

Technical measures for an effective limitation of the effects of light pollution

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Abstract: The technical prescriptions required for an effective limitation of the effects of light pollution are recognized based on the processes playing a role in the production of the artificial night sky brightness. In particular, the significance and the effect of the limits to the upward fraction of the light flux are discussed. A general limitation of the upward flux does not appear effective and the direction of the emitted light must be taken into account too. A comparison between the intensity of a sample of roads in the direction in which this light is more polluting and the restrictions to the intensity of the luminaires in the same directions enforced by some laws or bills, allows us to evaluate their effectiveness.

Legislative choices

Even neglecting the many and well documented effects of light pollution on the environment (two international scientific conferences on the effects of the artificial light on plants, animals and humans have been held in 2002 [1][2] and an incomplete bibliography collects more than 140 papers [3]) and limiting us only to consider the effects on the night sky visibility, the resulting picture is particularly worrisome. A look to the contributions presented in this book is sufficient to recognize it. From those impressive data it clearly appears that a legislative effort is indispensable in order to direct the progress and the development of the nighttime outdoor lighting in a virtuous way of respect of the environment and energy saving, which so far was not adequately undertaken. This legislative effort must be able to promote a change in the lighting habits and is demanded with the maximum urgency because light pollution grows in an exponential way, with growth rates that in Italy reach even the 7%-10% per year (e.g. [6]).

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What could be done? The more natural and effective solution, that to shut off all the lights, is obviously not practicable in the modern world where nighttime outdoor lighting is a social necessity. The second solution, in a hypothetical scale of decreasing effectiveness, would be that we renounce to install any new lighting system. This would not eliminate light pollution but at least would carry to zero its high yearly growth rate. This solution would not create the dark and it is seen positively from some peoples, however it could be conflicting with the development requirements of an advanced industrial country like ours. The third solution, proposed from more parties, is to allow the increase of nighttime lighting but placing, at the same time, a top limit to the yearly growth rates of the outdoor light flux installed in any town and to the yearly growth rates of the electric power consumptions for external lighting. As the top limit to the sanitary expense, applied in Italy, was not intended to kill sick persons but rather to rationalize the sanitary expense, these top limits would favour not the dark but a more rationalized lighting, the use of more efficient fixtures, the design of installations with larger utilization coefficients and the use of lamps with larger efficiencies. Of course, these provisions would have to be joined by provisions avoiding that the light flux within the top is wasted upward. In the United States a slightly different way is followed and some bills limit directly the installed light flux for square acre.

The regional bills approved in Italy, like e.g. the law n.17 of 27 March 2000 of the Lombardy Region that is considered the best law against the light pollution currently in force in Italy, have chosen to undertake a road still more soft, perhaps even too much soft. They have chosen to not place any limit to the installation of lighting systems. Everyone is free to illuminate whatever he wants. Naturally, if a so wide freedom is wanted but at the same time a law reasonably effective in limiting light pollution is wanted too, at least it must be required to follow, when making the lighting system, some fundamental rules and that they should not be leaved apart. If it is attempted to leave further freedom even on the rules, the result is an ineffective law. In this case, it would be better not to pass the law because it end up legalizing light pollution.

Territorial area where provisions must be applied

Between the indispensable, typical points of the more modern laws against light pollution, that we appreciate e.g. in the laws of Lombardy, Marche, Veneto and Tuscany, there is the fact that the provisions concerning the new systems are applied in the same way to the entire regional territory. The application of serious provisions to the entire territory protects in effective way the perception of the Universe of all the citizens, avoiding to create discriminations between citizens more or less privileged because living more or less close to a protected zone. Not only, but it also guarantees the effective protection of the most

sensitive sites, like astronomical observatories and natural parks. In fact, the mechanism for which the upward light flux propagates in the atmosphere going to illuminate molecules and particles along the line of sight of an observer (which scatter such light creating a luminous background that prevents or disturbs the perception of the stars) is characterized from the fact that the light propagates even to 200 km from the source. In practice, only the Earth curvature constitutes in clean nights an effective screen. Therefore today the adoption of the old scheme of protection, called "onion-like", for which a series of "protection zones" were created one within the other with provisions gradually tightening approaching the site to be protected (like e.g. in the criticized Italian standard rule UNI-10819), does not have any basis, unless zones with radii of the order of hundreds of kilometres are adopted.

In this panorama which is then the function of the "areas of more elevated sensitivity"? In the modern laws against light pollution, the "areas of more elevated sensitivity" are not introduced in order to apply more severe prescriptions than in the rest of the territory, what, as we have seen, would be useless when they have radii of the order of some tenth of kilometres. They are instead introduced for the adaptation of the existing systems that in such areas takes greater priority and commitment. In some case a more demanding use of the curfew is prescript in such zones too. The tendency seems to eliminate the areas of protection from the forecoming Bills replacing them with an adaptation extended to the entire regional territory in successive steps.

Criteria to adopt

Let's examine the provisions to be adopted in an effective legislation against light pollution. I will comment only the two main points. The basis of a truly effective protection is the minimization of the direct light emissions over the horizon from the luminaires and the limitation to the minimum necessary of the light emissions reflected from the lighted surfaces, avoiding overlighting and containing at best the light wasted outside of the areas to be illuminated.

a) limits to the direct emission

As far as the first point is concerned, if a law is wanted to be made effective, it is fundamental and indispensable the limit of 0 cd/klm at 90 degrees² and beyond to the intensity of the light emission. This limit must be applied to both the private and public lighting systems. I will spend therefore some word in

² This angle, called gamma angle in lighting engineering, is measured starting from the vertical line passing for the luminaire toward the bottom, so that gamma is 90 degrees in a plane parallel to the horizon and 180 degrees at the zenith of the luminaire.

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order to clarify some reasons of its importance and the difference with other provisions.

The Italian standard rule UNI-10819 (Prescriptions for the limitation of the upward dispersion of the luminous flux) limits a quantity integrated on all the upper hemisphere, the upward flux ratio. It ignores that the mechanism of propagation of light pollution depends on the emission direction and therefore neglects to put a greater care to that part of the flux mainly responsible of the propagation and the addition of the light pollution on the territory. In fact, one thing is the percentage of light flux emitted upward from the luminaires as compared to the total flux emitted from them, and another thing is the percent increment of the light pollution produced from them (fully eliminable) as compared to that produced from the lighted surfaces (unavoidable when reduced to the minimum necessary). The second one is the more interesting to the purpose of the limitation of light pollution.

Let's see what the first percentage means in terms of the second one. Let's consider e.g. the smaller of the limits to the percentage of upward light flux appearing in the standard rule UNI-10819, which is the same limit applied in the entire regional territory by the law of Veneto: 3% of the total light flux emitted from the light centre (this quantity is frequently called ULR or UFR). Since unfortunately the efficiency of the lighting process is very small, the illuminated surfaces reflect upward a very small fraction of the light emitted from the luminaires. This fraction depends on the utilization coefficient of the system and on how this is designed. Typically, an Italian street surface (dark asphalt CIE CII) reflects less than 10% of the light flux emitted from the luminaires. If, for every 100 lumen emitted from a luminaire, the illuminated surface reflects upward 10 lumen and if we allow that the luminaire send directly in the sky another 3 lumen, the total upward light flux will be 13 lumen. Therefore, we increased of 30% the upward light flux! (In practice, an accurate computation shows that frequently it is much greater).

Using fully shielded fixtures, on the contrary, the only upward flux is the one reflected from the lighted surfaces that, if the system is designed accurately, can be even smaller than that produced from a not shielded system for the same luminance, contrary to what sometimes is claimed.

Therefore the limit of 10% to the upward flux, appearing e.g. in the standard rule UNI-10819, means to allow a 100% more upward light flux (i.e. doubling it) respect to a fully shielded system. The limit of 23%, that appears again in the Italian standard rule UNI-10819, means to allow 230% more upward light flux (an accurate computation shows that it is still greater). Even a limit of 1% means to allow that luminaires add 10% more upward light flux to the unavoidable light flux produced from the illuminated surfaces.

At this point, someone could think that a 5% - 10% of upward light flux by

the luminaries added to the unavoidable flux due to the reflection of the road pavements is acceptable and therefore that a limit of 0,5% - 1% to the percentage of upward light flux from the luminaires can be reasonable. Unfortunately, it is not true because a second aspect enters in game.

The distribution of the light intensity (emission diagram) of the fixtures and that one of the surfaces are much different. Luminaires emitting an upward light flux less than 5% of the total emitted flux, usually, due to they construction emit this light to small elevation angles, just over the plane of the horizon (Fig. 1, left). On the contrary, surfaces typically have an intensity distribution, called almost-Lambertian, with small intensity at small angles and large intensities towards the zenith (Fig. 1, right). Therefore the light emitted at small angles over the horizon is produced mainly from the luminaires. Why the light emitted at small angles interests us? Because for geometric reasons, easy to understand (see e.g. Fig. 2), the emission at small angles propagates very far away whereas the light emitted to large angles tends to pollute only the nearby atmosphere. The first illuminates atmospheric particles even very far from the source, adding to

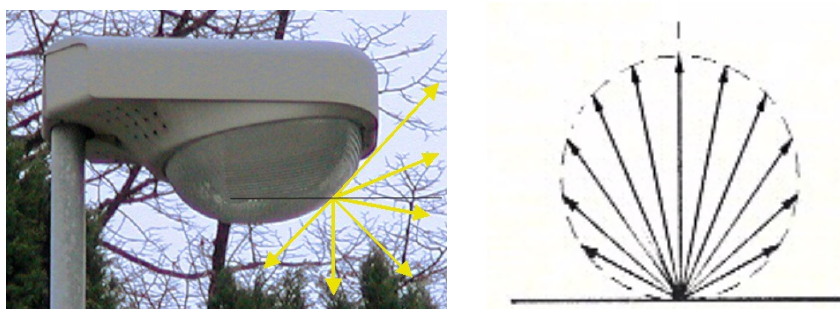


Figure 1. (left) Prismatic glass fixture: large emission at small angles; (right) Surface: small intensity at small angles.

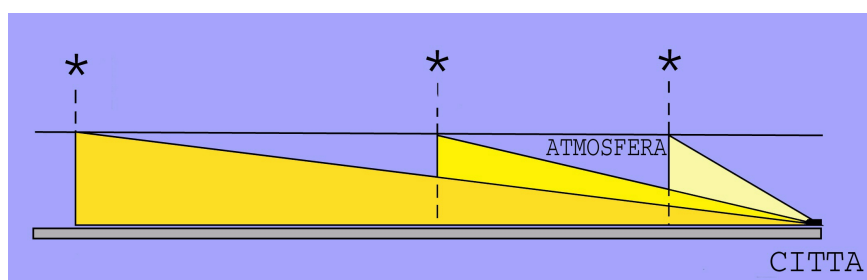


Figure 2. Emission angles of the light illuminating molecules and particles along the line of sight of an observer looking at a star near the zenith from a site quite far from the source (“città” means “city”).

the other light coming from other far sources and creating an addition effect very efficient in producing important levels of artificial brightness of the night sky. The second one, on the contrary, illuminates over the source and does not propagates nor add up too much.

As an example, it is estimated that at only 20 km from a light source the 95% of the zenith night sky brightness is due to the light emitted to small angles over the horizon (between zero and 45 degrees over the horizon i.e. between 90 and 135 degrees of gamma angle [7]). Since light pollution propagates freely beyond 200 km of distance, being practically only the Earth curvature to efficiently screen it [8], in a great part of the territory the artificial night sky brightness is produced mostly by the sum of the effects of "far" sources emitting at small angles. It is even estimated that even in areas inside a city as Padua (300000 inhabitants) 20% of the zenith sky brightness in clear nights is produced by the light of sources situated in the rest of the territory [9]. The process of propagation and addition is particularly efficient for nations with densely populated areas like Italy. Inside a radius of 150 km from a site at the edges of the Veneto plane more than 1800 towns can be counted, everyone with hundreds or thousands of luminaires.

A precise calculation based on a light design software [10] shows e.g. that in road lighting using fixtures with a percentage of upward light flux of 2% (small in comparison with the limits in the Italian standard rule UNI-10819 and in the law LR 22/1997 of Veneto) the light flux emitted to small angles and scattered from the atmosphere (the most effective in altering the night brightness) increases of 212% compared to that produced from the reflection of the road pavement alone. To this joins the part due to the reflection of the light wasted outside from the street surface. However, if the system is properly designed, this is much smaller and does not exceed that reflected from the road.

Using fully shielded fixtures, the only upward flux is the one reflected from the lighted surfaces that, if the system is designed accurately, could be even smaller of that produced from a not shielded system for the same luminance.

In order to try to support the standard rule UNI-10819, someone claims a presumed effect of shielding from the walls of the buildings near the road on the light emitted from the luminaires, but in practice it is poorly effective and only in particular cases that constitute a minimal part of the existing lighting systems. It can be easily noticed that, even in the central areas of cities and towns, there are wide open spaces and even the narrow roads encircled from a continuum sequence of buildings are properly shielded only transversely and not longitudinally. So there is no possibility to consider urban decore lighting (lanterns, globes and similar decoration fixtures) separately from road lighting.

Resuming, the direct upward light flux from the luminaires even when it seem negligible in respect to that emitted from the lighted surfaces, actually

constitutes a fundamental part of the polluting flux at a distance of few kilometres from the sources. In order to reduce the effect of this flux on the night sky there is no other solution that minimizing as much as possible the direct upward light emission of the fixtures.

The limit of 0 cd/klm at 90 degrees and beyond, prescribed e.g. in the law 17/2000 of Lombardy, indicates that the measured value must be expressed as an integer (e.g. if we measure 0,4 cd/klm we can approximate to zero, if we measure 0,6 cd/klm we must approximate to 1 cd/klm, as explained in the Regulations). Therefore, the instrument must have a minimum sensitivity of 0.5 cd/klm. This limit turns out to be adequate and there are laboratories which execute such measurements. We can verify that such limit is adequate by calculating the intensity of the light emitted from the road for unit of light flux emitted from the lamps of the system. We considered a sample of 21 street installations of very common type, obtained with various kinds of design, various average maintained luminances, semi-cut-off road fixtures with good optical quality. The road surfaces were standard CIE CII (dark asphalt), the most common in Italy. For every system, we calculated the maintained intensity of the light emission of the entire road at small angles ($\gamma = 95^\circ, 100^\circ, 110^\circ$) based on the average maintained luminance and on the other design parameters. We estimated the intensity in longitudinal sense, where it is larger. Table 1 shows the average intensity for unit of flux in our sample [11]. It is a maintained intensity. In order to minimize the pollution produced from the fixtures the limits to adopt must be at least a tenth of the values in the table.

Table 1.

Gamma angle	95 degrees	100 degrees	110 degrees
Longitudinal average intensity for a sample of 21 road pavements	2.0 cd/klm	4.0 cd/klm	7.8 cd/klm
Transversally the intensity of the light emitted by the road is much smaller			

Fig. 3 compares the intensity of the emission of the fixtures permitted by the limits in some laws or bills in Italy and the intensity of the emission of the surface [11] to gamma angles between 90° and 110° . Fig. 4 compares the fraction of the total intensity due to the fixtures and the surface [11]. The intensities of the road used in the figures are those in longitudinal sense while the comparison would have been made with the average over all the directions, that it is smaller.

Figure 3

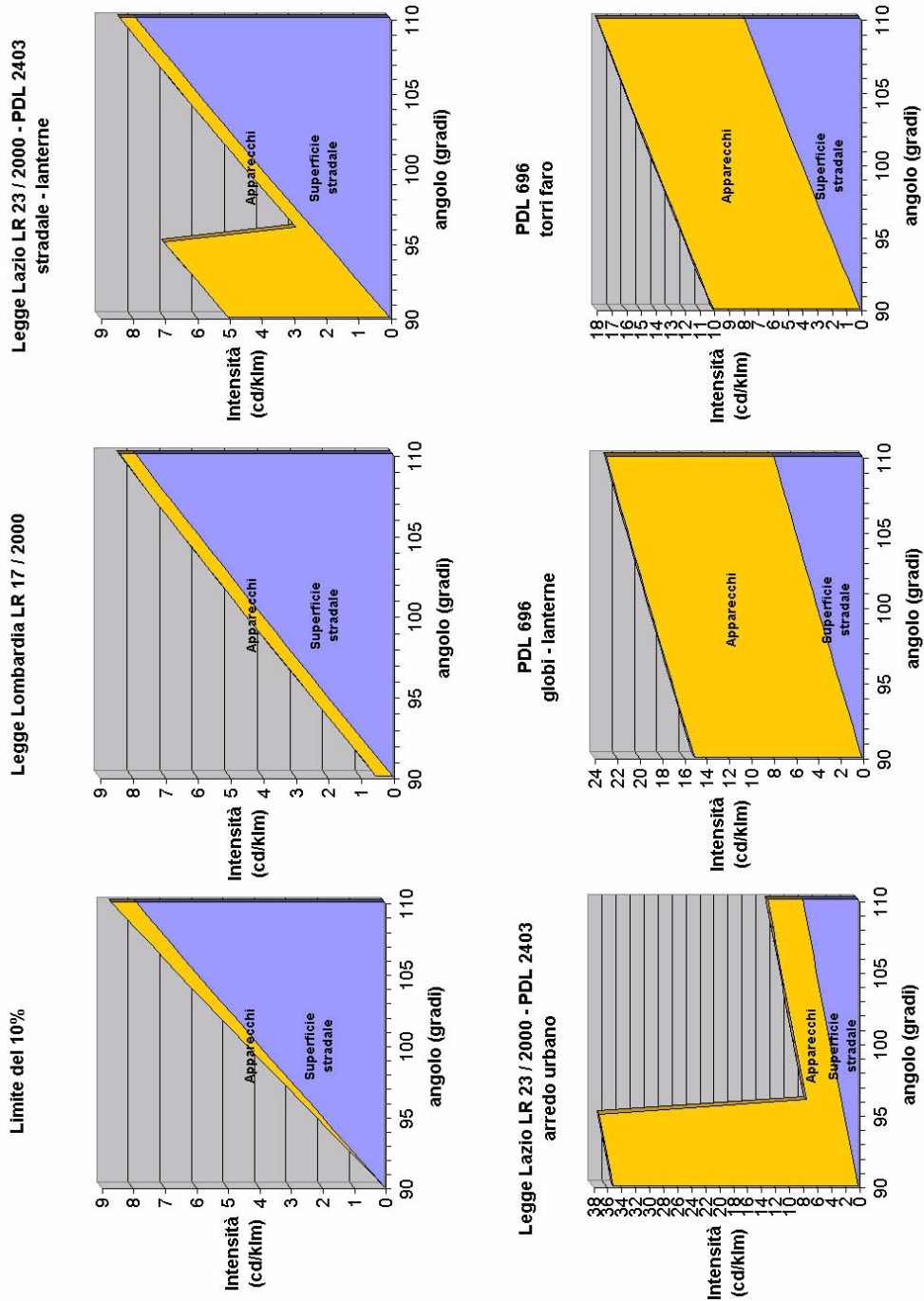
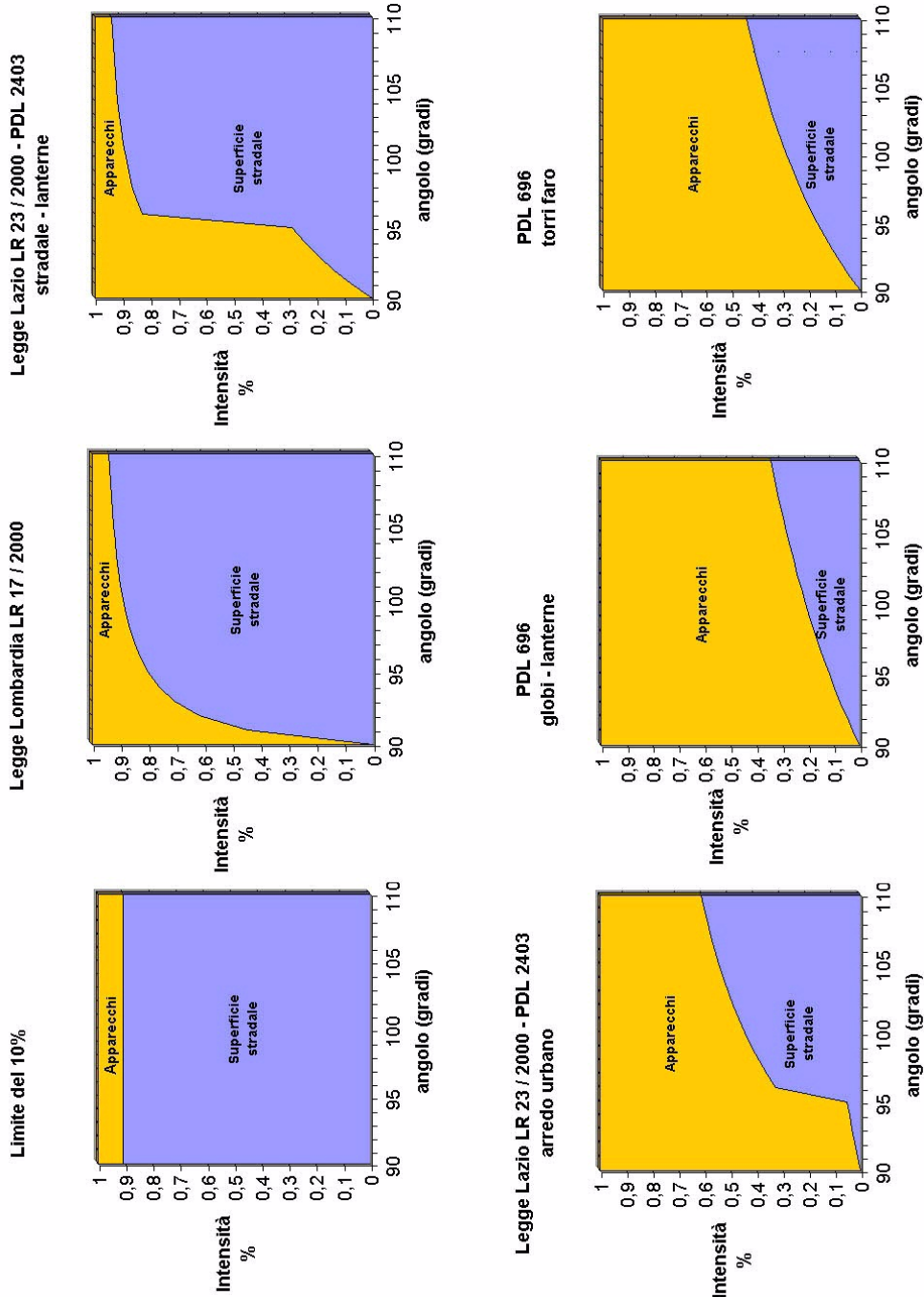


Figure 4



Note that the fixtures complaining with the 0 cd/klm at 90 degrees and beyond cannot emit light over the horizon, but can have any kind of light distribution under the 90 degrees. Fig. 5 shows two examples of prismatic-glass semi-cut-off fixtures complaining with the prescription (i.e. fully shielded). However, it is not necessary to resort to these fixtures because the many available flat glass fixtures have sufficient performances to replace them adequately.

Often it is claimed that flat-glass fixtures must be installed with a smaller pole spacing of those with curved or prismatic glass and this would lead to consume more electric power. However energy saving, depending on the amount of light flux installed for unit road length, depends in turn on how much light goes to the road and how much is wasted outside of it. Sometimes e.g. in order to obtain a smaller installed flux per kilometre, it could be preferable to install the luminaires at lower height, and then with a smaller pole spacing, so that the road intercepts a greater amount of light. The cost of the larger number of fixtures is paid off by the energy saving.



Figure 5. Extreme cases: fully shielded fixtures with prismatic glass (semi-cut-off). They fulfil the requirement of 0 cd/klm at 90 degrees and beyond.

Therefore, the greater pole spacing depends not much on a slightly larger throw angle of the fixture along the road axis but rather on its capability to be installed on higher poles still sending little light outside of the road, transversally. This mainly depends on the quality of the optic of the individual fixture and not on the category of closing glass.

b) limits to the reflected emission

A second indispensable criterion for an effective limitation of light pollution is to not over lit. The drafters of the laws of the Lombardy, Veneto and Tuscany correctly provided that the average maintained luminance of the surfaces must not exceed the minimums levels required by the standard rules for security and that it must be reduced when the use of the surface allows it. For cases in which there are no rules, the law of the Lazio introduced a limit of 1 cd/m² which has

been taken in the regulations of the Lombardy law and in the law of Marche. This value is of the order of the typical luminance required by security rules in the majority of city roads. This requirement lacks completely in the standard rule UNI-10819 which explicitly “does not consider the limitation to the night luminance of the sky due to reflection of the lighted surfaces”. It only provides a reduction of over-lighting after curfew, without any limit in other times.

The reduction of the useless light wasted downward in the surrounding areas is not specifically previewed up to now in laws and bills in Italy because of the difficulty to establish specific numerical limits to impose to the designer. However this is already implicit in a good planning, that must maximize the fraction of light effectively used from the system in order to diminish the energy consumption. A top limit to the downward wasted light, let's say between 1% and 10%, could be considered in future bills.

Conclusions

The technical criteria for an effective limitation of the effects of light pollution on the night sky brightness near the zenith in a territory, discussed above, are found adequately applied in the law of Lombardy n.17 of 27 March 2000, in its Regulations and in the law of Regione Marche. These laws are in agreement with the current legislative tendencies and with the demands of the organizations that fight light pollution. They are the most recent product of a continuous, accurate and successful update of that series of measures against light pollution hand on from bill to bill in parliament across several parliamentary legislatures, from n. 1296 in Senate in the XI legislature, to n. 511 in Senate in the XII legislature, to n. 751 in Senate in the XIII legislature, to n. 697 to the Chamber of Deputies in the XIV legislature, etc. These measures, even if lacking of top limits to the installed light flux and to the downward wasted light, are, however, reasonable and effective. Moreover, they are the simpler and easier rules to put into effect. It is easy to demonstrate that the actual provisions of other laws, like those of Veneto, Tuscany, Lazio and Piemonte, are much more difficult to apply and to verify.

The lighting community was present during the development of these fundamental rules. Not only some lighting engineers contributed, but these provisions are the result of years of innumerable debate, in many occasions, with the lighting people and their associations like AIDI (the Italian lighting association) and ASSIL (the association of the Italian lighting manufacturers). As an example, the limits to the intensity emitted by the luminaires was moved in 1994 from eighty degrees (like in the bill in parliament n.511 and in some laws of the United States requiring cut-off fixtures) to ninety degrees (like in the

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successive bill in parliament n. 751 and in the laws of Lombardy and Marche) after a meeting in the AIDI headquarter of Milan with the AIDI president, the ASSIL president, representatives of ENEL (the main Italian energy producer), the director of the magazine "Luce" and some prominent lighting engineers, when it was asked to leave full freedom to the light emission in the downward hemisphere.

Based on the presented arguments, the Italian standard rule UNI-10819 and the law of Piemonte region n. 31 of March 2000 that make reference to it, do not appear technically adequate to protect the night sky from light pollution. It is suggested to abandon any reference to such standard rule in laws against light pollution. The Italian organizations that fight light pollution support in Piemonte a new draft bill. Even some lighting engineers admitted that it is not adequate and that the way to refer the laws to a standard rule that would have to be completely remade is not practicable, while instead some of them defined "well made" the regulations of Lombardia and those in agreement with it.

Based on the experience of some Italian regions, it is recommended that the technical criteria are maintained inside the law and are not remitted to successive regulations. The laws remitting the drawing of the technical provisions to successive regulations went to a total standstill. Given the interminable discussions between the parties in the preparation of such regulations, today the only region to have approved the regulations is the Lombardy, for the simple reason that the provisions were already contained in the law and therefore precise directions were already given.

If someone want to improve the provisions of the laws and regulations of Lombardy and the law of Marche, it would be desirable the adoption of the following paragraphs, whose precious effects of rationalization have already been point out in the introduction: 1) the yearly growth rate of the installed light flux for nighttime outdoor lighting, public and private, in any municipal district cannot exceed the 2%; 2) the yearly growth rate of the electric power consumptions for nighttime outdoor lighting, public and private, in any municipal district cannot exceed the 1,5%; 3) the fraction of downward flux emitted by the luminaire outside of the surface to be lit cannot exceed (e.g.) 5%.

I wish that laws truly effective are approved soon on the entire national territory, so that a real and effective protection of the night sky and the night environment is assured to the population.

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Short biography of the author

Pierantonio Cinzano is one of the two founders, with Mario Di Sora, of the fight to light pollution in Italy, an argument which he deals with since 1989. He works on study and monitoring of light pollution from Earth and satellite at the Department of Astronomy of the University of Padua. He is president of the ISTIL, Light Pollution Science and Technology Institute, and Scientific Director of the Italian Section of the International Dark-Sky Association. He is full member of the technical committee 4-21 "Interference by light on astronomical observations" of the Commission Internationale de l'Eclairage (CIE), the Working Group 8 "Light Pollution" of the Italian Standardization Body (UNI) and the Working Group "Controlling light pollution" of the International Astronomical Union. He is author of many publications including the book "Inquinamento Luminoso e protezione del cielo notturno" published by the Istituto Veneto di Scienze, Lettere ed Arti of Venice and the ISTIL Report 2001. He is Editor of the volume "Measuring and modelling light pollution" published by the Italian Astronomical Society.