the disturbance: restricting outdoor lighting in time or location (curfew and zoning); photometric measures (light control, reduction of reflection); colorimetric measures (monochromatic light, filtering the light). Additionally, educational measures must be mentioned. These various measures are discussed in detail in Schreuder (1993, 1994a). See also CIE (1997); Crawford, ed. (1991) and McNally, ed. (1994). It is not possible to give a general rule that is always most effective. Not all countermeasures are directly related to the lighting itself. See NSVV (1997) and Schreuder (1998).

5. Road Lighting and its Alternatives

Our society is a complicated structure with elements that function closely together while being placed far apart. A complicated network of exchange of persons, goods and information is needed, which also has to function at night. Road lighting is essentially functional, its primary function being to permit societal activities to proceed also during the night and to do so with a high degree of road safety, subjective security and amenity.

A major practical problem is to find out when a road (a road section) needs to be lighted ('Warrants for lighting'). In the past, lighting engineers left the answer to this question to politicians. Nowadays, cost/benefit considerations are used to find answers to this question. CIE has organized a number of meetings on this subject (CIE 1997a, 1999, 1999a). Actually, this question consists of two

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distinct aspects. The first is that the decision to light or not to light is not a permanent one to be taken once and forever; the second is that there is really no strict dichotomy between 'to light or not to light'.

In the Netherlands, the two different aspects are studied separately and in great depth. The first deals with 'smart road lighting', the second with alternatives to road lighting.

5.1. Smart Road Lighting

Recently, a large experiment has been completed in The Netherlands related to 'smart road lighting'. The system is called 'dynamical lighting' or DYNO for short. Details are given in AVV (1999). On a very busy, multilane highway the light level can be adjusted according to the momentary values of traffic volume and weather. The road is a 14 km stretch of the A12 between the Hague and Utrecht. The speed limit is 120 km/h; the traffic volume was (in 1995) about 210,000 vehicles per day. Before 1995 the road was unlit. The lighting layout is conventional. The two carriage-ways are lit from the sides by means of SON-T lamps of 400 W with cut-off luminaires on 15 m high masts at a spacing of 50 m. The lighting level can be set at one of three levels: 0.2 cd/m^2; 1 cd/m^2 and 2 cd/m^2. The middle value agrees with the current road lighting recommendations for the Netherlands (NSVV 1990) as well as with those of CIE (1995).

The light level can be adjusted according to the following criteria: traffic volume, rain or fog. Under favorable conditions the lowest level (0.2 cd/m^2) is employed. When the traffic volume rises above about 1,400 vehicles per hour per lane, the second, or 'standard', light level (1 cd/m^2) is used. The same is done during rain and fog (visibility under 140 m). Under especially hazardous conditions (road works, snow or ice on the road, accidents) the highest level (2 cd/m^2) may be used. Over the two years of the experiment, the road lighting was used for 50% of the day on average (normally in the Netherlands this is 45%). During darkness, the low level was used 59% of the time, the normal level 37% and the high level 4% of the time. Obviously, the lowest light level causes the lowest light pollution.

The analysis showed that traffic behaviour (speed, headway, etc.) did not depend on the light level, nor did the accident pattern. From this it was concluded that the 'high' level (2 cd/m^2) really did not bring anything extra, so that further analysis and the consequent recommendations are based on an installation that has only two levels: 'low' and 'standard'. From the two years of experimentation, it has been concluded that energy consumption is 35% lower than for a traditional installation. This results, among other things, in 650 tonne less CO_2 emitted per year. In spite of the more expensive installation, the running costs are considerably lower; it is to be expected that maintenance costs will be lower as well. The conclusions are generally speaking very favorable. Similar installations will be used on many more motorways in the Netherlands, particularly in 'areas sensitive to light pollution'.

5.2. Alternatives to Road Lighting

When discussing the ways to fight light pollution, emphasis is on the zone that includes 'Areas with intrinsically dark landscapes: National Parks, Areas of outstanding natural beauty'. Although one tries to let the roads be unlit, this is not always possible. However, especially here, the dichotomy we mentioned earlier is not relevant. We mentioned earlier that the way the function is fulfilled is a matter of adequate visibility of objects. For busy high speed roads, the objects are primarily other (moving) cars, but for rural roads the main part of the visual task is to follow the run of the road (Schreuder 1998). In terms of the driving task, the first is mainly to keep centred in the traffic lane and to avoid collisions, the second to keep on the road. In lighting terms, this means (for the first) seeing road markings and detecting obstacles and (for the second) receiving optical guidance.

For the detection of obstacles, road lighting is essential as soon as lighting by means of vehicle headlamps in not sufficient any more. For road markings and optical guidance, 'full' road lighting is not required at all. It is along these lines that a number of experiments are under way in the Netherlands. As these tests are in the beginning stage, there are not yet any results that can be reported. The major experiments are:

- small non-cutoff fittings at 7 to 10 m high. Usually these are equipped with 7 W compact fluorescent lamps and are mounted halfway up conventional lighting columns that work in dense traffic. The small lamps operate when the traffic is so light that 'full' road lighting is not required;
- a similar design with small non-cutoff fittings on separate masts of 5 to 8 m high equipped with an array of Light Emitting Diodes (LEDs). These lamps operate throughout the night;
- road markings that are equipped with small lamps, usually LEDs, instead of, or supplementary to, retroreflectors. These LEDs may be powered via the electrical net or by stand-alone photovoltaic cells;
- post markers at the road side, equipped with LEDs or with fibre-optic light points;
- light guides (light tubes) along the guard rails at the road side.

All these proposals, and several more, are tested in field experiments that are currently under way. The results seem to be very promising, but it is too early to give any definitive opinion.

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