LIGHT TRESPASS: CAUSES, REMEDIES AND ACTIONS

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ABSTRACT

Light trespass is the result of light that does not reach its destination, or that is reflected after having reached its destination or is scattered by the media in between source and destination: by light that is "spilled".
Light trespass may disturb people for whom the lighting actually is designed. This may result in glare and other disturbances. Other people may suffer from it as well: those who have nothing to do with the lighting or the activities for which it is designed. These are the "victims" of the light trespass.
One may indicate three major groups of victims: the astronomers, the residents and the naturalists.
Astronomers - both professional and amateur astronomers - are often severely restricted in their observations as a result of light trespass (sky glow). Only a few sites on earth are left that are "clean" enough for serious high-accuracy measurements. Space astronomy cannot replace earth-bound observations. Several remedies are known and are applied on a limited scale to reduce the light trespass, such as the application of low-pressure sodium lamps and the use of careful light control.
Residents suffer particularly of light trespass in their bedrooms. On the basis of preliminary measurements it seems that the discomfort is acceptable if the illuminance is less than 3 lux on the plane of the bedroom window.
As regards the intrusion of light into the environment, only little is known. Obviously, shielding may help to reduce the light trespass. Quantitative data are lacking.
It seems that in order to combat effectively the light trespass and its negative effects, further research is needed. But also a further consideration of the matter within the lighting profession seems to be required. And finally, the liaison with other interest groups should be maintained or, preferably, be improved.

1. INTRODUCTION

The major application of artificial light is to make objects, that do not emit light themselves, visible for the human eye. For this, the light emitted by the lamps is directed towards the objects by means of optical control elements - lenses, prisms or mirrors. The optical design of these control elements is such that as much of the lamp-light as possible is directed towards the object - a matter of simple economy: all light that is emitted by the lamp, but that does not reach the object, is lost. It is lost economically speaking, but most of it is physically speaking not destroyed: most light that does not reach the object will go elsewhere. It is this light that is "spilled" that will often bother other people:

1. The people disturbed by the spill light are directly engaged in activities for which the lighting is designed. Examples are glare by street lights, vehicle headlamps or reflections of light fittings in VDU's. They cause disturbance and discomfort, and often have an adverse effect on the performance. This sort of disturbance is, therefore, directly counterproductive, and will be reduced as far as possible on economic grounds.
2. The people disturbed by the spill light have nothing to do with the lighting and its design: they are true victims. They are the victims of light trespass.

2. LIGHT TRESPASS

2.1. The causes of light trespass

Lamps emit light into nearly all directions be it not exactly as much in all directions. In order to direct the light towards the objects to be illuminated, some sort of optical control is needed. The most simple way is to shield light that would go elsewhere; this may reduce spill light but it hardly does improve the efficiency of the lighting installation. Usually, light control elements are used: lenses, prisms or mirrors. Now, in theory it is possible to design these optical control elements in such a way that all light - apart from a small unavoidable fraction that is absorbed - will reach the object. This requires an optical system that is large in respect to the dimensions of the actual light source. The gaseous discharge lamps that are - for reasons of economy - applied for nearly all outdoor lighting applications would require optical systems of very large size. Furthermore, in order to "control" the light really good, the optical control elements must be of high quality: poor optical quality results in a "blurred" imaging, adding to the spill of light. Lighting equipment that spills a lot of light is less expensive to built than equipment that controls the light very precisely. Now, a better light control in itself often enhances the economy of the lighting installation; so it is finally a matter of how much the customer is willing to pay for his equipment that determines the resulting degree of light control. The main cause for the light trespass controversy is that these customers are not the people that are bothered by the light spill.

There are two more sources of light trespass. The first is that the light, after it reached the relevant object, is reflected by it. This is of course essential for the idea of illumination: it is exclusively by means of the light reflected by the object that observers may see the object. However, not all the reflected light will reach the eyes of observers - the majority will be reflected in completely different directions, and will contribute to the light spill. And the second is the scatter in the atmosphere. When the light travels only a short distance through the air, and when the atmosphere is clear, this atmospheric scatter is small and may be disregarded. When, however, the atmosphere is turbid, as is usual near cities and industrial complexes, the scatter can be considerable.

2.2. The effects of light trespass

When discussing light trespass we will concentrate on the victims. There are three major groups of victims:

- The professional and amateur astronomers are disturbed to a very serious extent by light trespass. Indeed, many of the finer instruments cannot be used at all any longer as the result of such light trespass. It is a matter of major concern of the astronomical community to select and preserve sites suitable for astronomical observation.
- Residents are often disturbed by light entering their homes from outdoor sources. Obviously the disturbance is most serious in bedrooms.
- People staying outdoors are sometimes disturbed by light from near or far light sources; particularly if they want to study or to enjoy the darkness. It has been said - and not in a facetious way - that also darkness is a human right!

The number of "victims" is considerable, and their objections against light trespass are legitime. It is part of the task of the lighting community to reduce these legitimate objections as far as possible, without, however, sacrifying the benefits of the lighting for society. Switching off lights is not an acceptable and not a reasonable solution of the light trespass problems.

These groups have in common that the causes of the light trespass are similar. We may indicate five major sources of (out-door) light spill:

- public (overhead street) lighting;
- the lighting of vehicles, particularly of cars;
- the illumination of buildings and billboards ("floodlighting");
- the lighting of sports stadia;
- light from buildings shining out through the windows.

A major indirect contribution to light trespass is the scatter in the atmosphere, particularly at long distances. This is the cause of the well-known sky glow one may observe around big cities. In this respect, measures aimed at improving air quality may be quite favourable for the reduction of light trespass as well.

2.3. Cost-benefit considerations

The major source of light trespass, and thus the major cause for disturbance of light trespass is the public (overhead) lighting. Now public lighting is installed with very specific functions in mind:

- reduction of night-time road accidents (OECD, 1971, 1980; CIE, 1960; Schreuder, 1983);
- promotion of public safety (Tien, 1979);
- enhancement of amenity, particularly in residential areas (Schreuder, 1980);
- promotion of economic activity and tourism (De Boer (ed.), 1967).

The first of these four functions is the most important. It has been well established that (good) public lighting in important urban streets and on rural freeways may lead to an reduction of some 30% in the night-time injury accidents. This statement is based on a large number of investigations that have been summarized in the reports of CIE and OECD as quoted above. Furthermore, it has been shown that there is a relationship between the light level of the road lighting and the accident risk (Scott, 1980; Hargroves et al., 1979). However, a clear limit between "acceptable" and "non-acceptable" light levels has not yet been found. From this fact it is often deduced that more light provides more safety, and that there is no upper limit for this.

Obviously, the proper way to approach this question of the appropriate light level for roads and streets is the application of cost-benefit considerations. The benefits can be derived from the function of the road lighting, applying the "functional approach" (Schreuder, 1977, 1984; Padmos, 1984). They can be expressed in the reduction of traffic accidents.

The benefits are partly monetary, partly non-monetary. The costs include the actual costs of building, maintaining and running the lighting installation. The costs include non-monetary aspects as well; here, light trespass seems to be the most important.

The question is now to find an optimal compromise between the costs and the benefits, i.e. the maximum efficiency. From the benefit side it is not possible to use directly the accident numbers as they seem to go down for each increase in light level; from theoretical point of view it seems, however, very unlikely that this decrease will continue for all levels of practical importance. This may be clarified by applying the supply-and-demand approach (Schreuder, 1977). The supply of "visibility" continues to increase with increasing light levels, up to daytime levels.

The demand for "visibility", however, does not increase any longer after a certain - rather low - light level. The relationship has been studied by Economopoulos and by Gallagher respectively (see e.g. Economopoulos, 1977, 1978; Gallagher et al., 1977), the first concentrated on the supply side, the second on the demand side, the point being that after a certain level the amount of information offered by the installation still increases whereas the amount of information required to drive a car keeps constant at a level that is provided already at a certain light level; increasing the light level does not enhance the performance.
One of the major stumbling blocks in finding the optimum is the definition of the concept "visibility" as used above. It is clear now that this definition should be derived from the task of the observer in the street (the driving task in traffic), but it is not clear how to do this in a quantitative way (See e.g. CIE, 1977; TRB, 1984).

3. LIGHT INTERFERENCE WITH ASTRONOMICAL OBSERVATION

3.1. The problem

Light trespass is a problem for astronomy because it increases the level of background radiation from wich the objects to be observed have to be detatched. This background radiation is never zero, as a result of natural emission of the atmosphere and of scatter of stellar light. In the humid atmosphere at medium geographic latitudes this background radiation is always considerable and even more so at sea level. So, astronomical observatories are built preferably at high altitudes on mountain tops in the sub-tropics. This natural background radiation sets a natural limit to the intensity of astronomical objects that can be observed from the surface of the earth. With modern equipment it is possible to discern objects that are weaker that than this background; even objects one-tenth of the background may be observed with advanced techniques (Crawford, 1985). However, the limit is there.

One may reduce the background radiation by going up, and leaving the earth's atmosphere. Satellite observatory systems are, however, extremely expensive and very difficult to operate. In spite of the advantages of space astronomy, optical astronomy from the surface of the earth is not "finished" as may be seen from the number of new observatories and new telescopes. And precisely for this reason it is important to monitor, and if possible to reduce or eliminate light trespass.

As the limit of optical observation is the ratio between the background radiation and the radiation of the objects, it follows that particularly the observation of the weaker objects - and therefore the observations with the larger telescopes - suffer most from the light trespass.
The astronomical community follows two distinct lines:
- the reduction of light trespass for existing observatorial sites;
- the selection of "unpolluted" new sites.

We mentioned only optical astronomy. It will be clear that also astronomical observation in other regions of the electromagnetic spectrum may be affected adversely by disturbing sources. In fact, the types of disturbances and the solutions to reduce their influence are quite similar; we will speak only of optical astronomy (i.e. using the visible light) here, but we include infra-red and ultra-violet observation and radio observation as well.

3.2. The causes

As we have indicated already the main cause of light trespass is public lighting. For a number of important observational sites these factors have been determined. See e.g. Crawford (1985); Finch et al. (1979); Fisher & Turner (1977); McInnes & Walker (1974); Murdin (1985); Walker (1973). Surveys of the problems of observational sites and of the discussion of measurements are given by Crawford (1983, 1985); Anon (1984, 1985, 1985b); CIE (1978) and IAU/CIE (1980).
Particularly "Walker's law" is of interest: it relates the amount of light trespass ("sky glow") to the size and the distance of cities nearby (Walker, 1973; see also Crawford, 1985). As Walker's law is an empirical expression, it may be written in different ways (see e.g. Crawford, 1985). The most convient way to write it seems to be the one employed in the French study (Anon, 1984):

$$\log p = - 4.7 - 2.5 \log R + \log Ø$$

where p is the ratio between the sky glow as measured in the direction of the source at an elevation of 45° and the natural background radiation, R is the distance between the site and the source (in km), Ø is the total luminous flux of the outdoor illumination of the source (in lumen).
The background radiation is usually taken as amounting to $2.10^{-4} cd/m^2$. (In astronomical publications the unit of "magnitude per arc second square" is often used).
This relation is established for cities in the South-West of the United States (Crawford, 1983; Turnrose, 1974, Walker, 1973), but it seems to be applicable for other conditions as well (Fisher & Turner, 1977; Martin Mateo, 1983; Sanchez Beitia, 1983). It may be added that Walker's law is often expressed in terms of the number of inhabitants for the city that is the source of the spill light: it had been estimated that in many areas of the world outdoor city light amount to 500 to 1000 lumen per inhabinant (Finch et al., 1979; Fisher & Turner, 1977).
It is not quite clear where the light spill comes from. Usually it is assumed that road lighting is the major contributing factor (Fisher & Turner, 1977), but a survey in San Carlos, California, shows that nearly exactly half of all outdoor lumens are installed in other lighting schemes, and that those other schemes contribute much more than the street lighting to the upward luminous flux:

	Street lighting	Other outdoor lighting
lumen	9,642,000	9,730,000
upward lumen	481,000	2,922,000
% of total upward lumen	14%	86%

(after Finch et al., 1979).

A large part of the upward flux of the other sources is billboard lighting by means of floodlights; a practice that is virtually unknown in many countries outside the US. Similar data are quoted by Waldram (1972) who did find in an English town that the contribution of the downward flux to the sky haze luminance from non-cut-off road lighting lanterns was about three times as much as the contribution of the upward flux.

There seems to be some uncertainty regarding the amount of light spill and particularly regarding the different light sources and different light applications that contribute to it. Further research is urgently required; it may be pointed out that the CIE is particularly equipped to support this research.

3.3. Remedial measures

In astronomical circles it is usually accepted that remedial measures are required if the sky glow is more than 10% of the natural background radiation.
The remedial measures to be considered depend primarily on the type of astronomical observation to be made. Photography in the visible light require a reduction of spill light in the visible area: so do observations with the naked eye. (It should be pointed out that although professional astronomers usually depend on photography, very many amateur astronomers work visually. And it is the large body of amateur astronomers that do the bulk of the observations on meteorites and comets). Infrared and ultraviolet observations require a reduction in radiation in these spectral regions. Spectroscopic observations require reduction in the specific spectral ranges to be used. All these different regions are discussed in detail in the comprehensive French study (Anon, 1984); this study includes the discussion of other sources of disturbance as well - e.g. radio, thermal and vibrational disturbances.

In sensitive areas the lighting should be reduced as far as possible. The following measures are recommended:

- reducing advertisements and billboards;
- reducing the lighting for sports and recreational establishments particularly by restricting the time when they may be used (usually e.g. until midnight);
- eliminating upward radiation from light fittings, or at least from light fittings with high-output lamps;
- reducing the reflectivity of the surfaces that are directly illuminated by the light sources; (it should be pointed out that as regards road surfaces, the recommended practice is the contrary: in road lighting for motorized traffic the luminance of the road surface is the determining factor for the lighting quality; a high reflection enables a high luminance with reduced luminous flux and consequently with reduced light spill);
- applying light sources with a limited spectral emission; far out to be preferred are the low-pressure sodium vapour lamps that emit exclusively light in a very narrow spectral band around 590 nm; for all practical purposes, these lamps may be regarded as monochromatic light sources (Kaufman (ed.), 1981, p. 8-54);
- restrict the light emission of other light sources to the visible part of the spectrum by eliminating the infra-red and the ultra-violet radiation that are useless for lighting purposes and contribute considerably to the distrurbance for astronomical observation.

Several countries that have important astronomical observatories within their borders have set up regulations in this respect. Usually, all measures described above are included: it depends on the local situation which of these recommendations are the most appropriate or the most effective. Examples of such regulations are given by Anon (1982, 1984). Surveys are given in CIE (1978); IAU/CIE (1980); Anon (1985, 1985a); see also McInnes & Walker (1974). Crawford (1985) gives examples of ordinances and suggestions how these can be put into operation.

Another factor is the reduction of atmospheric turbidity (aerosols), and air of pollution in general. Apart from the in general benefits, astronomic observations may benefit from it as well, particularly if the observations are close to the sources of the light pollution.

A few additional remarks regarding the road lighting will be made. As indicated earlier, the quality of road lighting, particularly the lighting for motorized traffic, is expressed in the road-surface luminance (see Schreuder, 1967). This is the primary contributing factor towards the state of adaptation of the eye of the observer-traffic participant. And it is well established that visual performance augments with increasing ambient luminance, i.e. increasing state of adaptation (CIE, 1981). Now, it is possible to arrive at a high road-surface luminance with relatively low installed luminous flux by designing carefully the optical system of the street lighting lanterns. This design should be such that the maximum luminous intensity of the lanterns makes a downward angle of between 20° and about 40° with the horizontal. Light emitted above the horizon does obviously not contribute to the road lighting; and light emitted close to but under the horizon does not either as a result of the prevailing reflection characteristics of road-surface materials commonly in use. Such lanterns turn out to be the most effective as regards the resulting road-surface luminance per unit of installed luminous flux (the luminance yield). As indicated earlier, light coloured road surfaces are prefered. The reason is that they may increase the luminance yield. But there is more. Light emitted close to but under the horizon may easily reach the eye of the observer-traffic participant, and may cause considerable glare that can be counteracted only by increasing the luminance level - thus, by increasing the luminous flux and the light spill! The obvious solution is to shield the light sources of the street lighting lanterns in such a way that direct light cannot reach the eye of the observers. Again this calls for semi-cut-off lanterns; such a lantern design is applied very widely, particularly on the continent of Europe. It seems to be the most effective, both as regards the economy of the road-lighting installation as well as regarding the restriction of spill light. However, in Britain and in most other parts of the world, particularly in the USA, semi-cut-off lanterns are not used widely. The reason is that for road surfaces with a very fine texture, that usually show specular reflection, there seems to be some advantage in non-cut-off lanterns. This point is defended on the basis of the visual inspection of the road-lighting installations where even the faroff lanterns seem to contribute to the road-surface luminance. Calculations show, however, that this is mainly a visual impression that is not supported by facts (see e.g. CIE, 1976; Burghout, 1977, 1980). Furthermore, such fine-textured surfaces are not used any longer for main roads as they tend to be very slippery when wet.

The recommendation to apply low-pressure sodium light is another where economy of the installation, visual performance and reduction of the disturbance for astronomical observations go hand in hand. Low-pressure sodium-vapour lamps show the highest luminous efficacy of all existing light sources: values up to 200 lumen per watt are currently available for lamps on the market (Sprengers & Peters, 1986); Sprengers et al., 1985). For comparison: current high-pressure sodium lamps may reach 110 lm/W; high-pressure mercury lamps 50 - 70 lm/W, fluorescent tubes some 50 - 90 lm/W and incandescent "general purpose" lamps - the well-known bulbs at home - not more than some 7 lm/W! Furthermore, the visual performance under the - monochromatic - light of low-pressure sodium lamps seems to be higher than when applying other light sources - be it that in the past these advantages seem to be somewhat over-estimated. The monochromatic light has of course one serious drawback: it is not possible to discern colours. For roads for motorized traffic this drawback seems to be only small: in most European countries motorways - if lighted at all! - are lit by low-pressure sodium lamps (Schreuder, 1986). In residential areas the drawback is larger. However, enquiries under inhabitants did not indicate that there are serious objections (Van den Brink & Tan, 1979). Experience of using low-pressure sodium light in residential areas are such that this seems even there to be a quite acceptable light source. Nevertheless, in several countries low-pressure sodium lamps are not permitted (Denmark) or used on a very limited scale (USA). It should be pointed out, however, that in the USA a turning point seems to be reached. Particularly for the reason to reduce the disturbance at astronomical observations, low-pressure sodium lamps are applied in several sensitive areas with great success (Finch et al., 1979). As a point of fact, nearly all the local and national requirements and ordinances quoted earlier explicitely specify the use of low-pressure sodium-vapour lamps for outdoor use in sensitive areas.

A matter of special concern is the lighting of vehicles. At present, there seems to be no practical way to reduce the amount of light spill from vehicle head lamps, and furthermore it seems to be unlikely that the use of cars can be restricted. In fact, the Spanish ordinance explicitely excludes vehicle headlamps from the regulations against light pollution (Anon, 1982).

3.4. The role of CIE

"All of this says, really, 'Do the best possible professional lighting "design for the task, including all relevant factors, of which astronomy "is one'". These are the words of David Crawford, who is the protagonist of the case of the astronomers; not switching out lamps or banning lighting, but doing a professional job (Crawford, 1985). Obviously, this is a challenge for the lighting community and for the lighting profession. It is a very short-sighted point of view to believe that astronomers are just a bunch of egg-heads that do not deserve serious consideration. Fortunately, such points of view are expressed hardly any longer!
The lighting community accepts this responsibility. Proof for this is the CIE Statement concerning protection of sites for astronomical observations (CIE, 1978), the joint IAU/CIE (1980) publication on minimizing sky glow near astronomical observatories and the more recent IES Statement on astronomical light pollution and light trespass (Anon, 1985a). Particularly, the joint IAU/CIE publication is considered as the most important contribution in this area (see e.g. Anon 1984a, 1985a).
The task of the lighting profession is not finished, however. In the preceeding sections we have noted several aspects where further activities, particularly further research is urgently required. And in view of the international nature of the problems - and of the astronomical investigations - it seem nothing but appropriate that CIE undertakes these tasks. It is a matter for further considerations of the CIE officers to select the most effective way to perform this task. An excellent, concise description of this task is given in the IES document:
"- Continue to support research to develop a comprehensive system for the "predetermination of light requirements for the effective performance of "visual tasks.
"- Encourage the development of specifications for outdoor lighting that "recognize the possible adverse effects of stray light on the environment "and make provisions for control.
"- Continue efforts to cooperate with the astronomical community in the "development of lighting practices that protect observatory sites from "light pollution". (Quoted from Anon, 1985a, p. 662).

4. TWO CASE-STUDIES

4.1. Halley's Comet

As was pointed out by worried amateur astronomers, one may expect "that our generation may be the first, in the long history of the earth, where many will be unable to see the return of Halley's Comet in 1985" (Quoted from Anon, 1985a, after Anon, 1982a). It was suggested to dim temporary the lighting, but as we know that was not done. And the result was as expected: the majority of city dwellers indeed could not see Halley. The tidal wave of books and television coverage could diminish but not repair the damage. It is essentially different to see the wonders of the sky with one's own eyes or see it on TV!
Nevertheless, the coverage was extensive and mostly of high quality. This point towards another fact that should not be overlooked: the great interest in Halley's Comet, even as is a was invisible for most, proves that astronomy receives a large amount of interest and attention of the lay public. Still, the facts are clear: the lighting profession permitted mankind to work, to enjoy also when the natural light is absent - to continue to live and love. The costs for mankind is that he is enstranged from the natural night sky - including the occasional comets!

The harm to the professional astronomers is considerable as well, in spite of the fact that many interesting investigations have been proposed and made as well by a number of space probes. The close passage of Halley's Comet presents an unique possibility for the scientific astronomy to gather a wealth of data, that are of a much wider interest than the birth, live and death of comets alone. In fact a very large worldwide effort was set up in order to gather as much information as possible and to coordinate the efforts of observation and of data handling. A voluminous publication by the IHW Staff gives some idea of the extent of this work (see Anon, 1984b). The International Halley Watch (IHW) includes 7 observational networks, 6 of which rely on optical observation. 47 countries and 875 astronomers participate in these networks. This large number of countries involved is significant because of the type of observations one is expecting to make, as many phenomena in comets are very rapid (some last only several hours) and many can only be observed from rather restricted areas of the earth surface. So, it is not possible to select as observation sites some mountain top far from all urbanisation:

Halley observations have to be made from all locations. Thus, restrictions of urban sky glow is even more urgent than for general astronomical observations. Finally, it is clearly explained in this paper how space and earth observations both are essential: the space observations are time snap-shots only, giving no long term evolutions; they are, however, from very close to the comet. Overall surveys of the aspects of Halley's Comet are given in many more popular publications, e.g. Calder (1980) and Harpur (1985). Incidently, both refer to light polution as a possible disturbance for observations, for professionals as well as for amateurs.

4.2. The European observatory

Many European countries, particularly in Northern or North-Western Europe suffer from poor weather. So, even before artificial lighting restricted the possibilities for astronomical observations, such observations were difficult as a result of water vapour and turbulence in the air, of clouds, and of the short nights in the summer. Astronomers searched for observation sites in more favourable locations. Added to this was the wish to observe more regularly also the Southern skies, invisible from the Northern hemisphere. However, the search for new observation sites was prompted much more by the increase of light pollution. So, as the first observatories outside Europe but operated from European institutions were on high mountains in the sub-tropics where trade-winds permitted good observations, now even there, light trespass is the limiting factor. The point in fact is the European Observatory in the Canaries. The observatory at Izana on Tenerife that was very promising indeed (see McInnes & Walker, 1974; Murdin, 1985; Sanchez, 1985) cannot used any longer for high sensivity optical observations: recently it is used mainly for solar research. New optical telescopes will be installed on the highest peak of the remote island San Miguel de La Palma, a small island at the North-Western tip of the Canary Islands group - in the middle of the Atlantic Ocean. A tremendous amount of infrastructural and logistic work was needed in order to have the large telescopes in operation; the largest British telescope (the 2.5 m Isaac Newton) was moved from Britain towards La Palma (Herman, 1979; Smith, 1985) and even larger telescopes are planned (Boksenberg, 1985). The end result will be one of the largest observation complexes of the world, operated jointly by Britain, Norway, Denmark, Federal Republic of Germany, The Netherlands, Ireland and, of course, Spain. The official inauguration of the observatory on Saturday June 29, 1985 was an important social and political affair (Anon, 1985b).

It is interesting to note that in the original study of McInnes & Walker of 1974 and also in the earlier studies of Walker (1970, 1971) the main consideration to prefer La Palma over Tenerife was the air turbulance; now it is primarily the light pollution that determines the preference. This is in line with the findings of the IAU Commission 50 (Anon, 1985) where a rapid increase in light pollution is reported. In fact, it is stated on several occasions that La Palma is one of the very few "clean" sites left on the world (Crawford, 1985). It is therefore of the highest urgency to keep these few sites "clean".

5. LIGHT IMMISSION; LIGHT POLLUTION

In Section 2 we indicated three groups of "victims" of light trespass: the astronomers, the residents and the naturalists. We indicated as well that the amount of interest these three groups receive from the professional world is quite distinct. Because of this we will combine the second and the third group in this section in spite of their inherent differences.

Light immission refers primarily to light from outdoor lighting installations that enters the living areas, particularly the bedrooms. The legislation in the Federal Republic of Germany speaks of light emission if risks, distinct disadvantages of distinct discomfort arises for man, animal or plants (Anon, 1975). As regards the maximum value that still can be tolerated, the results of measurements from Hartmann (1984) are quoted, where it was found that the discomfort in bedrooms is tolerable if the illuminance in the plane of the window is less that 3 lux, (see also Hartmann, 1982). Steck (1984) suggests the use of "cut-off" lanterns in residential areas, having less than 10 cd in horizontal direction and less than 30 cd in a downward angle of 10° with the horizontal, both per 1000 lumen. This is in fact the old CIE designation (CIE, 1967). When, however, this proves to be insufficient, Steck suggests to add shields, or preferably optical elements to the lantern (ibid). In fact, he suggests the design of new appropriate lanterns for residential areas, a suggestion that may be found elswhere as well (Caminada & Van Bommel, 1980, 1984, Schreuder, 1980).
In the IES Statement (Anon, 1985) the wording "light trespass" is primarily reserved to these aspects, although also glare for drivers and for aviators seems to be included. As regards the restrictions to light immission, there seem to exist rather different requirements within the USA. The ordinances of Milwaukee (Wis.) and Skokie (Ill.) are similar to the German values: the limits are about 2 lux and 3 lux respectively. San Diego (Cal.) limits the light immission, however, to 0.21 lux!

Light trespass and glare are closely related. At the one hand this relation is a result of the similarity of the physical causes and consequently of the remedial measures; at the other hand is the fact that in both cases people suffer from the light. We will discuss here an item where the two (trespass and glare) are closely intertwined: the disturbance of observation for pedestrians (particulalrly for elderly) in residential areas. Traditionally, the street lighting lanterns for residential areas are of the non-cut-off type. The reason is that the lighting of residential areas, just as the lighting of pedestrian areas and shopping malls, has been considered as a matter of aesthetics: mostly, architects did design the lighting and the lanterns, basing themselves on architectural form and not on functional considerations (see e.g. Begemann, 1986; Kalff, 1943). In order to create a lively environment, sparkling light points usually were preferred - that is, non-cut-off lanterns that cause considerable glare. Furthermore, many designers did believe that a non-cut-off light distribution would allow a larger spacing between the light points, thus reducing installation and running costs. This indeed is the case - at least to a certain extent: spacing to mounting heigh of some 4:1 is acceptable - when the road luminance is used as a criterion of quality for the road lighting. This is relevant for the lighting of thoroughfares (CIE, 1977a) but not for residential areas. There is still some doubt what is the most relevant criterion of quality for the lighting of residential areas. The most relevant criterion might be the luminance of the faces of people that are met in the street - friends, or foes! (Schreuder, 1980). One aspect often is overlooked in these considerations: the glare from which pedestrians may suffer, particularly the elderly. It is well established that the disturbance from glare increases with increasing age, primarily as a result of an increase in the turbidity of the ocular media (Vos, 1984; Padmos, 1984a). Again here the remedy is obvious: shielding the light sources. This is in line with the recommendations given for reducing other adverse effects of light trespass: considering the elderly pedestrians supports the idea that, in residential areas as well as in traffic areas, semi-cutoff street lighting lanterns are to be preferred.

A major source of discomfort as a result of light immission is the lighting of sports stadia. In the Netherlands some work is done in this respect. Folles (1980) found on the basis of enquiries under lighting experts that for residents the light level should be lower than 0.03 to 0.7 lux depending on the location and the circumstances; it was, however, not always possible to define precisely in which plane the illuminance had to be determined.

Schreuder (1980a) came on the basis on the theoretical considerations to similar conclusions. In order to limit the disturbance for road traffic, the sports stadium lighting lanterns should have a luminous intensity of not more than 40.000 cd in the direction of the observers. In many current situations this will lead to an illuminance of the order of 1 lux. It should be pointed out, however, that these studies primarily were aimed at reducing glare for motorists in the vicinity of sports stadia. As a final conclusion it was found that unacceptable light trespass (including glare) could be avoided if current lighting installations were equipped with baffles that optically screen the light sources from the areas around the stadia. In most cases these baffles are commercially available.

As stated earlier, the more general environmental effects of light did receive very little attention from the lighting profession, in spite of the fact that in many countries environmental pressure groups did have quite an impact e.g. in switching off street lighting. This is an unfortunate state of affairs, as in this way the discussions were fought on a political level, and because the arguments used were usually emotionally rather that rationally based.

In this respect the British initiative of the Landscape Advisory Committee (LAC) is interesting to note. The LAC set up requirements for the lighting of trunk roads passing through attractive rural areas:

- provide fully satisfactory lighting of the carriageway;
- spill very little direct light outside the carriageway;
- be visually satisfactory and not too intrusive by day;
- when viewed from a distance the "glow" effect should be minimised;
- the lantern shall not have a visible bowl (i.e. have a flat bowl).

Theses points, quoted from an (unpublished) circular letter from the Department of Transport (Holmes, 1985) seem to offer a good starting point for a programme to reduce the visual impact of rural road lighting. It might be added that these points are in line with other suggestions of the same Committee (Lovejoy, 1986).

6. CONCLUSIONS

We may conclude from the foregoing that light trespass is a complex phenomenon that may cause different degrees of disturbance to a wide range of "victims", the most important being the astronomers, the residents and the naturalists. In all cases it is clear that screening the light sources may have a beneficial effect; in the case of disturbances of astronomical observations the use of monochromatic (low-pressure sodium) lamps is highly recommended.

Further activities are needed, particularly from the part of the lighting community and the lighting profession. The negative results of light trespass can be reduced to a considerable degree by a good lighting design; at present, it is not generally accepted to take aspects of light trespass into account when making light designs. So, apart from the development of better design methods - i.e. methods that are better suited to handle light trespass considerations - there seems to be a need for a further education of the lighting professionals to apply those improved design methods. Furthermore, the authorities that order the lighting installations, and have to pay for them, must be convicted of the need to spend some extra money in order to preserve nature and to free people from the nuisance of light trespass. Finally, the industry should be prepared to make a greater effort in designing lighting equipment (both light sources and lanterns, including electrical gear and optical elements).
The liaison between the lighting and the astronomical communities is well established. It is recommended to try and improve the relationship with other specific interest groups as well, particularly with architects and urban designers, with consumer organisations and with environmental protection organisations.

In these areas, the CIE as the international organization that joins the lighting profession will have a crucial position. It is recommended

- that CIE promotes further study in the area of light trespass;
- that CIE promotes the education of lighting professionals with emphasis on negative side-effect of lighting including light trespass;
- that CIE promotes further international co-ordination with other professional bodies to reduce light trespass.

REFERENCES

- Anon (1975). Bundes-Immissions-Schutzgesetz. (Federal law for immission protection). 2nd edition. (Ref.: Steck, 1984).

- Anon (1982). Real Decreto 2678/1982 de 15 de octubre (In Spanish). Boletín Oficial del Estado 28 de octubre. Madrid, 1982.

- Anon (1982a). Dim the lights for Halley's Comet. Science 82 (1982) (June) 16. (Ref.: Anon, 1985a).

- Anon (1984). La protection des observatoires astronomiques et geophysiques. Rapport du Groupe du Travail. Institut de France, Academie des Sciences, Grasse, 1984.

- Anon (1984a). Ordinance amending the San Diego County Code to provide for regulation of light pollution. Ordinance No. 6900 (New Series). San Diego, 1984.

- Anon (1984b). Exploration of Halley's Comet from the ground. The International Halley Watch (IHW) and its observing nets. ESA Bulletin (1984) 39 (Aug) : 37-50.

- Anon (1985). Identification and protection of existing and potential observing sites. (Draft). Report IAU Commission 50. International Astronomical Union, New Delhi, 1985.

- Anon (1985a). A statement on astronomical light pollution and light trespass. Journal of IES 14 (1985) : 658-662.

- Anon (1985b). The observatories of the Canaries, on the occasion of their inauguration, June 28-29, 1985. Vistas in Astronomy 28 (1985) Part 3.

- Begemann, S.H.A. (1986). De verduistering in de verlichtingskunde (Black-out in lighting engineering). University of Technology, Eindhoven, 1986.

- Boksenberg, A. (1985). The William Herschel Telescope. In: Anon (1985b).

- Burghout, F. (1977). Simple parameters significant of the reflection properties of dry road surfaces. In: CIE (1977).

- Burghout, F. (1980). On the relationship between reflection properties, composition and texture of road surfaces. In: CIE (1980).

- Calder, N. (1980). The comet is coming! British Broadcasting Corporation, London, 1980.

- Caminada, J.F. & Van Bommel, W.J.M. (1980). New lighting considerations for residential areas. Int. Lighting Rev. 31 (1980) 69-75.

- Caminada, J.F. & Van Bommel, W.J.M. (1984). New lighting criteria for residential areas. Journal of IES 13 (1984) 350-356.

- CIE (1960). Street lighting and accidents. Publication No. 8. CIE, Paris, 1960.
- CIE (1967). Recommendations for the lighting of roads for motorized traffic. Publication No. 12. CIE, Paris, 1967.
- CIE (1976). Calculation and measurement of luminance and illuminance in road lighting. Publication No. 30 (2nd ed. 1980). CIE, Paris, 1976.
- CIE (1977). Measures of road lighting effectiveness. Symposium, July 5-6, 1977. CIE, Karlsruhe, 1977.
- CIE (1977a). International recommendations for the lighting of roads for motorized traffic. Publication 12/2. CIE, Paris, 1977.
- CIE (1978). Statement concerning protection of sites for astronomical observatories. CIE, Paris, 1978.
- CIE (1980). Proceedings 19th session. Kyoto 1979. Publication No. 50. CIE, Paris, 1980.
- CIE (1981). An analytic model for describing the influence of lighting parameters upon visual performance. Publication No. 19/2. CIE, Paris, 1981.
- Crawford, D.L. (1983). Astronomy's problem with light pollution. Tucson, 1983 (year estimated).
- Crawford, D.L. (1985). Light pollution: astronomy's problem with urban sky glow. (Draft). Tucson, 1985 (year estimated).
- De Boer, J.B. (ed.) (1967). Public lighting. Centrex, Eindhoven, 1967.
- Economopoulos, I.A. (1977). Relationship between lighting parameters and visual performance in road lighting. In: CIE (1977).
- Economopoulos, I.A. (1978). Photometric parameters and visual performance in road lighting. University of Technology, Eindhoven, 1978.
- Finch, D.M.; Jewell, J.E.; Leite, M.J. & Nelson, B. (1979). Atmospheric light pollution. In: CIE (1980).
- Fisher, A.J. & Turner, H.J. (1977). Outdoor lighting and observatories. IES Lighting Review (1977) (Febr.) 25-32.
- Folles, E. (1980). De verblinding door sportveldverlichting en haar invloed op het wegverkeer en omwonenden (Glare by the lighting of sports stadia and its influence on road traffic and residents). Polytechnisch Tijdschrift B 35 (1980) 248-255.
- Gallagher, V.P.; Schwab, R.N. & Janoff, M.S. (1977). Implementing a roadway lighting system based on the visibility index concept. In: CIE (1977).
- Hargroves, R.A.; Marsden, A.M.; Cobb, J. & Scott, P.P. (1979). Road lighting and accidents. In: CIE (1980).

- Hartmann, E. (1982). Untersuchungen zur belästigenden Wirkung von Lichtimmission. Vortrag. Landesanstalt für Immissionsschutz, Essen (1984) (year estimated). (Ref.: Steck, 1984).
- Hartmann, E. (1984). Lichtimmission; Ergebnisse einer Forschungsarbeit. Paper presented at Light 1984, Mannheim, 5-7 June 1984.
- Harpur, B. (1985). The official Halley's Comet book. Hodder & Stoughton London, 1985.
- Herman, R. (1979). Sky eyes go south for nothern stars. New Scientist (1979) (7 June): 826-829.
- Hoag, A.A.; Schoening, W.E. & Coucke, M. (1973). City sky glow monitoring at Kitt Peak. Publ. Astron. Soc. Pacific 85 (1973) 503.
- Holmes, R.W. (1985). Circular letter, 23 Jan. 1985 (Not published).
- IAU/CIE (1980). Guide lines for minimizing urban sky glow near astronomical observatories. Publication of IAU and CIE No. 1. CIE, Paris, 1984.
- Kaufman, J.E. (ed.) (1981). IES lighting Handbook. IES, New York, 1981.
- Kalff, L.C. (1943). Kunstlicht und Architektur. Robert Kiepert, Berlin, 1943.
- Lovejoy, D. (1986). Environmental and aesthetic aspects of motorway and trunk road lighting. The Lighting Journal 51 (1986) 35-36.
- Martin Mateo, R. (1983). Light pollution at the IAC observatories. (In Spanish). Instituto de Astrofisica de Canarias, La Laguna, 1983.
- McInnes, B. & Walker, M.F. (1974). Astronomical site testing in the Canary Islands. Publ. Astron. Soc. Pacific 86 (1974) 529-544.
- Murdin, P. (1985). Nighttime skies above the Canary Islands. In: Anon (1985b).
- OECD (1971). Lighting, visibility and accidents. OECD, Paris, 1971.
- OECD (1980). Improving road safety at night. OECD, Paris, 1980.
- Padmos, P. (1984). Visually critical elements in night driving in relation to public lighting. In: TRB (1984).
- Padmos, P. (1984a). Glare and tunnel entrance lighting: Effects of straylight from eye, atmosphere and windscreen. CIE-Journal 3 (1984) 1-24.
- Sanchez, F. (1985). Astronomy in the Canary Islands. In: Anon (1985b).
- Sanchez Beitia, E. (1983). Night time sky brightness as a function of the distance to the urban centres on the islands Tenerife and San Miguel de la Palma. (In Spanish). Instituto de Astrofisica de Canarias, La Laguna, 1983.
- Schreuder, D.A. (1967). The theoretical basis of road-lighting design. In: De Boer (ed.) (1967).

- Schreuder, D.A. (1977). The relation between lighting parameters and transportation performance. In: CIE (1977).

- Schreuder, D.A. (1980). The lighting of residential yards. In: CIE (1980).

- Schreuder, D.A. (1980a). Fysiologische verblinding veroorzaakt door sportveldverlichting (Disability glare from sports stadia lighting). Polytechnisch Tijdschrift B 35 (1980) : 256-259.

- Schreuder, D.A. (1983). De relatie tussen verkeersongevallen en openbare verlichting (The relation between traffic accidents and public lighting). R-83-12. SWOV, Leidschendam, 1983.

- Schreuder, D.A. (1984). Visibility aspects of road lighting. In: TRB (1984).

- Schreuder, D.A. (1986). Road lighting in Europe. Paper presented at ILE symposium, Birmingham, April 1986.

- Scott, P.P. (1980). The relationship between road lighting quality and accident frequency. Lab. Report LR 929. TRL, Crowthorne, 1980.

- Smith, F.G. (1985). U.K. Astronomy on La Palma. In: Anon (1985b).

- Sprengers, L.M. & Peters, J.I.C. (1986). SOX-E(conomy) - A new generation of low-pressure sodium lamps with improved overall performance. The Lighting Journal 51 (1986) 27-30.

- Sprengers, L.; Campbell, R. & Kostlin, H. (1985). Low pressure sodium lamps with a luminous efficacy of 200 lm/W. Journal of IES 14 (1985) 607-615.

- Steck, B. (1984). Lichtimmission. Licht (1984) 453-456.

- Tien, J.M. (1979). Lighting's impact in crime. Lighting Des. Appl. (1979) (Dec).

- TRB (1984). Providing visibility and visual guidance to the road user. Symposium July 30 - August 1, 1984. Transportation Research Board, Washington, D.C., 1984.

- Turnrose, B.E. (1974). Absolute spectral energy distribution of the night sky at Palomar and Mt. Wilson observatories. Publ. Astron. Soc. Pacific 86 (1974) 545-551.

- Van den Brink, T.D.J. & Tan, T.H. (1979). Openbare verlichting in woongebieden (Public lighting in residential areas). Verkeerskunde 30 (1979) 425-428.

- Vos, J.J. (1984). Disability glare; A state of the art report. CIE-Journal 3 (1984) 39-53.

- Waldram, J.M. (1972). The calculation of sky haze luminance from street lighting. Lighting Res. Technol. 4 (1972) 1.

- Walker, M.F. (1970). Publ. Astron. Soc. Pacific 80 (1970) : 672.
- Walker, M.F. (1971). Publ. Astron. Soc. Pacific 83 (1971) : 40.
- Walker, M.F. (1973). Light pollution in California and Arizona. Publ. Astron. Soc. Pacific 85 (1973) : 508-519.