Luminaires which do not shine upwards: efficiency and technologies

The key for reducing the most harmful light emissions is using *just such luminaires, which are not visible as high-luminance objects when viewed from above.* An elementary check they do not shine upwards: their luminance should be lower than the luminance of the lit areas below and around them. Directions close to horizontal ones are especially critical, as they cause pollution propagating to distances of over one hundred kilometres, and make the far-away luminaires visible as dominant points in the night landscape whenever they are not below horizon.

In many regions no other luminaires can be installed outdoors (if they use lamps producing more light than some limit, 700 lm to 3500 lm, usually 1500 lm). The wording of corresponding legislation contains usually a very small allowance for horizontal direction (or for direction parallel to a very long slope): even such luminaire is compliant, whose specific luminous intensity is less then half a candela per thousand lumens of the luminous flux produced inside it. This allowance is needed to obey the law completely in real world, where random tilts of luminaires (along the road, usually) up to 0.5 degrees are common even when using a level to position the luminaires ideally (still larger tilts are usual for luminaires hanged on cables). To illustrate it: a luminaire with a 100W discharge lamp can appear no brighter than four candle-flames together, when viewed from anywhere above itself (in comparison, its maximum luminous intensity when observed from below can reach ten thousand candelas). Properly installed luminaires obeying this rule are often called **fully shielded**" in the scientific literature (we shall use its short **FS** occasionally). They offer plenty of space for architects willing to make the luminaires decently conspicuous; in fact, all luminaires are allowed (due to the above mentioned generous limit of < 0.49 cd/klm) to have luminances ten times larger than those of the lit areas, sometimes even hundred times larger! (Let's remember that common bad luminaires, comprising over 95 per cent of current European stock, have luminances exceeding those of the lit ground thousands of times, even dozens of thousands of times).

The technology for achieving zero emissions horizontally and upwards is very simple. The luminaire is to have an opaque body containing a cavity with the lamp (or lamps), ending by a horizontal opening at the bottom. All old-time luminaires applied at railways were of this type, with no highly specular optical surfaces inside their cavity. Modern luminaires which should distribute the emitted light optimally onto the target surface have to be equipped by one or several mirrors inside, with a complicated geometry, to distribute light in a sophisticated way (tuned up to the configuration of terrain and to positions and properties of other luminaires).

Old FS luminaires used to have an open cavity, with no transparent or translucent element (a lens, flat or meniscus-shaped) at or above the bottom opening. Modern FS luminaires tend to include such an element to prevent dust entering the cavity and reducing the specularity or even reflectivity of the mirrors. To keep the emissions at horizontal directions at zero, such an element (called a refractor as well, or sometimes a diffuser, if it is meant to randomise the directions of the outgoing rays) is to be hidden inside the cavity as a whole. An easy daylight check is that the luminaire can be laid on the table by its bottom opening and remains stable, or that the refractor ceases to be visible from a side (and therefor from all the upper hemisphere).

To reduce those emissions which do not go steep down enough, manufacturers prefer using a flat glass as the refractor. It concerns surely all emissions to angles higher than 75 degrees from nadir (direction just down to the ground), these are always unwanted. Using flat glass is no technology necessity however, many luminaire types are large enough to comprise a meniscus within them (the fact that it is hardly ever used hints on suitability of flat glass to diminish emissions over 75 degrees). In any case, glass should be of a low-iron type to be non-absorbing for light (nothing very common nowadays, with a possible exception of really educated manufacturers). Generally, there is no obligation to use a lens at all – dust and dirt can be cleaned from suitably coated mirrors on the occasion of lamp replacement. Frequent claims that bare mirrors (which can be coated by a durable mineral layer) deteriorate quickly are supported by no field research, in my knowledge. An alternative is to change the mirrors instead of cleaning them at the site (cleaning them in the workshop, or even recycling them). Glare protection by refractor is absent in such a case, but luminous intensity in needed directions can be maximised at the beginning of the luminaire life, maybe even for the lifetime of the luminaire. Hopefully, luminous intensity in unneeded directions can be kept low in the same time by proper cavity geometry and non-corroding mirror surfaces. (Technically speaking for insiders, IP 65 has not been proved as the winning possibility yet, or?)

Glass lenses are often considered as less transparent than plastic lenses. This might apply for iron-rich (partly absorbing, cheapest) glass and **new** plastic refractors. Proper comparison should be made, however, after at least fifteen years of duty. Diminished translucency of plastic refractor is to be expected, and, especially, diminished transparency. Luminous intensity maxima at angles around 67 degrees (desirable for installations with extreme spacing) can be expected to go down also due to the deterioration of mirrors. The still employed assumption that all deterioration of the luminaire can be expressed by a single number (scaling down all the original luminous intensities) is surely wrong. Especially for plastic refractors. No field research is known to the author as this is concerned, even no research by luminaire manufacturers. In spite of tens of millions of suitable luminaires being available for that purpose in the EU...

Luminaires which do not shine upwards are THE option for the best-quality lighting which is employed by some enlightened agencies even without a legal enforcement. This includes Departments of Transport (responsible for road lighting) in several states of the U.S.A. for decades already. And many municipal lighting utilities. There is nothing revolutionary about such luminaires. Why the good experience does not spread out itself to the whole world quickly?... hidden interests of some industries? Then legal enforcement is to help the good thing to win!

Hundreds of luminaires, thousands of light distributions

The offer of fully shielded luminaires is giant already. So large that it may be a problem to select an optimum product (and its optimum optics setting) for any particular lighting task. As a first aid, I've made thumbnail overviews for many manufacturers, and hypertext numeric overviews sorted e.g. on maximum luminous intensity at about 70 or 65 degrees. See e.g. directories ../ies2/EasyLight-SaveTheSky ../ies2/acuity_brands_lighting ../ies2/siteco/. (I'd gladly add another sets, when I'd get recent photometry files of all fully shielded products from any manufacturer.)

From the computed images it is evident that many fully shielded luminaires can be used even for extreme spacings from 1:5 to 1:6 (or even for 1:7), achieving very good uniformity of illuminance or luminance of the street.

Coated glass, the only proper lens for any luminaire

In the third millennium, cheap an extremely efficient one-layer antireflection coatings from porous SiO_2 have been developed. They are employed both for window glazing and solar collectors already. Demands for luminaires are very similar to demands for solar collectors: high transmittance especially at large incidence angles. Transmission over 98 per cent up to 50 degrees angle of incidence and over 80 per cent at 70 degrees (!) are achieved this way (see transmis1.25.png). And such values should last for decades. Coated low-iron glass (called white glass as well) is clearly the best technology for luminaire lenses, maximising the useful light output and still reducing glare at large angles. No plastic bowls protruding down from luminaires can perform better. The old argument of not-enough-large transmission of flat glass at 65 or 70 degrees is no more applicable! The cost difference of common bad (greenish) float glass and the best glass with over 95% transmissivity ist small enough compared with total price of any luminaire. It pays off due to better luminaire efficiency which is not limited by lens ageing. (Some luminaires in the directories mentioned above use lenses with antireflection coatings, for Siteco the coatings are mentioned in several photometric files)

Number of producers of such glazing is rising quickly, there seems to be more than ten of them already. For links to basic physics, technologies and producers see antir_bookm.htm. Common technology is sol-gel dip coating and subsequent hardening (lenses are to be shaped prior to hardening).

Novel parameters of quality streetlighting

In the course of being a stakeholder of EuP streetlighting preparatory study, I came to a novel idea how to help promotion of such high-quality, low-pollution technology. Road lighting standards include a quantity which describes glare in some way. Most often, it is called *threshold increment* (of contrast threshold, at which the object gets noticed; **TI**). This is computed from the so-called veiling luminance, a bright fog" produced by dispersion of light inside eyes (esp. old eyes). All light entering the eyes contributes to veiling luminance, to unwanted light signal which brings no information about environment and makes detection of real objects difficult. But bright lights close to the observed target contribute more than lights which are (angularly) far from them.

Even good lights (having 0 cd/klm at 90 degrees from nadir and less than 30 cd/klm at 80 degrees) may be a source of considerable veiling luminance when they are close to the observer, shining steep down. However, it is easy to get rid of such glare: simply by a sun visor (of a car or of your cap), a peak. The only light which is not easy to get rid of is that one which comes from near the observed object (the object is typically a road before you, the obtrusive lights are headlamps of a car going toward you – or, the bad streetlights in distance). The difference between hight-quality lights and bad ones would be much more apparent if the threshold increment would be computed just for light which is difficult to screen by a visor: for light which is less than 15 degrees from the target.

This advantage of top-quality lights should be extended by considering twice higher veiling luminance, computing it for 66 years old people instead for young ones. (Technically: I use $L_v = 18\,\Sigma(L/\theta^2)$, computed for $\theta < 0.1$ degrees in my raw2lum. Common TI is then $65 \times L_v/L_{av}^{0.8}$.)

My recommendation: introduce 3 additional parameters into EasyLight, Roadpollution and into any standards: TI_66-15, TI_66, TI-15; 15 stands for angle, 66 for age.

(A remark for the EuP study: maxima TI_66-15 should become an important system-level requirement. Should be below 5 in all cases).

Conclusion

Various parameters can help to distinguish bad and good lighting. One is however of prime importance, becoming an Occam's razor for outdoor lighting: achieving **zero specific emissions horizontally and above**. It's the easiest property to verify and it helps more than any other one. And it is really simple to achieve.

jh, Feb 2007