Sustainable outdoor lighting: the most efficient and least polluting

Outdoor lighting reconstruction is an excellent possibility to achieve a much better service with much less power consumption. This is important, as the power consumption for streetlighting rises steadily (by some 1 per cent per year in the EU), with light amounts (and, consequently, pollution of night environment by light, as pollution = change of the particular parameter of the environment due to added components of anthropogenic origin) rising twice more quickly, due to improved lamp and luminaire efficiencies. The development of outdoor lighting up to now has been completely unsustainable.

Unfortunately, such achievements (better service with less light and power) are extremely scarce outside those six Italian regions where effective environmental legislation concerning outdoor lighting exists. Such a legislation was introduced in Lombardy in 2000 (by unanimous vote of all representatives) and made even more demanding in 2004 (protecting all nature protected areas against man-made light, see e.g. http://cielobuio.org). Its success led to its replication in five another regions, including all Adriatic coast. The principles contained in that legislation are as follows:

1. no light emissions horizontally and upwards (technically, it's expressed as 0 cd/klm)
2. no more light onto the target area than recommended by safety standards
3. just the most efficient lamps allowed
4. optimised pole positions and light proportion hitting the proper target
5. dimming technology applied (allowing to reduce the light flux by at least thirty per cent)

The same principles are to be obeyed everywhere, for any new lighting installation or a reconstruction, to achieve its best quality and low power consumption. They should be demanded for each project, which is not financed altogether by *private* money of its owner – the donors can make these principles obligatory (such an approach, using a less comprehensive set of principles, is applied e.g. by the US state Connecticut).

Comments on single points

Ad 1, no light emissions horizontally and upwards (0 cd/klm in these directions)

Usually, just luminaires with no lens which would protrude down from the upper opaque luminaire body, can fulfil the requirement. Flat glass, hidden in the luminaire body, is mostly used as their lens (protecting the luminaire optics from dirt and insects) – this can be made from non-absorbing glass (low-iron one, common for solar collectors) covered with ideal, durable anti-reflective layers (with a third-millennium technology of sol-gel dip process and subsequent hardening; such glass is becoming common e.g. for protecting most valuable paintings, as it is almost invisible), to achieve maximum efficiency.

Such luminaires have to be installed perfectly levelled (when tilted, even an excellent luminaire shines far away into improper directions). If old poles with tilted arms are used, the luminaires have to contain a *joist to compensate the tilt*, or there is to be an adapter with such a joist or bend between the arm and the luminaire.

(What's 0 cd/klm? Less than 0.500 cd/klm. For a good 50W high-pressure sodium lamp producing 4400 lumens = 4.4 klm, this means that the luminous intensity of the installed luminaire, to any horizontal or upward direction, can be anything below 2.20 cd. In another words, it can be as bright as two candles together.)

Ad 2, no more light onto the target area than recommended by safety standards

This deserves to be extended. Adhering to any outdoor lighting standards is voluntary. So it is, which standards will be chosen. There are standards on street illumination meant for hurrying car drivers (riding at speeds over 50 km/h) to help them to see where the road goes or to notice minor obstacles on the road – these recommend some minimal luminance (how bright the road appears) in large distances, over 60 m from the driver. And there are standards serving primarily to pedestrians and cyclists, to see well and to be seen by drivers – these should be applied within town and village streets. These standards speak about average illuminances of the streets (in lux) and their uniformities (ratios of minimum to average illuminance) or explicitly about illuminances of the least lit spots. This last quantity is the important one: it says, what amount of light is enough for adequate visibility. When this is enough, there is no reason to have more elsewhere: the average values should be, ideally, very close to these minima. Any brighter, more intensively lit spots are a hindrance to see well the minimally lit areas. And any directly visible lamp or a luminous opening of a luminaire is a hindrance too, perceived as glare.

A municipality can choose to which light levels it wants to light the streets. *A higher level of illuminance means, inevitably, increase of power consumption, with little benefit for people* (the eyes adapt to the prevailing light levels, not perceiving their absolute values, and see well provided the glare is minimised). An example of such three minimal illuminances (of "darkest spots") is 0.6 lx, 1 lx and 3 lx, depending on the maximum traffic on the street.

So, the 2nd rule should read rather: *Choose the desired illuminances (expressed in lux) of the least lit spots* of each street, depending on the maximum traffic on it. Try to keep the average value of street illuminance less then twice the minimum value. Try to limit the maximum spot illuminance; the higher it is, the darker the least lit spots appear (remember that the best lighting is daylight, with its completely uniform illuminance outside shadows). For a reconstruction, don't increase light levels from the existing ones without a serious reason, instead, try to make the illumination more uniform. Check if the past light levels were not too high (maybe, due to a wish to compensate dark spots which people didn't like). Consider, that a common full-moon light is about 0.1 lx and even the strongest winter full moon high in the sky does not illuminate the landscape by more than 1/4 lx.

Increasing light levels a lot by the reconstruction would be unsustainable, even if power consumption would be reduced and quality of lighting improved (less glare and better uniformity). It would give a false signal to another municipalities: let's add light too! The reconstruction should boost the quality, not the quantity of light.

Not more light, but a *lower speed limit (and its monitoring and enforcement)* is the really helpful measure to increase safety. It might be wise to impose a special local speed limit at night, if the default nationwide limit is too generous. The risk of accidents is larger at night than in daytime, regardless of artificial light intensities (e.g., due to fatigue of drivers), and also noise is more harmful at night (lower speed reduces noise a lot). 40 km/h would be a reasonable compromise with hurrying drivers even in those streets where 60 km/h applies in daytime. Lower speed reduces fossil carbon emissions, whereas more artificial lighting increases them.

Ad 3, just the most efficient lamps allowed (emitting 87 lm/W or more, if 50W or stronger lamps are employed)

The most efficient strong light sources are low pressure sodium lamps, then high pressure sodium lamps. Fluorescent lamps may be the best solution for cases where more efficient lamps are too strong (the goal is the minimum power consumption, for the chosen minimum levels of illumination). For low luminous fluxes, LEDs are becoming to be able to offer the needed illuminance with less power (thanks to excellent possibilities to direct their light just where needed).

The point was meant to exclude the use of mercury vapour lamps and low-efficiency versions of sodium lamps. This is to be extended by including power consumption of the so-called ballasts, which limit the current to the discharge lamps. The power consumption of lamps+ballasts (usually 1.1× to 1.3× the consumption of lamps themselves) is to be minimised. Electronic ballasts are to be preferred, as they convert less power to heat. And, in fact, the "lumens per watt" should be considered not for a new lamp, but rather for a lamp after some 12000 hours of duty (four years of all-night use) – this applies primarily to metal halide lamps, whose luminous output decreases a lot during their lifetime.

Ad 4, optimised pole positions and light proportion hitting the proper target

The point might read: find the minimum possible light emissions from the luminaires, which provide the desired minimal illuminances of the street (of course, this implies minimising any light going away from the street pavement, and avoiding any illuminances larger than the desired minimal one at the pavement). The requirement regarding poles concerns investment costs if new poles are installed: their number should be kept low, as each additional pole is expensive (even the maintenance costs rise). The Italian regional environmental legislation demands pole distances being at least 3.7× their height. The better the light distribution from the luminaires (as little light outside the street as possible, large luminous intensities directed into the middle between the poles, and less light steep down to avoid a bright spot below each luminaire), the less number of poles is needed and the less power is needed for the specified lighting task.

In fact, the goals 2, 3 and 4 are to be solved together, using such luminaires which offer the least power consumption for achieving the desired minima of luminance in the least illuminated spots. It can happen, that the most efficient solution misses the desired light levels just a bit (e.g., using 35W lamps, whereas the next available "size", 50 W would give almost twice more light then needed). Then the fainter-lamp solution is the proper one: reducing the light levels by thirty per cent is irrelevant, nobody can notice the difference. Twice less light becomes apparent if the nominal intensity and the halved one are put side by side, so that the eyes can compare them instantly.

Ad 5, dimming technology applied (allowing to reduce the light flux by at least thirty per cent)

Technically, all lamps (but low-pressure sodium ones) can be dimmed not BY one third, but even TO one third, of their nominal luminous flux. This is the desired level later in the evening, when the traffic calms down. As it concerns most of the night (e.g., it can be applied ggradually since 7 or 8 p.m. in winter, and for the whole night in summer), it enables huge power savings. At the same time, thanks to stabilisation of voltage early in winter evenings when the lamps work at their nominal output, lamp lives are prolonged, sometimes more than twice. This saves both maintenance labour costs and environment (less lamps need be produced, purchased and recycled).

Two technologies are competing here: central dimming by reducing the voltage by which the lighting system is fed (this assumes using just low-efficiency magnetic ballasts in the luminaires) and individual dimming by using hi-tech electronic ballasts in the luminaires. Such ballasts can offer either two light levels or a continuous dimming to any light level. The latter one should be able to keep the lamp flux on the desired level all the lamp life (the lamp is more efficient when new, and sometimes its nominal output, due to the discrete offer of lamp wattages, is a bit too large even after years of duty). Electronic ballasts may be programmed manually, or digitally controlled by impulses sent through the power grid or by wireless technologies.

Last but not least, even if lighting can be dimmed to one half or one third for most of the night, the environment-friendly option is to switch it altogether, when not needed by anybody. Light does not protect us from ghosts or criminals, this is but a deeply rooted

superstition. Years of lamp lives are increased exactly proportionally to the length of switch-off night intervals, and of course power is saved too, so simply.... Car drivers find their way even with no streetlighting, and people sleep better in unlit streets. Natural darkness is healthy for us and the wildlife. There are many villages and towns across Europe which switch off their lights for long parts of nights (not switching them on at all at the end of the night from May to July, as there is daylight already when people get up, also thanks to the daylight-saving time). Avoiding strong light indoors late at night (what is reasonable also for human metabolism and health, even when people don't sleep) enables people to adapt to natural light levels outdoors to see their way (except perhaps within deep forests), as was the case all the times since *homo sapiens* appeared.

Further information

A European conference on outdoor lighting takes place at lake Bled, Slovenia, in October. See http://www.darksky2007.si and study the outstanding conference brochure, even if you cannot participate at the conference.

For a draft introduction to the environmental aspects of lighting see http://amper.ped.muni.cz/light/EuP/lp_intro.pdf; this gives links to some recent draft documents on pollution measurement, legislation, luminaire parameters and technology.

A comprehensive gate to the topics is http://savethenight.eu