Light pollution: Information and energy waste

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ABSTRACT

Nowadays, the Artificial Lighting is widely used by the community as a way to get some additional visual information that allows it to extend its activities during the night-time. Although the main aim consists of lighting some concrete zones, avoiding light diffusion towards other adjacent areas – and even directly towards the atmosphere – becomes impossible, so a **visual noise** known as **Light Pollution** is consequently created.

This dispersed light has a negative influence in the environment in several different ways: natural zones or citizens privacy intrusion, affectation to both flora and fauna – especially to those that mainly develop their activities at night-time – difficulties when carrying out astronomic observations, etc. It is possible to talk about **informative residues** of the lighting process and, since this light production is concerned with an energetic spending, it can also be pointed the existence of an **energetic resource wasting**. Even though this problem is nowadays widely known and it is already being studied, the actions taken in order to reduce it are infrequent, and the growing of **the environmental influence of Light Pollution is far away from suffering a reduction**.

In Catalonia æ Autonomic Community, located in the north-east of Spain with 32.000 Km2 of extension and 6.150.000 population (in 1999) – the Autonomic Government has created the Law for the Environmental Ordination of the Outdoor Lighting for the Protection of the Night Environment. The Regulations, which will make it possible to achieve the practical application of the law, are about to be published. In order to carry out this application, it is necessary to develop some procedures that make it possible the evaluation, comparison and correction of real Light Pollution. The field studies performed by our Estudios Luminotécnicos team has allowed us to create a methodology that we believe it can be useful at this stage.

LIGHT POLLUTION CHARACTERISATION

The first studies on Light Pollution come from the Astronomic field and they used some mathematical models (Treanor, Walker, Garstang...) aimed to evaluate the **sky background luminance increase**, phenomena which properly reflects the influence Light Pollution has in astronomic observations, for it indicates the "background noise" originated.

But, from the lighting technique point of view, it is more adequate to study the causes of this perturbation, rather than the perturbation itself, i.e., analysing the light flux which is emitted in the wrong directions, different from those which are being tried to be lighted. Such effect can be seen "materialised" in the photograph below. (next page)

This flux represents "what we are doing wrong" and it evaluates "how badly we are doing it"

The concept of Upward Light Output Ratio (ULOR: light proportion emission above the horizontal plane) of the illuminations is usually used as a way to predict the importance of the skyglow produced. However, the flux that

Figure 1. Barcelona's Glow

Figure 2. SFE diagram for the same type of luminarie in two different streets.

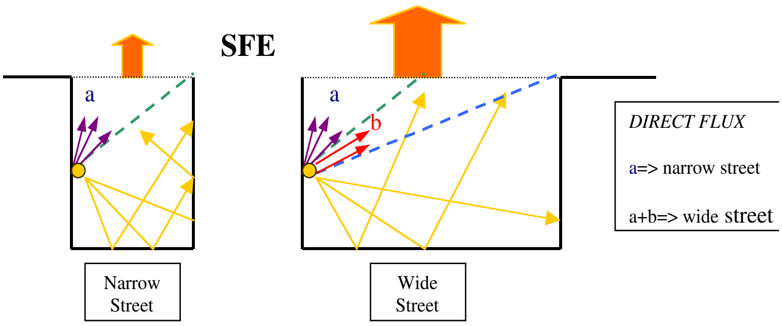
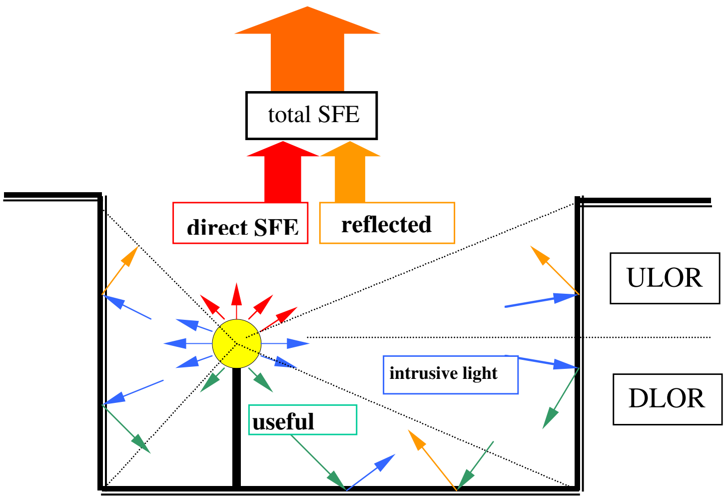


Figure 3- SFE Representation



really enters the sky depends not only on the ULOR but also on the geometric properties of the zone that is being lighted, for its profile can avoid some emissions.

Furthermore, flux reflected on pavement, walls, etc. must be added to that coming directly from the lighting fixture.

Summing up, our proposal is based on the characterisation of the problem by using what we have named **Superior Flux Emission**, which is the total (direct and reflected) flux that arises from the physical whole studied. As it will be explained next, this is a quantifiable and predictable magnitude, which can be expressed in lighting units (lumen). This units measure the physical real magnitude of the problem and, by means of an adequate analytical treatment, they make it possible to differentiate the influence of the different pollutants and, consequently, to evaluate the effectiveness of the possible corrections. Summarising: it can be known "what is bad" and "how much damage it produces".

We have done comparisons in different places, between real **background sky luminances** and our evaluations based on the **Superior Flux Emission Model**. It has been found a significant correlation that has validated our methodology. In some cases, it is necessary to take into account not only the SFE magnitude, but also its spectral composition, for the dispersion degree varies depending on the radiation's wavelength. To perform this, we apply a "balance" which depends on the characteristics of the lamps studied, obtaining the **Relative Emission Degree (RED)**, addimensional index which allows us to compare, for instance, the dispersion differences for the same SFE, depending on the lamp types used.

SFE AND RED DETERMINATION

In the studies on the quantification of the light flux that is spilled to the sky – and which, therefore, is likely to increase the natural sky luminance –all kind of light fixtures concerned with this phenomena will be analysed. Public road lighting installations – as well as private ones –, small shops lights, big supermarkets, etc...

The methodology followed for the determination of SFE and RED is based on the inspection of the studied zone, computer simulations, and both the classification and software treatment of all the different cases, as it will be described in the next chapter.

For the study of this case, more than 20 parameters should be taken into account. They cold be classified in the following groups:

Urban Typology of the zone: Buildings height, streets width, street longitude, building level, façade characteristics,...

Illumination characteristics Light levels, type and orientation of the luminaries, type and wattage of lamps,...

Private illumination level The non-public illumination levels are quantified here (from private windows up to wall charts and lasers,...)

Characteristic of the way use The level of use of the way, for it is this parameter which determines – depending on the hou – the light levels and uniformity needed.

Because of this, in each of the studied zones, it is required to take some measures, such as:

- Public way illumination
- Façade illumination
- Façade and wall charts luminance
- Geometric measures of the zone

All this data will be input in an *indoor lighting simulator software*, where the studied case will be simulated. In it , we represent the façades as the walls of the room. Their diffuse reflectance will be calculated by supposing they are Lambertian surfaces, where:

$$L = \frac{E \times \rho}{\pi}$$

Once known E and L, which have been obtained from the field work, we can get the value of the diffuse reflectance, needed to perform the simulations.

Luminaries' disposal is also known, as well as its photometric characteristics and the lamps type.

The private lighting fixtures –such as wall charts, windows, etc. –will be represented by means of a luminarie which has a Lambertian spectral distribution, whose light flux will be known, because its mean luminance is also known:

The light flux that cross the ceiling can be considered the *pollutant light*. This can be directly obtained by using the relation:

$$\phi = L_{MEAN} \cdot \pi \cdot S$$

In a specific area, the SFE can be calculated as the light flux that escapes from the urban characteristics of the studied case. And the risk of having intrusive light can be obtained from the light levels on walls, for that is the flux which is likely to cause annoyance in people's life.

$$Ilumination = \frac{lightFlux}{Surface}$$

The RED can be calculated according to the spectral distribution of lamps used.

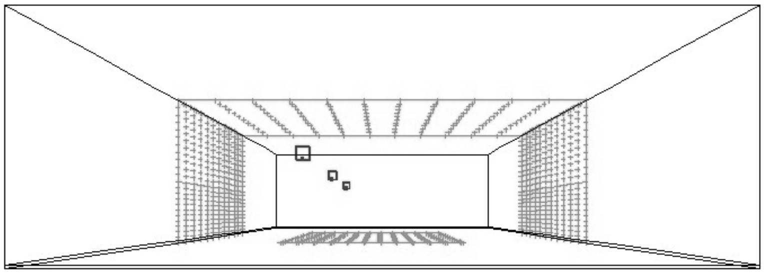
It can be quantified by:

$$RED = SFE_{MV} + 0.66 \cdot SFE_{sv}$$

where SFEMV is the value of SFE produced by mercury vapour lamps
SFESV is the value of SFE produced by sodium vapour lamps

formula that was developed by Mr. Javier Diaz Castro, from the Canarias Astrophysical Institute. It takes into account the fact that ultraviolet waves – more abundant in

Figure 4- Image of one of the simulations



mercury lamps than in sodium ones –are more likely to be both reflected and refracted by atmosphere particles and water droplets (which is, in fact, the cause light pollution). Actually, the proportions of SFEMV and SFESV correspond to the proportions of the Installed Flux in each of the different kinds of lamps

Basing on these studies, as well as on simulated cases, it would be possible to get some analytic results, where we could evaluate the influence some of the studied parameters has in terms of pollution.

For example, if we study a street with these characteristics:

High pollutant luminaries with sodium vapour lamps.

Width	20m
Buildings height	13m
Length	35m
Emead	16 lux

By changing the simulation parameters, it is possible to get variations in the results of the general case (Table 1 below)

In this concrete case, the simulation has described a zone equipped with potentially high pollutant luminaries (high ULOR). Important considerations, derived from the analytic study:

Private lighting influence: If the percentage of private lighting is modified (by changing its light flux), it is possible to notice the variation of its contribution. The characteristics of the photometric properties of this type of illumination (very similar to those of the opal fluorescent), make it possible to consider them as high ULOR luminaries, although with variable emitted flux. This influence is much more conspicuous in the case of low polluting luminaries, where the major influence is often produced by private lighting.

Luminaries Type If the current high pollutant luminaries were changed for others with ULOR=0, the pollution would be reduced in 64% (from 13 lm/m2 down to 4,7 lm/

Table 1- Results in a studied area

Case	a/h rate	Luminarie type	% public	% private	SFE(lm/ m2)	EFS/FTI rate	% direct SFE	% reflect. SFE	% public SFE	% private SFE	% intrusive light
Original	1,54	Spherical	91,4%	8,6%	13	15,4%	70,8%	29,2%	84,6%	15,4%	41,8%
0 % private	1,54	Spherical	100,0%	0,0%	11	14,3%	70,9%	29,1%	100,0%	0,0%	42,1%
20 % private	1,54	Spherical	80,0%	20,0%	16	16,6%	75,0%	25,0%	68,8%	31,3%	40,6%
30 % private	1,54	Spherical	70,0%	30,0%	19	17,2%	73,7%	26,3%	57,9%	42,1%	39,5%
NO spherical	1,54	ULOR=0	91,4%	8,6%	4,7	5,6%	29,8%	70,2%	61,7%	38,3%	21,5%
a/h=1	1,00	Spherical	91,4%	8,6%	9	10,7%	62,2%	37,8%	86,7%	13,3%	47,0%

m2). Private lighting is the cause of the direct influence, which is about 29,8%.

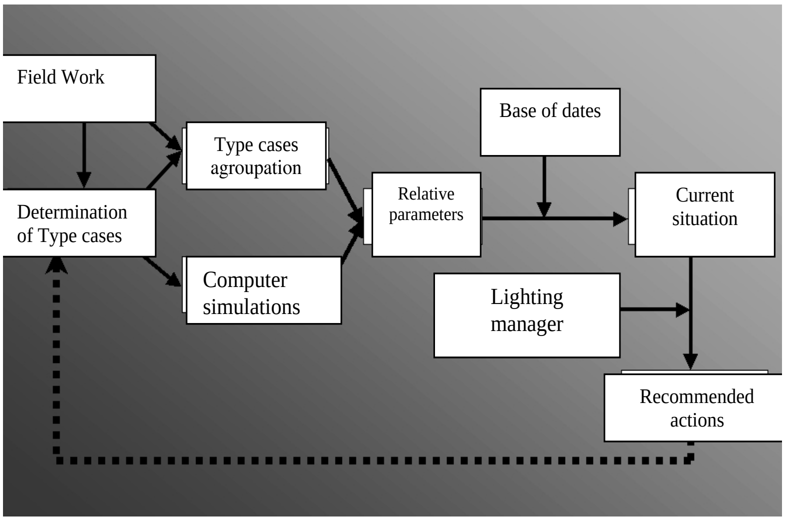
Urban characteristics The characteristics of the surroundings play an important role. If we consider an increasing of two floors in the high of the buildings (up to get w/h=1, namely, 20 meters in high buildings), we would reduce 31% the pollution, thanks to the reflections in the closed-space.

By making some regulations in the computer program, it is possible to calculate the different light sources that should be taken into account.

The direct or reflected contribution in each of the studied cases is obtained by means of the creation of parallel studied cases, where the diffuse reflectances at walls are equal to zero, enabling the analysis of the direct influence. After this, by subtracting the value obtained to the complete original case, it is possible to get the reflected value.

Several simulations have to be done for each of the type cases, considering the different pollutants parameters – public and private, for instance –, as well as the influence of each type of illumination and their contribution to light pollution, both direct and reflected.

Figure- 5 Basic diagram on the study process



APPLICATION IN THE STUDY OF EXTENSIVE AREAS

If one wants to apply the precise study described in the previous chapter to a wide area, it is needed to both performing a diagnosis and cataloguing the type cases. An exhaustive inventory has to be done, which has to include all the cases that are likely to produce light pollution. These will be called **studied cases**.

These studied cases will be related one another depending on their common characteristics, such as luminarie type, urban properties, lamps type, levels got, etc. What is to say, the studied cases will be grouped, classified and related to some called **type cases**, which will be simulated by computer.

As it has already been explained, it is possible to extract some parameters from each type case. The light pollution can be obtained from these parameters, depending on the studied zone. For example, SFE/m2 (pollution per square meter). There are also other ones, such as light pollution as a function of the Total Installed Flux (ULOR/TIF), the contribution of each of the different kinds of illumination considered (private SFE/ total SFE...), etc.

Some relationships between the simulated cases will be therefore set. It is possible to consider some different type cases (as many as wanted), each one with its specific importance.

From all this procedure, it is possible to get a group of parameters, which will permit to quantify global pollution. Usually, due to the great variety of information managed, it is essential to use software specifically programmed for the management and calculation of dates, and also to get a global evaluation of the general situation in the studied area in terms of light pollution.

Afterwards, it is possible to suggest some actions to restructure the current installation. All the procedure explained before will be applied at the new recommended situation. In the picture below it is possible to notice the expected results for a 20.000 population city near Barcelona. More than 290 cases and 350 computer simulations were done.

It is also possible to compare the situation in different areas: (Figure 7).

GENERAL CONSIDERATIONS FROM THE STUDIES PERFORMED

The methodology shown was developed to carry out the execution of the Study-Diagnosis of Light Pollution, which included all Catalonia. It made it possible to get a total SFE evaluation, as well as to draw a map that showed its distribution in different zones.

Similar results were obtained in the Mallorca Island Study. (Figure 8)

The information of the previous studies, because of their geographical wideness, was based on some "concrete samples", backed by general "statistical information".

A more detailed study, based on a more detailed inventory, has been developed in a 20.000 population City near Barcelona and, nowadays, new studies are in progress. Among them, the much more advanced is that of the Montsec Area, the future location of an Astronomical Observatory.

In all these cases, it has been possible to establish, besides a global characterisation and evaluation of the problem, an analytic diagnostic on the different causes and influences. This has made it possible, in the case of the city analysed with more detail, to define and to evaluate all the actions which have to be performed, as well as the Light Pollution reduction their application would produce.

On the other hand, it has also been possible to establish some general considerations that, in some aspects, can contradict the intuitive image of the problem, so it can be interesting to summarise them.

A/ There are three different sorts of factors that are concerned with the origin of Light Pollution

- Structural: they depend on the general conditions of the zone: population density, socio-economic activity, etc
- Specifics: directly related to the concrete case: urban properties, lamps type, luminaries type, etc
- Singulars: Which are due to the existence of some elements that do not follow the characteristics of the general context: facilities, spare areas, communications...

B/ Inside zones with the same structural characterisation, it is possible to notice very significant differences in the specific rates: SFE/m2; SFE/person..., which indicates the very importance of taking into account considerations about skyglow when designing a illumination.

C/ The differences in the amount Pollution in different areas (see map) has a natural tendency to become uniform because of two reasons:

- Distance Dispersion in the most pollutant zones
- Generation from specific factors in the zone itself.

It is convenient, therefore, to establish preventive measures, which could avoid degradation.

D/ Direct emission (high ULOR) is usually considered to be the main cause of Light Pollution but, even though its contribution – when existing –is quantitative more important, its frequency is much lower. The major proportion in

Figure 6

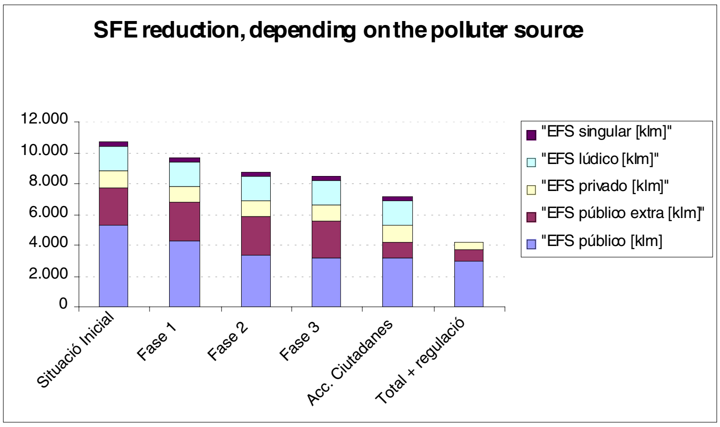


Figure 7. RED in different towns of the same area

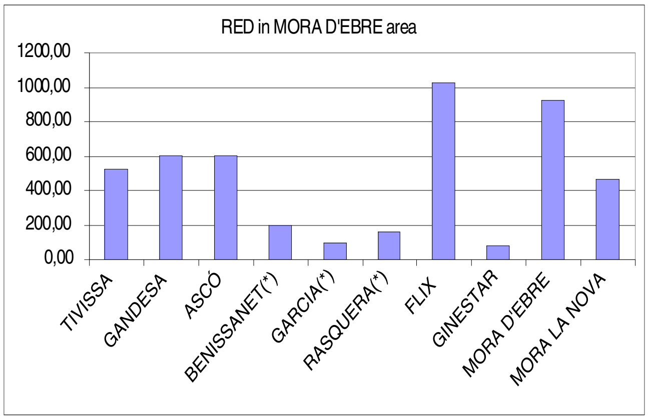
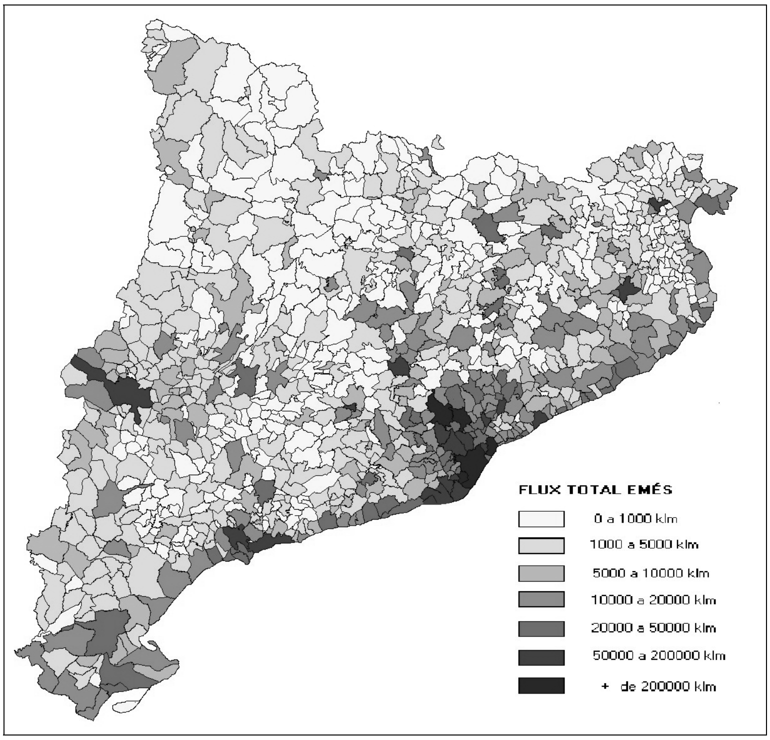


Figure 8. Distribution map of the public lighting SFE in Catalonia



the total ULOR value comes from the reflected light. This is why politics on unjustified increases of light levels are especially worrying.

E/ Public Lighting is normally the most important contribution to skyglow. Anyhow, the contribution coming from other types of Illumination – commercial, private, decorative, sportive –cannot, by all means, be undervalued. Although the percentages are very variable, they often reach 25%. Singular factors normally represent the most problematic contribution.

F/ The methodology of study proposed allows us both to value and stand out the waste of energy: the FSE divided by the average efficacy of the lamps indicates the electric power whose energetic consume is lost in the sky. To this waste energy could be added that coming from the loss that represents intrusive light.

CONCLUSIONS

It would not be realist to suppose the problem could be completely solved. The skyglow component created by direct flux could theoretically – but only theoretically –be completely avoided. However, reflected flux is unavoidable without the total renounce to outdoor illumination at night-time, for it is precisely light reflection in objects that allow us to see them.

It could seem, in a not very careful lecture, that Light Pollution reduction is related to a decrease in the safety conditions and in the environmental beauty that our society is getting from the current illumination. However, by paying some little attention, it is easy to realise that such assumption is not true: Superior Flux Emission, or the projection of intrusive light into the zone that surrounds the area to illuminate, do not contribute, by no means, to improve neither the light conditions nor the economic ones. In the latter case, Light Pollution represents an important waste of energy. This economic saving is a very important factor that has to be taken into account in order to contribute to the setting of politics that contribute to the Reduction of Light Pollution.

It is not necessary to renounce to anything but to the excess and wasting. The current situation, described in these pages, is not the consequence of an outline based on effectiveness criterions; it is the result of either a lack of awareness or an underestimation of the problem. Introducing some criterions for the reduction of Light Pollution in the parameters of design would provoke an environmental and economic benefit as well as an improvement in our quality of life.

GLOSSARY

TIF: Total flux installed
SFE: Superior Flux Emission
RED: Relative Emission Degree
ULOR: Upward Light Output Ratio