Towards an efficient control of light pollution :

the optimization of the public lighting system from

an accurate modeling of light pollution

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The physics basics of light pollution models

The modeling of light pollution is tackled in many studies since the eighties with the main ideas presented in the Garstang (1986, 1989) publications. All these works are based on different physical processes and atmospheric properties which are summarized in this part.

The modeling of light sources

First of all, an emission model as realistic as possible of the light sources is necessary which gives the light intensity distribution (in candela unit) in each direction of space. This can be obtained from global experimental measurements which nowadays benefit from satellite imagery like the DSPM survey which was the basis for the first global light pollution atlas done by the Cinzano team (Cinzano et al. 2001,2004) or in the near future with a higher resolution survey captured from the ISS [1] (by Don Pettit from NASA). But ground-based measurements of the cities sky glow (Walker et al 1978, Kowalesky 1984, fish-eye photographies of Pierre Brunet[2] from ANPCEN, measurements with the Sky Quality Meter built by Unihedron [3]) can also test models a posteriori. Ab initio calculations can finally be carried out by adding the contribution of each lighting by taking into account both the direct light emitted above horizontal and the light reflected by the ground with specific reflection coefficients depending on the material of lighted surfaces (Aube et al 2007, Baddiley 2007, Lozi et al. 2008 from AFA). However, such calculations need a complete database of the light sources at large scale like France on the one hand providing their geographical coordinates and their characteristics both intrinsic (luminous flux, spectrum of the light used, ULOR) and specific to their setting (mounting heights, inclination, ground properties), and on the other hand a heavy calculation much more difficult to carry out. I propose here a hybrid approach using statistical data for public lightings with the Thotpro program initially created by Michel Bonavitacola (1998) and further developed within the LICORNESS association which brings a scientific support to ANPCEN.

1- http://eol.jsc.nasa.gov/EarthObservatory/Cities_at_Night_The_View_from_Space.htm

2- http://astrosurf.com/anpcn/communication/CD_ANPCN/PowerPoint/PierreBrunet/Panoramas%20%e0%20360%b0%20des%20d%f4mes%20de%20pollution.ppt

3- http://unihedron.com/projects/darksky/

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The models for light propagation

After having specified the light sources properties, the atmosphere has to be considered in order to describe the diffusion of light which produces the light pollution at large scale. Models (Garstang 1989, Cinzano 2004, Baddiley 2007) take into account both the Rayleigh diffusion by the air molecules and the Mie diffusion by the aerosols composed by natural (sand, pollens,..) and anthropic (industrial and car dust emission) dust particles, and the water vapour which tends to increase the particle size by condensation of water droplets around them and thus enhance the diffusive properties of atmosphere. The Rayleigh diffusion has a nearly isotropic distribution whereas the Mie diffusion entails mainly diffusion forward, favouring a nearly straight propagation of light in the direction of emission. Besides, this latter is much more efficient than the Rayleigh one by two orders of magnitude. The angular distribution of diffusion well constrained for molecules is less for aerosols because it depends on both the size and geometrical distribution of particles, and the chemical composition. However, recent models take into account in a realistic way the main characteristics which are the anisotropic diffusion and the retrodiffusion effect. As far as the vertical stratification of the atmosphere is concerned, models usually consider an exponentially decrease profile with a reference density and a scale height specific for molecules and aerosols respectively near 8 km and 1 km. The evolution of light pollution with the meteorologic conditions is really interesting to study, particularly by taking into account the features of city climatology as described in Bonavitacola (1995). This kind of work will be done in a next step. In this paper, we will focus on keeping standard conditions for the atmosphere with a fairly good transparency characterized globally by an homogenous horizontal visibility around 50 km (similar to the case K=0.5 of Garstang 1989) in order to demonstrate the key features necessary to control and diminish light pollution. Models often consider a simple diffusion treatment (Baddiley 2007) or the effect of double diffusion (Garstang 1989, Cinzano 2001), which is enough in the aim of astronomical observations needing an optical depth as little as possible. Aube et al. (2007) take into account the multiple diffusion process and find again similar result to the Garstang work for the same atmospheric conditions.

The lighting engineers' models

Finally, I would like to introduce a brief discussion of models developed by lighting experts in these last years to improve the efficiency of lighting installations and to include the environmental impact of lighting. The most interesting model is the one developed by the french lighting association AFE (2006) which calculates the total luminous flux lost towards the sky, including both the direct emitted flux above the horizontal line characterized by the ULOR (Upwards flux Light Output Ratio) parameter and the reflected flux onto the aiming area to light (road, place…) and onto the surroundings areas (walls of houses emphasizing the issue of intrusive light, gardens, natural landscapes, …) characterized by their specific reflection coefficients. However, this kind of model does not consider precisely the initial direction of light, a key parameter in the physical description of the propagation and diffusion of light within an optically thin medium as our atmosphere. The new model of OSP (Outdoor Site lighting Performance) developed by Brons, Bullough et Réa (2008) has the same drawback since it calculates the total luminous flux lost towards the sky by measuring the mean illuminance at the boundaries of a fictive box corresponding to the spatial limit of the public domain without considering the precise direction of the incident light. I will demonstrate this crucial importance of the initial direction of the light emission in the following but we can already understang the key idea by thinking about the common experiment of a sunny day. At noon, the sun lighting us projects a well defined shadow of our body because the diffused light by atmospheric molecules responsible for the blue colour of sky is low. Unlike at the sunset, the sun's light crosses a larger path in the atmosphere and is highly diffused which entails much less defined shadows. This is the same for the light coming from street lightings where the light rays emitted near the horizontal will be much more diffused than the ones emitted near the vertical. This diffusion which is mainly directed forward for aerosols concentrated in the low layers of atmosphere will efficiently propagate light pollution at large distance from the light sources.

The THOTPRO model

Our light propagation model is based mainly on the formalism developed by Garstang and Cinzano including the Rayleigh and Mie diffusions in a vertically stratified atmosphere. However, I include systematically the elevation effect using topographic measurements of the SRTM[1] satellite with a ground spatial precision around 100m at our latitudes and an elevation precision around 20m, and the screening effect due to the mountains. These effects are important to take into account, particularly in mountain regions, and they can make it possible to localize areas where the night environment remains little impacted even if cities are present quite near.

Statistics released by ADEME are used to know the main characteristics of public lighting in France. We deduce that nowadays the number of street lighting per inhabitant is 0.15 and that the averaged electric power per light source is 150W. Besides, using the fact that around 60% of light sources are high pressure sodium-vapour sources, 30% are high pressure mercury-vapour and 10 % are metal-halid lamp, we deduce the averaged emitted lumen by a theoretical street lighting with a mean energetic efficiency (LOR) of 80%. Next, statistics about the French population released by INSEE but also for foreign countries are used to assess the averaged lumen output per inhabitant. We then estimate the averaged angular photometric distribution from different kind of light sources settled in the country. A very important quantity is the ULOR to know the amount of light emitted directcly above horizontal by the source. The AFE recommends ULOR < 3% for functional lighting and ULOR < 20% for ambient lighting. However, in practise, the bad installation of fixtures (probably caused by a non optimized conception) with non zero inclination of poles between 5° and 15° with respect to the horizontal, and even greater in some cases, increases very greatly the direct emitted flux lost towards the sky. Our practical experience and the use of software created by lighting people like Dialux[2] show that most of the light sources and inclinations observed entails a mean ULOR around 14%, a value used in our reference simulation.

Besides, reflection onto the ground and the surroundings is also taken into account with a diffuse reflection coefficient equal to 0.08 corresponding to the typical properties of roads in France and a specular reflection coefficient increasing towards the grazing angles similar to values adopted in the work done by Baddiley. The screening effect by buildings can also be included partially for the reflected light onto the vertical walls of buildings but the global effect in simulations remains negligible. When more information is available for some cities, they are included in the database to improve the modeling.

1- http://www2.jpl.nasa.gov/srtm/

2- http://www.dial.de/CMS/French/Articles/DIALux/Features/Features.html

Policies of reduction of lighting during night can thus be integrated to have much realistic situation for distribution of light pollution at a precise hour of the night. Results obtained from our statistical distribution of light sources (Figure 1) with an ULOR of 14% are very similar to the angular distribution of light sources used in Garstang (1989) and Cinzano (2000). In addition, ground-based measurements also validate our results. Most of light sources included in our compiled database correspond to cities but locally we can add a light source with its specific properties.

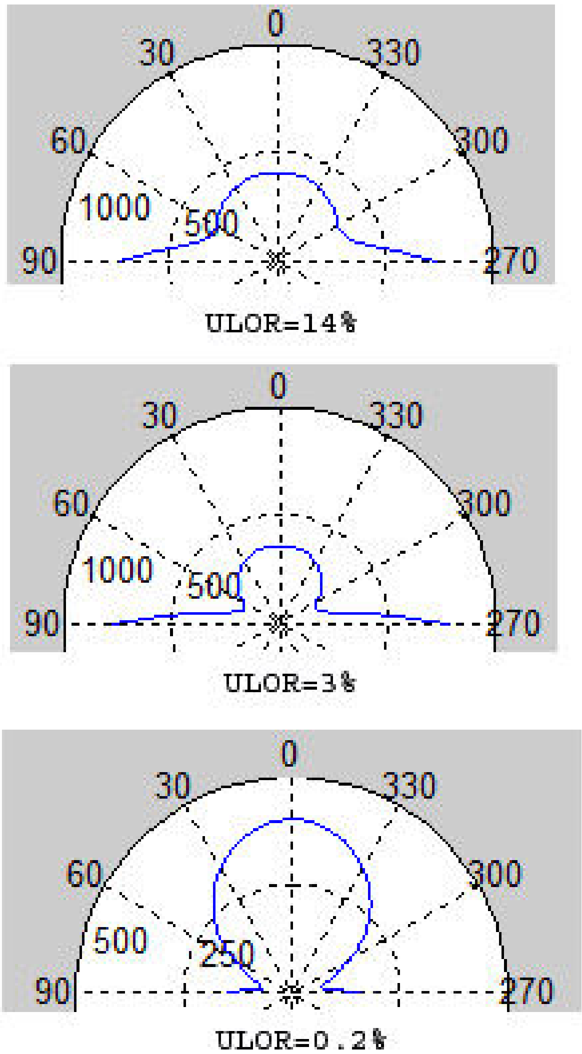

Figure 1 : Examples of angular light intensity distributions used in the THOTPRO model for a statistical set of light sources with a mean ULOR equal to 14%, 3% and 0.2% respectively. The intensity scale is arbitrary but one can notice that the contribution due to the direct light emission in the first 10° above the horizontal is far from being negligible in the case of ULOR equal to 3%.

	Light pollution index	Night sky quality	Degree on the Bortle's scale	Loss of magnitude for night sky background
	q > 32	Very bad	N > 7.5	d > 3,8
	10 < q ≤ 32	Bad	6,5 < N ≤ 7,5	2,6 < d ≤ 3,8
	4 < q ≤ 10	Poor	5,5 < N ≤ 6,5	1,75 < d ≤ 2,6
	2,5 < q ≤ 4	Medium	4,5 < N ≤ 5,5	1,35 < d ≤ 1,75
	1 < q ≤ 2,5	Correct	4,0 < N ≤ 4,5	0,75 < d ≤ 1,35
	0,5 < q ≤ 1	Good	3,5 < N ≤ 4,0	0,45 < d ≤ 0,75
	0,32 < q ≤ 0,50	Very good	3,0 < N ≤ 3,5	0,3 < d ≤ 0,45
	0,10 < q ≤ 0,32	Excellent	2,0 < N ≤ 3,0	0,1< d ≤ 0,3
	q ≤ 0,10	Pristine	N < 2	d < 0,1

Figure 2 : Color index scale used in the light pollution maps obtained with THOTPRO to indicate the increase of the articificial light luminosity with respect to the natural one averaged for all directions.

Practically, we represent our results by a color scale (Figure 2) corresponding to the ratio q between the brightness of the sky polluted by artificial lighting averaged for all azimuts at a zenital distance equal to 45°, and the natural one considered at the minimum of the solar activity cycle and equal to $1,75.10^{-4}$ cd/m^2 i.e. 22 magnitude per square arcsecond for the zenith sky brightness in the V photometric band in astronomy. The different levels of this scale were chosen to correspond approximately to the Bortle's scale well known by amateur astronomers to quantify by naked eye the night sky quality and particularly the level of light pollution. The most polluted skies are in brown-red-orange-yellow with a sky brightness greater than a factor 32-10-4 and 2,5 respectively with respect to the natural brightness. An example of a damaged night environment is shown in Figure 3. The night sky becomes again pleasant when the artificial component of the night sky brightness is near 100% of the natural brightness, corresponding to the green level of this scale and illustrated in Figure 4. Nowadays, there are still few studies about the impact of light pollution on the night environment and ecosystems but recent work on Anoures batracians by Deslandres (2007) for instance show that this impact becomes to diminish significantly from this level of light pollution. Finally, colors from clear blue to dark blue correspond to skies less and less polluted until this pollution becomes negligible for areas in grey/white, the artificial lighting then contributing only for a maximum of 10% to the total night sky brightness at 45° from the horizon, even if some diffuse sky glow can still appear in the first degrees above the horizon.

Figure 3 : Photography taken from an hill at 3.5 km at South-West of Chambery corresponding to the orange level of our scale of light pollution where the milky-way is nearly not visible except some nights where it remains barely visible only near zenith.

Figure 4 : Photography taken at 8 km at the South-West of Chambery corresponding to the green level of our scale where the summer milky-way in Saggitarius is well visible till 15° above the southern horizon. However, we can notice the sky glow caused by the Grenoble area which is located at 38 km from this site and which is well present till a height of 15°.

It is also important to notice that the increase of the sky artificial brightness given for each level is an average in azimuth. Even if an increase of only 10 % seems already to be low at 45° of height, this can be correspond practically to a real increase of 50% in a specific direction towards a big city with an obstruction of 40° in azimuth damaging really the night environment in this direction and an increase of only 5% in average in the other directions.

The results of simulations with THOTPRO

The current situation of light pollution in Savoie, a county in the South-East of France

The reference simulation presented in Figure 5 show the level of light pollution in Savoie for an atmosphere with a very good transparency (visibility around 50 km).

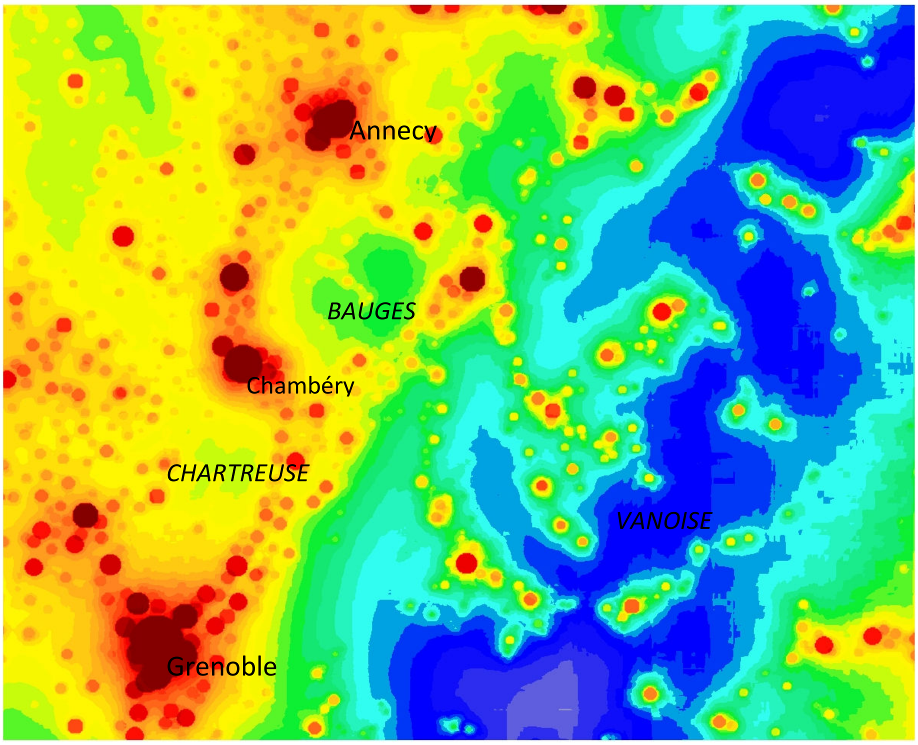

Figure 5 : Map for lightings with an ULOR equal to 14% and an averaged electric power of 150W per light source equivalent to a luminous flux of 15klm for a high pressure sodium vapour technology and a standard atmosphere with a visibility around 50 km.

We notice obviously that the level of light pollution is maximal in big cities such as Chambery, Grenoble or Annecy and that this pollution is not confined at the cities boundaries but that it is propagated on large distances of tens of kilometers around them, which produces damages in the Chartreuse and Bauges regional natural parks even they are low densities of population in these areas. However, the night sky quality remains quite good in these latter areas thanks to both elevation and screening by mountains effects. The central area of the Vanoise national park keeps a very good night sky whereas the peripheric area is damaged due to over-lighting of skiing resorts and to the use of old-style lightings often weak efficient with ULOR > 20%. For a systematic study of light pollution in national and regional parks in France, the reader can consult a previous study done by Deslandres (2006).

Light pollution is not caused by atmospheric pollution

Look at now the effect on light pollution of a perfect atmosphere with an aerosol-free content where light can propagate on hundreds of kilometers without being diffused. The corresponding simulation is presented in Figure 6. We can notice that, although light pollution is somewhere slightly diminished, we do not find locations not damaged by this pollution even far from cities. Thus, we demonstrate here that the luminous nuisances, as some people prefer to speak about, are always present even in absence of atmospheric pollution and this is true either in urban areas or in rural areas. Therefore, this pollution is really caused by non optimized practices in public lighting. We can particularly notice that light pollution is even slightly greater in very remote locations as the central area of Vanoise because the extinction effect during the propagation of light is weaker for an aerosol-free content of atmosphere. Atmospheric pollution can thus only be a worsening parameter locally inside and near the cities (< 14km) because the increase of the aerosol content finishes to increase the extinction of light at large distances.

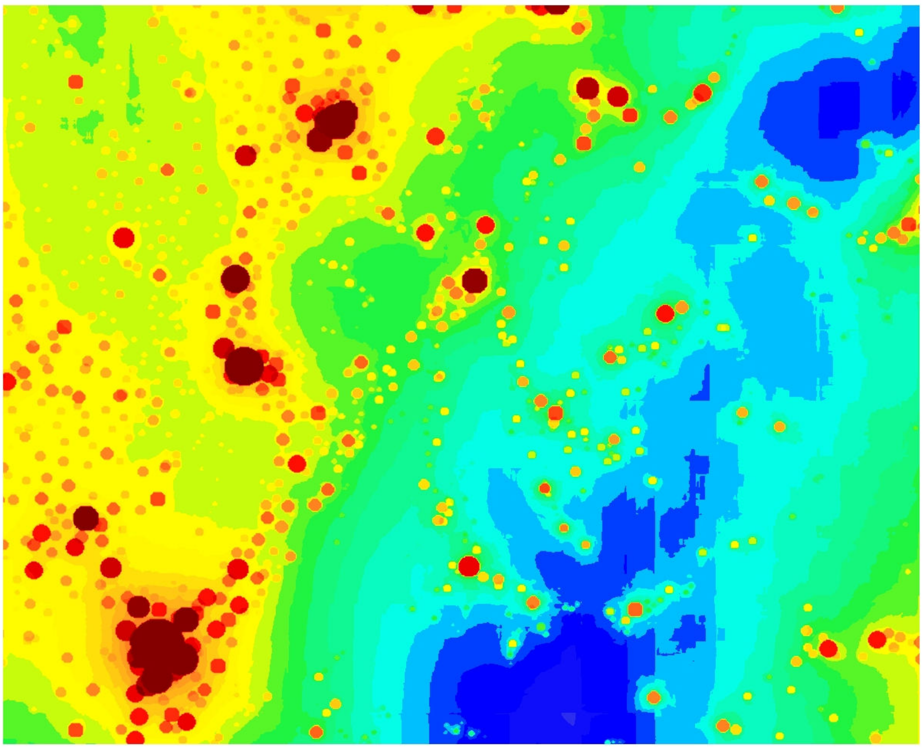

Figure 6 : Map for lightings with an ULOR equal to 14% and an averaged electric power of 150W per light source corresponding to a luminous flux of 15 klm for high pressure sodium sources with a perfect aerosol-free atmosphere.

A prescription on ULOR< 3% for lightings is not sufficient

We can now look at the effect of an optimization of lightings in public lighting considering as a typical case the generalization of the prescription on ULOR<3% of AFE for all lightings and keeping an averaged electric power of 150W for each of them. This policy particularly demands all the lightings to be settled with a minimal inclination of poles (< 10°) and to remove all the decorative lightings such as bowl diffusers. The result of such a policy is really weak as the result of the simulation indicates (Figure 7) and thus this kind of measures is un-efficient to control light pollution. Other simulations done with a continuous diminution of this parameter ULOR show a constant improvement on the limitation of light pollution.

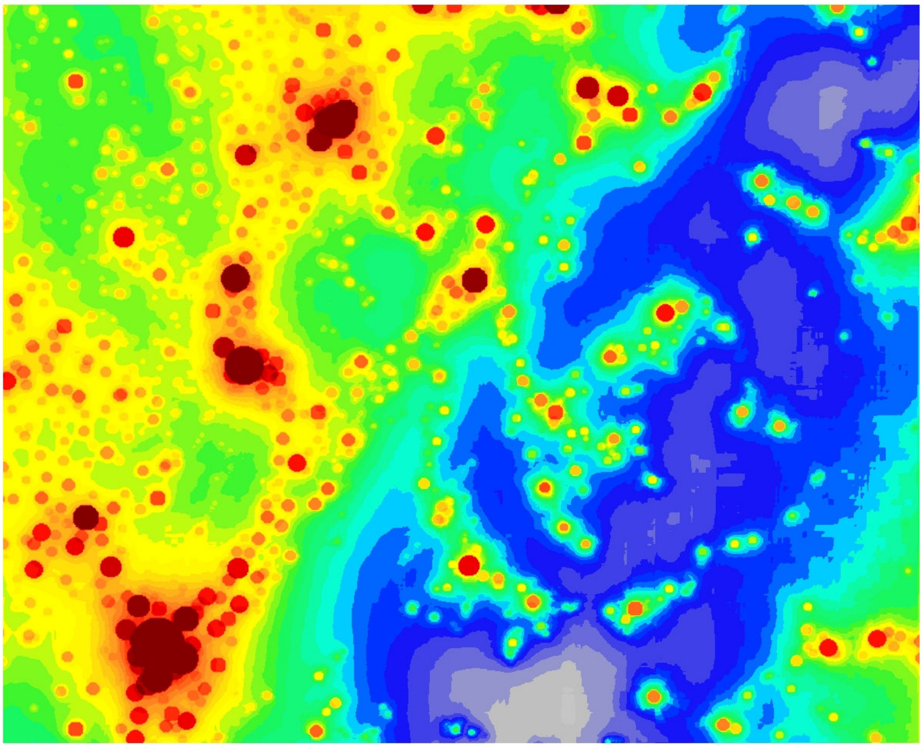

Figure 7 : Map for lightings with an ULOR equal to 3% and an averaged electric power of 150W per light source.

The use of full cut-off lightings is necessary and needs to be generalized

Let us study now the case where only lightings without direct emission above horizontal are allowed, i.e. with an ULOR strictly null while keeping the same averaged electric power equal to 150W. This is the case of full cut-off lightings. In this case, only the reflected part of the luminous flux by the ground goes towards the sky mainly for angles above 45°. The resulting simulation then show a really decrease of light pollution (Figure 8) as soon as one goes few kilometers from city centers. But light pollution remains very important in the inner cities. We must underline here that the modelling inside cities is not enough accurate in our case because it would need to account for the real spatial distribution of lightings whereas our treatment consider an isotropic distribution for each city.

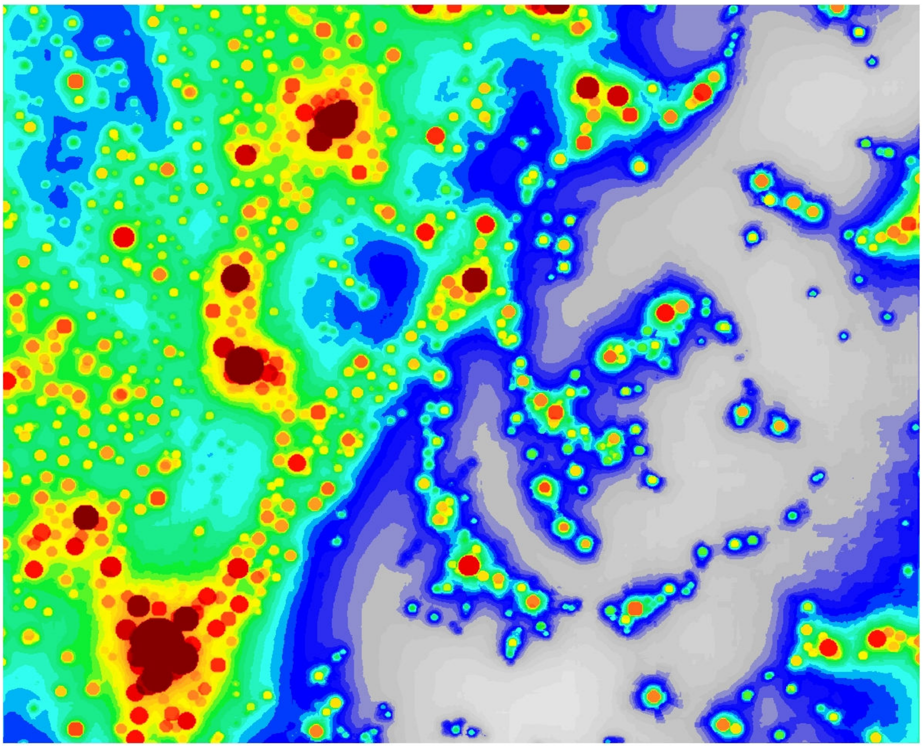

Figure 8 : Map for lightings with a null ULOR corresponding to full-cut-off lightings and with an averaged electric power of 150W per light source.

This kind of result is similar to Soardo (2008) although it is in total contradiction with the initial subject of his study. In fact, Soardo considers that it is useless to use full cut-off lightings in order to limit light pollution because all the light emission coming from any kind of lighting can be modelled by a lambertian source due to the screening effect by the surrounding buildings, with a luminous flux given by the sum of the ULOR and the contribution of the reflected light. But actually the true light intensity emitted by a light source is betrayed by the un-correct hypothesis of a « diffuse » equivalent source. On the contrary, this treatment consists eventually in modeling a full cut-off source with a ground having a diffuse reflection ! Actually, the screening effect by buildings for the direct light emitted above horizontal can be only efficient in crowdy inner city centers with narrow streets and big buildings, which represents a very little part of lightings in a city. For instance, when we go up on a hill near a big city, we observe the direct flux emitted by many lightings (see Figure 3) and anyway the direct emitted flux in a direction parallel to the road can not be stopped efficiently. With this simulation, we can see that all the light rays coming from a lighting have not the same weight as far as the generation of light pollution is concerned. If it is true that the reflected flux dominates in intensity (until 7% of the total luminous flux emitted by a lighting in functional lighting in practice with classical R2 type road pavements) the total potential lost flux towards the sky called UPF in the AFE calculations, this contribution remains localized and the main part of this flux is sent into space (except in overcast conditions) whereas the flux directly emitted just above horizontal, even it corresponds only to 3% of the total luminous flux of a fixture, can propagate in the low layer of atmosphere on large distances.

More precisely, the contribution of the reflected flux on a lambertian road with a reflection coefficient of 0 .08 between 0 and 15° of height where it can take part in efficiently to light pollution at large distance (> 14km) is less than 0.6% of the total luminous flux of a fixture, in the worst case where the screening by vegetation and buildings is not efficient. We can thus see that if an ULOR of only 1% or 3% is allowed, light pollution will be increased at least respectively by 266% or 600% at large distance from this source for these considered directions with respect to a full cut-off fixture where ULOR=0. The damage on night environment being significative when the artificial sky brightness reaches 10% of the natural component, and considering the upper limit of 0.6% due to the optimal lighted surface in the case light is need, we derive that ULOR < 0.06% is a necessary condition to limit efficiently light pollution at large distance from a source. This strict restriction can be compared to the maximal light intensity of 0,49 cd/klm allowed by the Italian law in Lombardy for instance.

The conclusion of this simulation is thus that the use of full cut-off fixtures have to be generalized contrary to misleading ideas given by some lighting experts, and they have to be settled with a zero inclination with respect to the horizontal line in most situations since even these kind of lightings have a luminous flux which increases very quickly below horizontal. For even better built full cut-off fixtures, it will be possible to incline them for some degrees if the photometric diagram is compatible with ULOR=0 in that configuration. Finally, we want to emphasize that such a fixture, which always has a flat glass or an efficient paralume stopping all light above horizontal, makes it possible most of the time to increase the spacing between lightings for a given luminance contrary to some false ideas. In a next paper, we will show different situations where the ratio between the spacing and the poles height can overpass easily the value of three which remains the rule in many lighting installations while keeping a lighting uniformity in agreement with the EN13201 european norm. We give a striking example of what we say in the annex of this article using the DIALUX software of public lighting.

A derogation with a possible value till 20% for the ULOR in city centers could be taken if the minimal height of vertical walls of buildings is greater that the sum of the pole height where the lighting is settled and the horizontal distance between the lighting and the buildings' walls for each azimutal direction around the light source. Thus, this measure will limit direct emission of light below 45° of height which produces mainly light pollution at large distance. However, this kind of lighting needs also to prevent intrusive light from entering the private area of each inhabitant, which is particularly difficult to obtain without full cut-off lightings.

A limitation of light levels to light correctly

Finally, let us interest in a global reduction of the light power used in public lighting while keeping their full cut-off property. Such a policy can particularly be justified by a general over-lighting of streets in France. An averaged illumination not greater than 10 lux should be the norm in the main cases which is already similar to the illumination of 40 full moons.

This diminution of the lighting levels is based on common sense and is different from some averaged luminance and illumination levels favoured by EN13201 norm. The averaged luminance should be particularly limited to 1 cd/m^2 but without going below 0.3 cd/m^2 for the traffic roads. Actually, most of the light levels exceeding this threshold is due to the too luminous surroundings of the area to properly light in cities and is the consequence of practises of over-lighting in the last decades. Most of the lighting can be obtained by using high pressure sodium vapour lamps with a power of 50W and 70W coupled with electronic ballasts ensuring a high energetic efficiency while maximizing the utilization factor of each fixture. This is the practice favoured by ANPCEN which proposes to fix an upper limit to the linear light power as already done in Switzerland, and this is coherent with European labels such as « Cities of energy » and EEA (European Energy Award). Besides, the lighting of roads outside cities is very often not understanding since cars have their own lighting system and the use of reflective passive signalisation is really the perfect solution in this situation on many points of view such as economy, security and ecology.

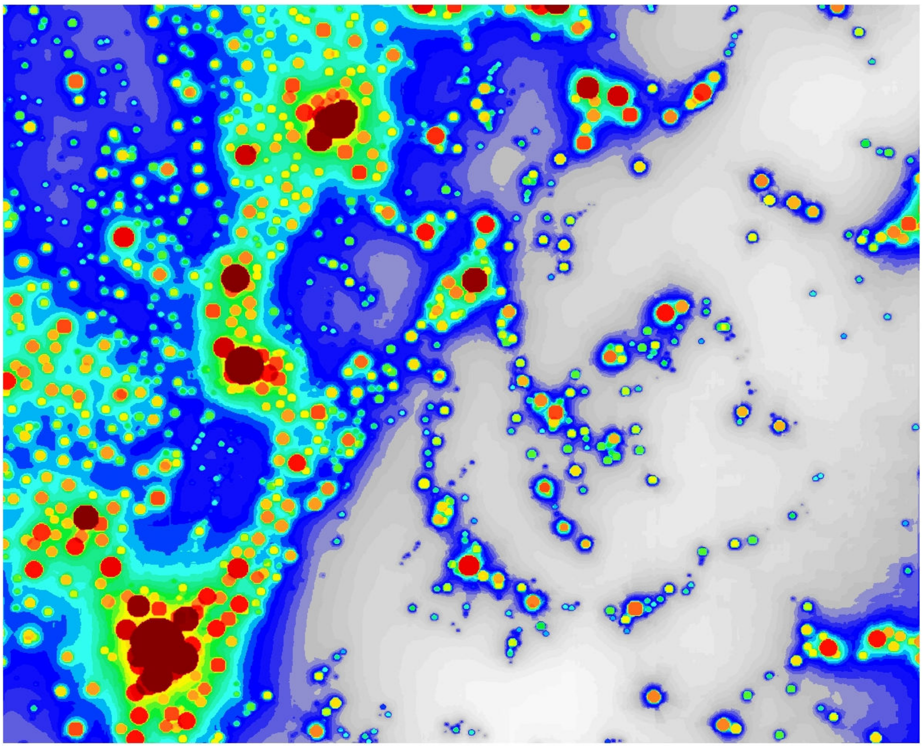

Figure 9 : Map for lightings with ULOR=0 and a reduces electric power to 70W.

The last simulation presented follows this trend by considering full cut-off lightings with a reduced averaged electric power to 70W. We then obtain a very reduced light pollution (see Figure 9) which is in striking contrast with the current situation of figure 5. The sky and night environment become again very good as soon as we go out city centers while keeping an efficient public lighting system based on the simple idea to light where and when it is needed with the suitable level.

Conclusion

In this article, we demonstrate, from a modelling of light pollution the most realistic as possible, that the main policy necessary and sufficient to limit it and its impact on night environment is to develop the use of full cut-off lightings where no light is emitted directly above horizontal in the conditions of use in public lighting. We also show that a global reduction of the averaged light power from 150W to 70W is very interesting and really possible with the high pressure sodium technology. We already precise that the use of white light sources as metal-halide or LED are much more harmful for the night environment and needs to be ruled with lighting levels lowered to take into account the greater light diffusion in short wavelengths and to be reserved for city centers (see the next article of Alain Legue).

The research of a maximal photometric efficiency by cancelling the direct luminous flux emitted above horizontal and by lighting with the correct level remains the solution to favour in order to optimize the public lighting and thus minimized its impact on night environment.

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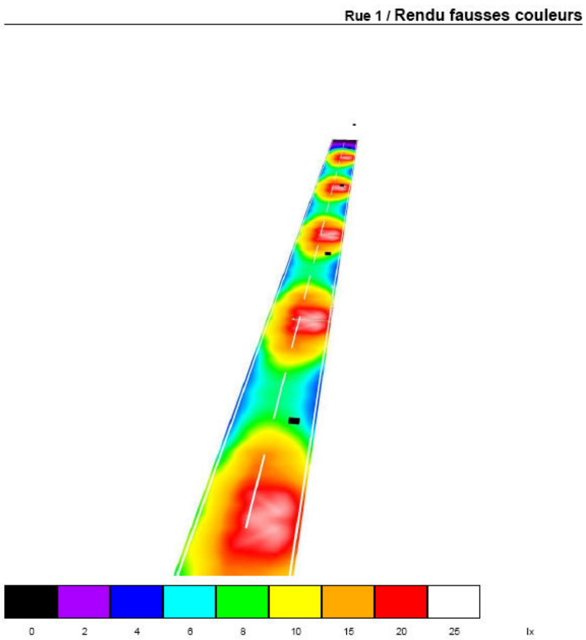
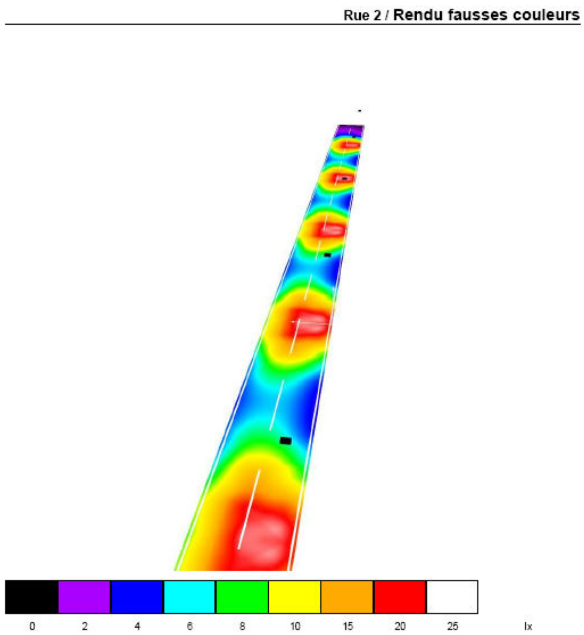
Annex : Comparison with Dialux of two lighting installations with a full cut-off fixture and the same fixture with a curved glass lens

To argue on the fact that Full Cut-Off (FCO) lightings do not imply lower spacing than other kind of lightings and that unlike they allow the best photometric performances emitting no light above horizontale in the same conditions of use, I present here this study I carried out with Dialux for the street lightings iridium of Philips with a 70W HPS lamp.

There is the full cut-off case (rue 1) with a flat glass lens compared to the curved glass lens (rue 2). In these two cases, the lighting sources are settled at 7.5 m of height and the spacing between them is 32,4m i.e a ratio spacing/pole height ~4.3 well greater than 3 and without inclination in order not to have direct emission of light above horizontal in the FCO case with ULOR=0% and to minimize it in the other case with ULOR=0,51%. The aimed photometric characteristics corresponds to a county road crossing a village for instance with an averaged luminance of 0.75 cd/m^2.

We can see that only the FCO manage to obtain this level of luminance and that the overall light uniformity is better (see the 3D picture below) with an averaged illuminance of 11 lux at the ground level while minimizing also the glare (TI). The lighting wit a curved glass lens actually needs a lower spacing or a lamp with a greater light power entailing then over-lighting to respect the luminance level for this kind of road. By this example, we thus demonstrate that FCO lightings are winner from all points of view (economy, ecology, photometry). One must notice here that the lightings used here have ferromagnetic ballasts and that the use of electronic ballasts will improve the energetic yields. It is necessary to maintain the lighting horizontally because for an inclination of 5°, we already have ULOR=0,03%.





Editeur (trice)
Téléphone
Fax
Email

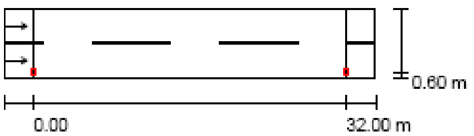
Rue 1 / Données de planification

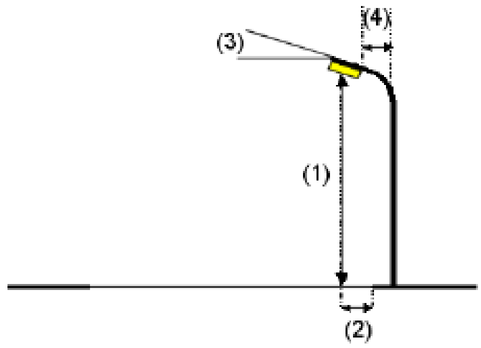
Profil de la rue

Chaussée 2 (Largeur: 7.000 m, Nombre de voies: 2, Revêtement: R2, q0: 0.070)

Facteur d'entretien: 0.85

Disposition des luminaires





Luminaire:	Philips IRIDIUM 9 SGS252 FGD 1xSON-TPP70W CON CR P5X
Flux lumineux de(s) lampe(s):	6600 lm
Puissance par luminaire:	81.0 W
Disposition:	d'un côté, en bas
Espacement poteau:	32.000 m
Hauteur de montage (1):	7.855 m
Hauteur du point d'éclairage:	7.600 m
Saillie (2):	0.600 m
Inclinaison du bras (3):	0.0 °
Longueur du bras (4):	1.000 m

Valeurs maximales de l'intensité lumineuse

pour 70°:	413 cd/klm
pour 80°:	15 cd/klm
pour 90°:	0.00 cd/klm

Dans chacune des directions qui, pour les luminaires installés et utilisables, forment avec la verticale inférieure l'angle indiqué.

Pas d'intensité lumineuse au-dessus de 90°.

La disposition répond à la classe d'intensité lumineuse G4.

La disposition répond à la classe d'indice d'éblouissement D.6.

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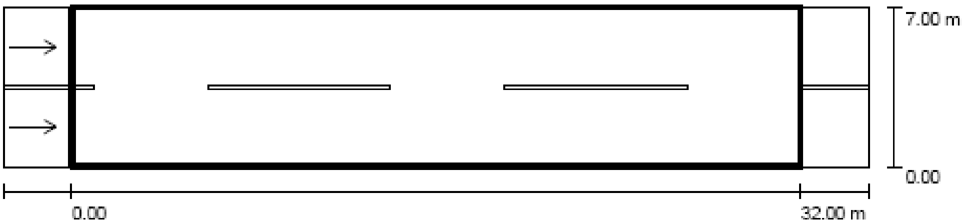
Rue 1 / Champ d'évaluation Chaussée 2 / Aperçu des résultats



Facteur d'entretien: 0.85

Echelle 1:272

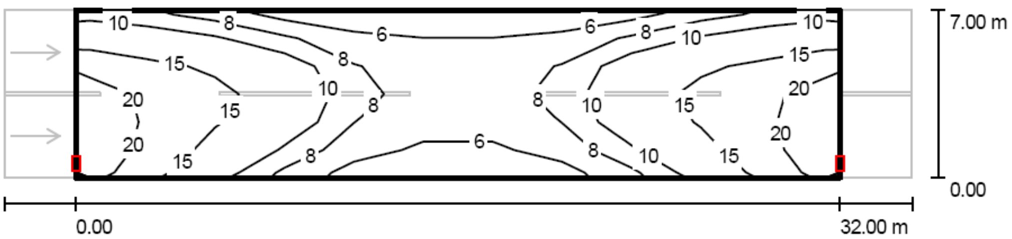
Trame: 11 x 6 Points
Eléments de rue correspondants: Chaussée 2.
Revêtement: R2, q0: 0.070
Classe d'éclairage choisie: ME4a (Toutes les exigences photométriques sont remplies.)

	L_{moy} [cd/m²]	U0	Ul	TI [%]	SR
Valeur effective selon calcul:	0.75	0.5	0.6	11	0.5
Valeurs de consigne selon la classe:	≥ 0.75	≥ 0.4	≥ 0.6	≤ 15	≥ 0.5
Rempli/Non rempli:	✓	✓	✓	✓	✓

Observateurs correspondants (2 qté.):

N°	Observateur	Position [m]	L_{moy} [cd/m²]	U0	Ul	TI [%]
1	Observateur 3	(-60.000, 1.750, 1.500)	0.75	0.5	0.6	11
2	Observateur 4	(-60.000, 5.250, 1.500)	0.78	0.5	0.7	7

Rue 1 / Champ d'évaluation Chaussée 2 / Courbes isolux (E)



Valeurs en Lux, Echelle 1 : 272

Trame: 11 x 6 Points

E_{moy} [lx]	E_{min} [lx]	E_{max} [lx]	E_{min} / E_{moy}	E_{min} / E_{max}
11	4.96	23	0.434	0.214

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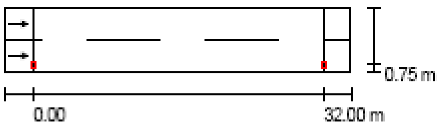
Rue 2 / Données de planification

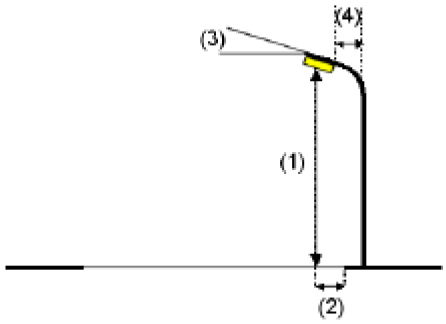
Profil de la rue

Chaussée 1 (Largeur: 7.000 m, Nombre de voies: 2, Revêtement: R2, q0: 0.070)

Facteur d'entretien: 0.85

Disposition des luminaires





Luminaire:	Philips IRIDIUM 9 SGS252 PC 1xSON-TPP70W CON CR P5X
Flux lumineux de(s) lampe(s):	6600 lm
Puissance par luminaire:	81.0 W
Disposition:	d'un côté, en bas
Espacement poteau:	32.000 m
Hauteur de montage (1):	7.863 m
Hauteur du point d'éclairage:	7.600 m
Saillie (2):	0.750 m
Inclinaison du bras (3):	0.0 °
Longueur du bras (4):	1.000 m

Valeurs maximales de l'intensité lumineuse

pour 70°:	476 cd/klm
pour 80°:	40 cd/klm
pour 90°:	4.60 cd/klm

Dans chacune des directions qui, pour les luminaires installés et utilisables, forment avec la verticale inférieure l'angle indiqué.

La disposition répond à la classe d'intensité lumineuse G3.

La disposition répond à la classe d'indice d'éblouissement D.6.

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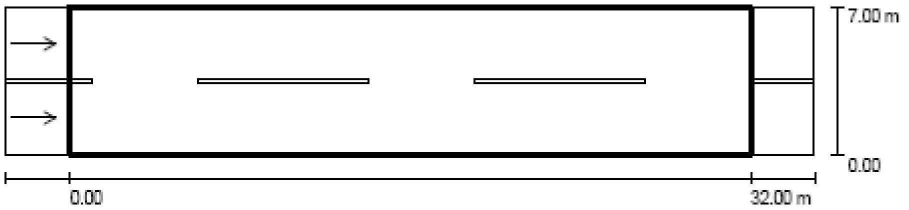
Rue 2 / Champ d'évaluation Chaussée 1 / Aperçu des résultats



Facteur d'entretien: 0.85 Echelle 1:272

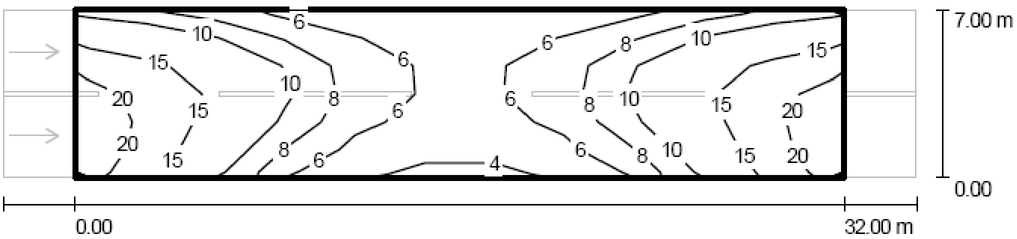
Trame: 11 x 6 Points
Eléments de rue correspondants: Chaussée 1.
Revêtement: R2, q0: 0.070
Classe d'éclairage choisie: ME4a (Toutes les exigences photométriques ne sont pas remplies.)

	L_{moy} [cd/m²]	U0	Ul	TI [%]	SR
Valeur effective selon calcul:	0.73	0.5	0.7	13	0.5
Valeurs de consigne selon la classe:	≥ 0.75	≥ 0.4	≥ 0.6	≤ 15	≥ 0.5
Rempli/Non rempli:	✗	✓	✓	✓	✓

Observateurs correspondants (2 qté.):

N°	Observateur	Position [m]	L_{moy} [cd/m²]	U0	Ul	TI [%]
1	Observateur 1	(-60.000, 1.750, 1.500)	0.73	0.5	0.7	13
2	Observateur 2	(-60.000, 5.250, 1.500)	0.76	0.5	0.8	10

Rue 2 / Champ d'évaluation Chaussée 1 / Courbes isolux (E)



Valeurs en Lux, Echelle 1 : 272

Trame: 11 x 6 Points

E_{moy} [lx]	E_{min} [lx]	E_{max} [lx]	E_{min} / E_{moy}	E_{min} / E_{max}
10	3.87	23	0.370	0.169