THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

Vol. 91, No. 5 OCTOBER 1997 Whole No. 667

Fighting Light Pollution in the Ottawa Area -- Technical Elements

By Robert Dick and Arnie Weeks

Ottawa Centre, R.A.S.C.

Collecting Background Information

Members of the Ottawa Centre Light Pollution Abatement Committee (LPAC) are not lighting designers or illumination engineers. We had to rely on lighting consultants and manufacturers for design philosophies, standards, guidelines and performance characteristics of a wide range of applications and products. Our Committee efforts were divided into administrative or programmatic work and the compilation of technical information on practical lighting systems for roadways and pedestrian paths. In the industry jargon, the metal housing (fixture), lens system, lamp and associated circuitry is called a "luminaire." It quickly became evident that there were different kinds of housings and lamps that govern whether a luminaire was light polluting or astronomy-friendly

With that background information, the LPA Committee accumulated information to support the Light Pollution Abatement Program (LPAP), and developed the written and visual materials such as slides and handouts that were needed for our presentations. We recommend luminaires that may differ from what others advocated for light pollution abatement. Here I explain the rationale for our decisions

Sources of Light Pollution

There are three contributors to the overall light pollution problem that affect our members: glare, light trespass and sky glow. As amateur stargazers, most of us have experience with all three.

Glare is caused by light that is emitted close to the horizontal direction. Such horizontal light can be seen for many kilometres and reduces our dark adaptation. Lighting professionals are well aware of how glare can reduce the personal safety of both motorists and pedestrians by reducing the visibility of hazards. Glare can be quantified by relating the luminance of a light source to the illumination of a surface. The angle between the illuminated surface and the light source is also a factor. The level of acceptable glare is a compromise between physiological studies and what is technically feasible The brighter the light, the lower the reflectivity of a surface, and the closer the light is to our centre of vision, the greater the level of glare. The horizontal light also scatters off dust and large air molecules close to the ground where the air is dense, making the air appear to glow. An urban observer must therefore look through a blanket of light to see the stars. That reduces the contrast between the sky and celestial objects.

Light trespass is light that falls where it is not wanted. A typical example is street lighting that shines on the front and back yards of houses and into bedroom windows Some people like such spillage of light because it reduces their need to illuminate their own property since the cost is borne by the municipality. Few homeowners resent the intrusion enough to complain and have the municipalities mount visors on the offending lights.

The third contributor, sky glow, is, in part, represented by the natural glow from the recombination of atoms and radicals in the atmosphere, but such faint natural light is greatly overwhelmed by the artificial light that scatters off dust and gases in the low atmosphere. It varies seasonally because snow reflects more than 80% of the incident light up into the sky. When combined with direct upwards directed light from luminaires, it drastically increases the brightness and the extent of the light-domes over urban areas. Typically between two to five percent of the total amount of light from roadway lamps shines directly up into the sky. It is overwhelmed by that reflected by snow. In winter perhaps 30 to 75 percent of the light from the lamp is reflected by snow into the sky. That depends, of course, on the effectiveness of municipal snow removal.

Lamps

The colour of light has also been identified as light pollution when it discolours or otherwise creates an unattractive environment. There are basically four types of lamps that are widely used today Their ability to emit visible light is compared in figure1:

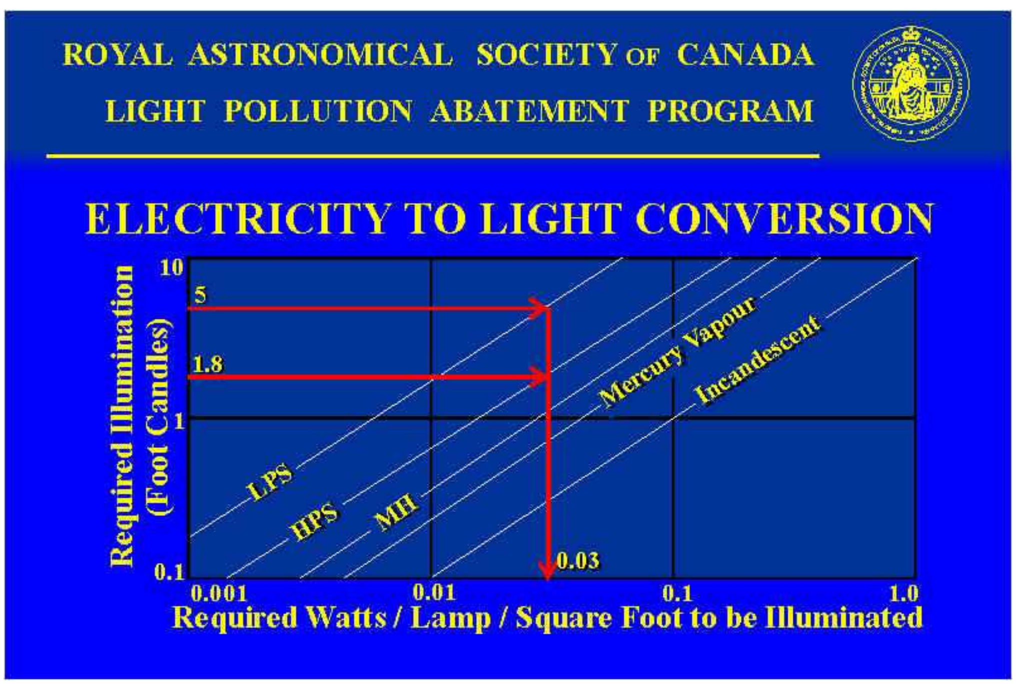


Figure 1 - A comparison of the energy required to illuminate a surface for a number of lamp types. Roadway illumination levels depend on the classification of the roadway, but typically roads are illuminated between 1 and 6 lux (cd m^{-2}).

The ubiquitous incandescent lamp is not energy efficient because it emits most of its light in the infrared part of the spectrum, which is not visible to the human eye. Where low illumination levels are required, however, it may be more preferable than the three High Intensity Discharge (HID) lamps compared in the accompanying table and discussed below.

ROYAL ASTRONOMICAL SOCIETY OF CANADA

LIGHT POLLUTION ABATEMENT PROGRAM

LAMP TYPES	ADVANTAGES	DISADVANTAGES
Low Pressure Sodium (LPS)	• *lowest power consumption* • *relatively long lifetime* • *constant brightness over lifetime*	• *poor colour rendering* • *not in common inventory* • *poor light control (large bulb)*
High Pressure Sodium (HPS)	• *low power consumption* • *fair colour rendering* • *relatively long lifetime* • *good light control (small bulb)*	• *brightness decreases over lifetime* • *not available in low light outputs*
Metal Halide (MH)	• *good colour rendering* • *available from standard inventory* • *good light control (small bulb)*	• *less energy efficient than LPS* • *brightness decreases over lifetime* • *some colour change over lifetime* • *relatively short lifetime*
Incandescent	• *fair colour rendering* • *readily available in low wattage ratings*	• *poor energy efficiency*

Table 1 - Comparison of between various lamp types

Low Pressure Sodium (LPS) lamps concentrate their emission in the yellow sodium lines at 0.5889 and 0.5895 microns (millionths of a metre). Because the energy is concentrated over a very narrow range of visible wavelengths, LPS lamps are the most energy efficient of the HIDs. They bathe the area about the lamp in a pure yellow light, however, making any reasonable colour recognition impossible. The volume of the lamp that emits the light is also very large, so it is very difficult to control where the light will fall without the aid of complex optical systems.

High Pressure Sodium (HPS) lamps emit light over a wider range of visible wavelengths and provide greatly improved colour recognition. The illumination source is very small, about the size of the end of a little finger, so it is more easily controlled by relatively simple optics.

Metal Halide (MH) lamps are sometimes confused with the old, and now almost extinct, mercury vapour lamps. MH lamps produce an almost white light that permits very accurate colour rendering. They also have a small light source, which allows precise light control. They are less energy efficient, however, and have a shorter life span HPS lamps.

Since the goal of the Ottawa LPAP is to reduce the degradation of our night skies so that our members and other citizens can enjoy them, we decided to support the use of HPS lamps or, if there is a need, MH lamps. We encourage the use of those two types of lamps because we want to reduce the amount of up-light, which is best accomplished with lamps with small and controlled light sources.

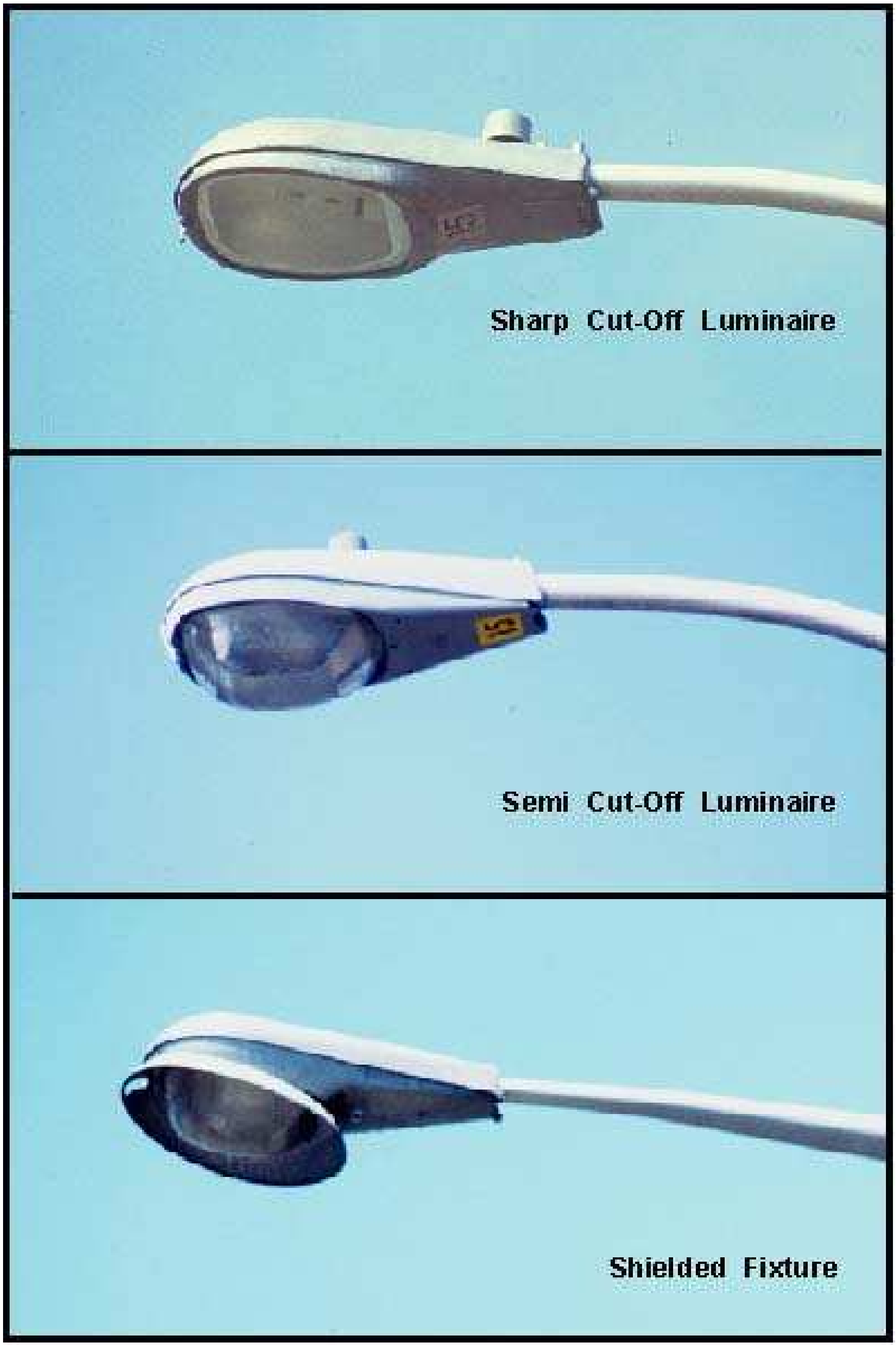
Fixtures

The fixture of a luminaire is the housing around the lamp. It includes the optical components, either reflectors or refractor elements. There are three kinds of fixtures: unshielded, partially shielded, and full or sharp cut-off.

The worst type of fixture for astronomy is the unshielded variety. They are used in many commercial signs, exterior home lighting, and yard lights. About half of their light shines directly up into the sky, and about a quarter creates considerable glare. Only about a third illuminates the buildings or grounds.

Figure 2 - Variation on the cobra head design. From top to bottom are the sharp cut-off (installed where glare and light trespass is to be minimized), semi-cut-off cobra (now found in most applications), and shielded (an after market option used where citizens complain about light trespass).

The next few types of fixtures have some form of shielding. There are three types shown in figure2: a design with reflective optics and flat glass (sharp cut-off), a cobra head with a small ovoid lens (semi cut-off), and a cobra head with a shield (shielded).



Sharp Cut-Off Luminaire
Semi Cut-Off Luminaire
Shielded Fixture

Figure2

The ovoid refractor or lens beneath the lamp in the center of the figure is designed to scatter light over a wide area and represents the "standard cobra type" used to illuminate most roadways and parking lots. In order to maximize the coverage, a small percentage of light must be emitted above the horizon as shown in figure3.

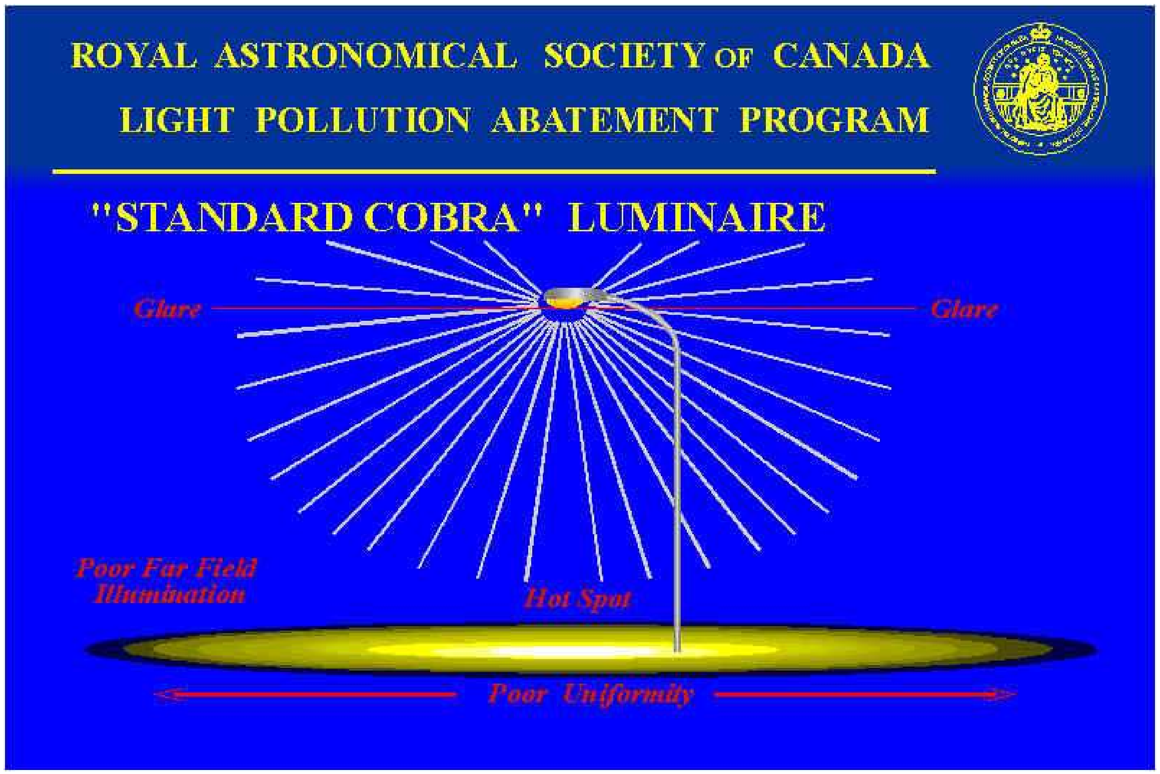


Figure 3 - The lens of a standard cobra head relies on scattering light to distribute it over a wide area. That results in a "hot spot" directly under the lamp and low level illumination around the lamp. The scattering process results in light shining horizontally (producing glare) and above the horizon (directly contributing to sky glow).

Depending on the details of the design, the amount of upwards-directed light they may emit is less than 5% for older cobra head designs, and less than 2% for semi-cut-off and cut-off types.

Another type of fixture, full or sharp cut-off, emits 0% upwards-directed light. They generally have reflective optics and a flat glass cover under the lamp, and may look like a "cobra on a diet" and is shown in the top of figure 2. Others resemble a rectangular "shoe box" or circular "hat box". Sharp cut-off fixtures have a mirror system that focuses the light into a well-defined pattern on the ground. This is shown in figure 4.

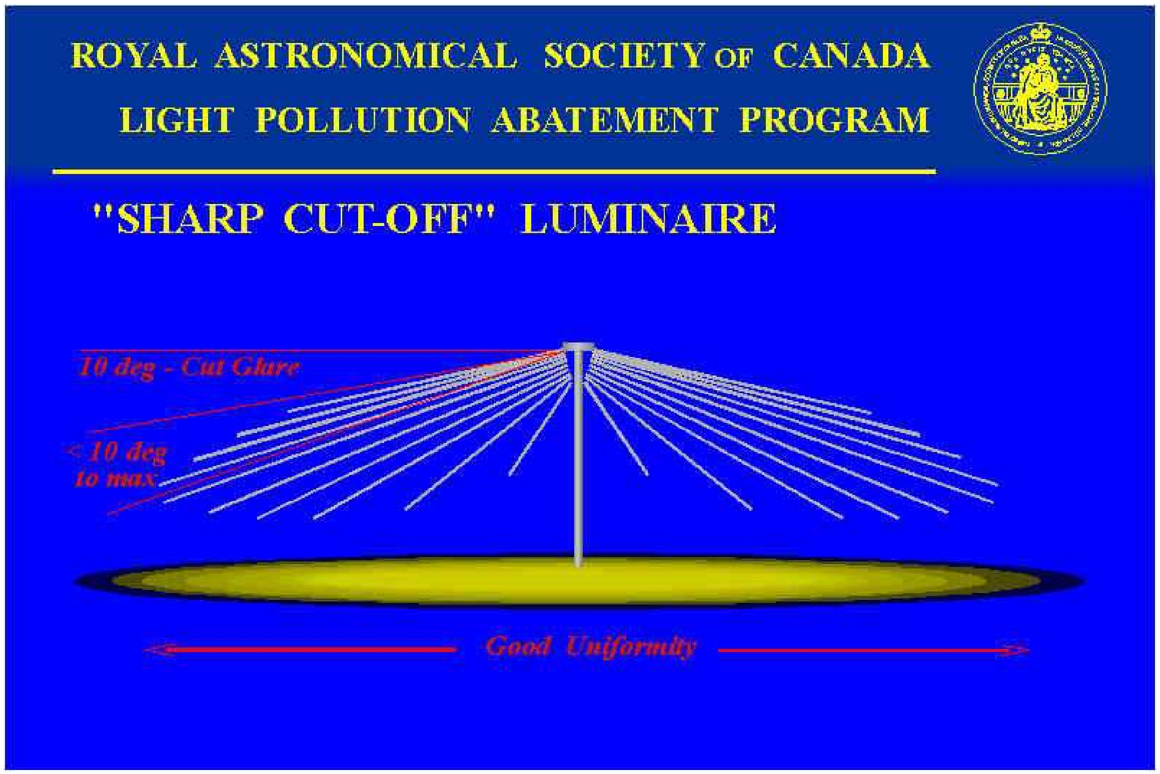


Figure 4 - The sharp cut-off design uses internal mirrors to focus the majority of the light into a uniformly illuminated footprint The restriction in the vertical plane within 10 degrees of the horizon significantly reduces glare and eliminates horizontal light that would otherwise be seen for a great distance.

The flat glass cobra head fixtures, like their full cut-off cousins, have the lamp recessed in the housing with a flat glass sealing the bottom of the fixture. The design precludes any upwards-directed light. The shape of the reflector in a sharp cut-off luminaire limits the amount of light falling within 10 degrees below the horizontal plane to less than 10% of the luminaire output. We show here a comparison of the light distribution patterns from the standard cobra head design as well.

Sharp cut-off fixtures differ slightly from the full cut-off designation. The shape of the reflector system (some designs have several mirror segments) can provide more uniform and trespass-free illumination than other full cut-off and shielded fixtures. Full cut-off fixtures do not necessarily distribute the light as uniformly and may produce a bright area under the fixture at the expense of illumination further away. That may be preferred, however, when the reason for the light is to mark a street intersection as opposed to illuminating it.

Ground Illumination

The role of most lighting is to illuminate the ground. An installation should provide the largest possible illuminated footprint without causing light trespass and glare. We show in figure 5 a comparison between an ovoid refractor cobra and a good, sharp cut-off square pack (or shoebox) design. Switching luminaires changes the distribution of light on the ground. In order to maintain the illumination levels one must space the poles that support sharp cut-off luminaires closer together than the poles for standard cobra head designs -- every four times the height of the luminaires.

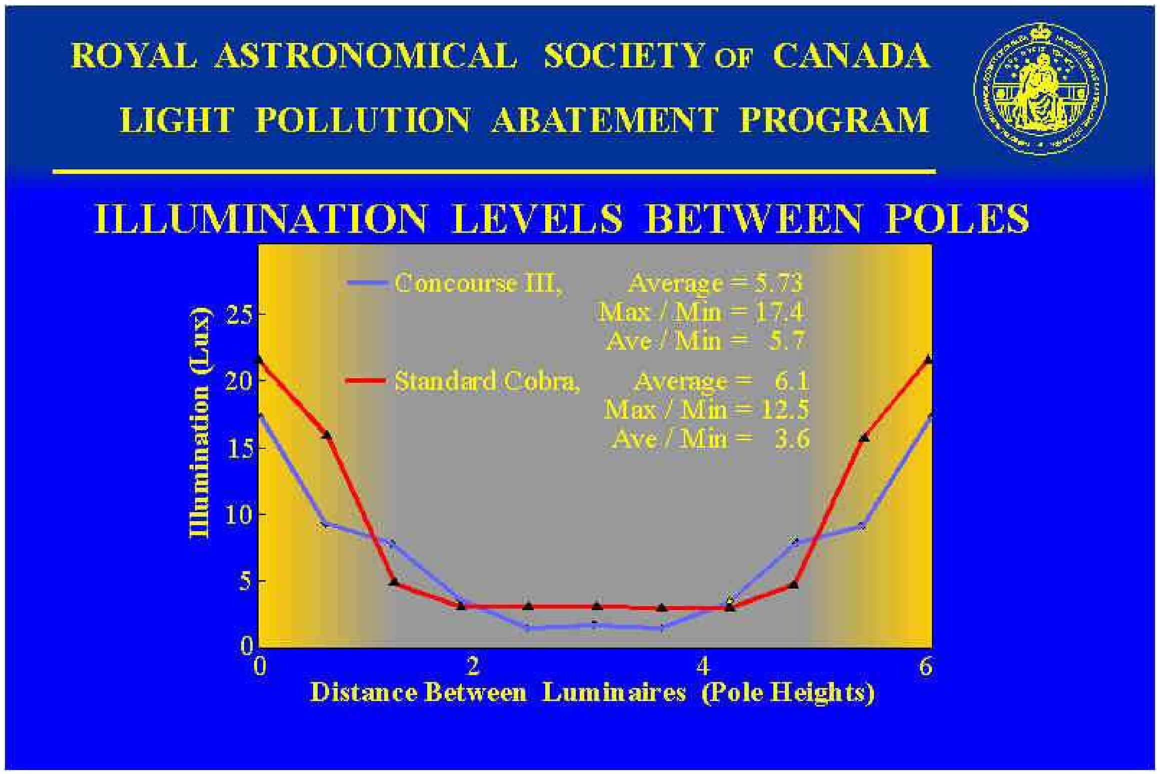


Figure 5 - Comparison between the illumination produced by a spacing between poles of six times the height of the luminaire above the road surface versus distance along a roadway. Examples are for a standard ovoid refractor cobra-type luminaire and a flat glass square pack luminaire.

We are not aware of any full cut-off or sharp cut-off optics that can illuminate as large an area as an ovoid refractor. That is why they have been so popular. The argument for their continued use centres on the perceived need to maintain the level of illumination mid-way between poles. The guidelines and specifications for that illumination level are based on research using existing products in the 1970s (Illumination Engineering Society of North America) and early 1980s (Transportation Association of Canada: Guidelines for Roadway Illumination, 1983). The levels are based on perception in a visual field with glare. The counter argument is that, with a sharp cut-off fixture, the levels of glare are lower and hence lower illumination levels may be acceptable. See figure 6.

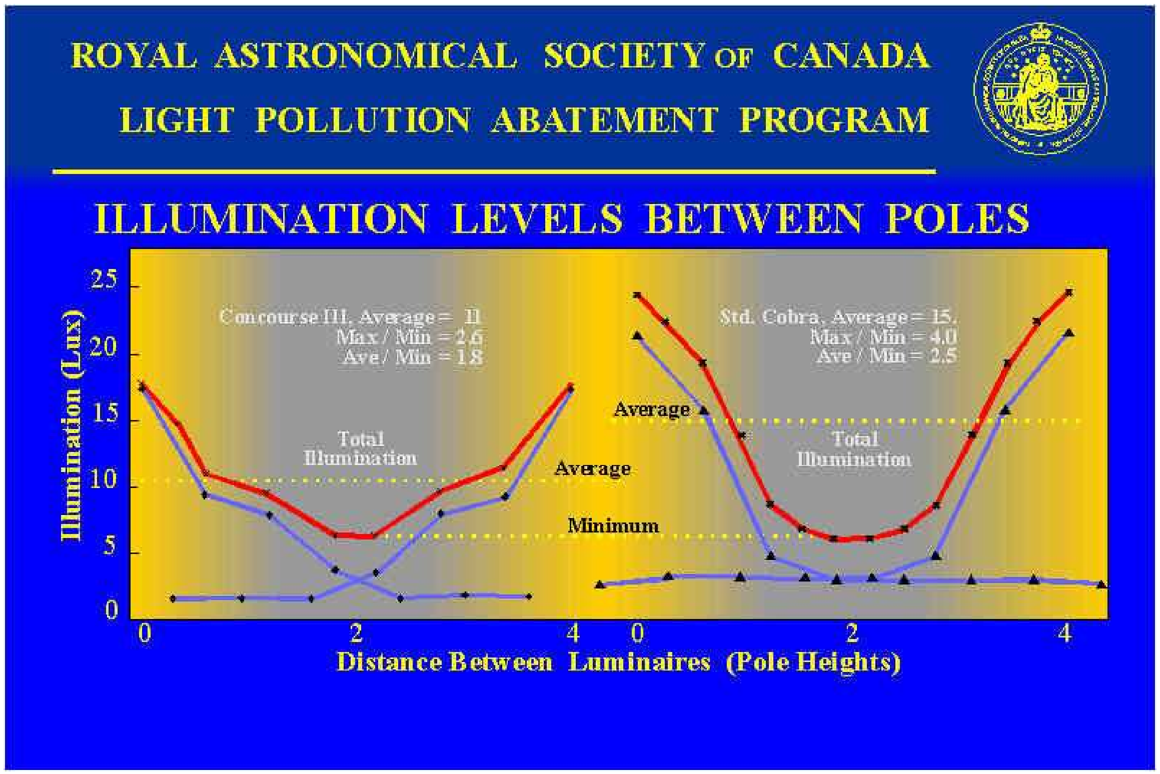


Figure 6 - Comparison of the illumination distribution for a pole spacing of four times the luminaire height. The same luminaires as in the previous figure were used. The relatively high illumination levels in mid-span suggest that lower wattage luminaires may be used. The flat glass optics provide a more uniform distribution of light than the ovoid refractor designs.

At the present time we cannot be more forceful because the matter is still being investigated. However, the new release of the Illumination Engineering Society of North America Standards may support our conclusion. That is very important because the maintenance of existing levels of illumination between light poles with flat glass luminaires will require that poles be spaced closer together, which has a decisive impact on the system cost, as discussed in the next section.

Another example of the effect of fixture on the illuminated footprint below a lamp is shown in figure 7.

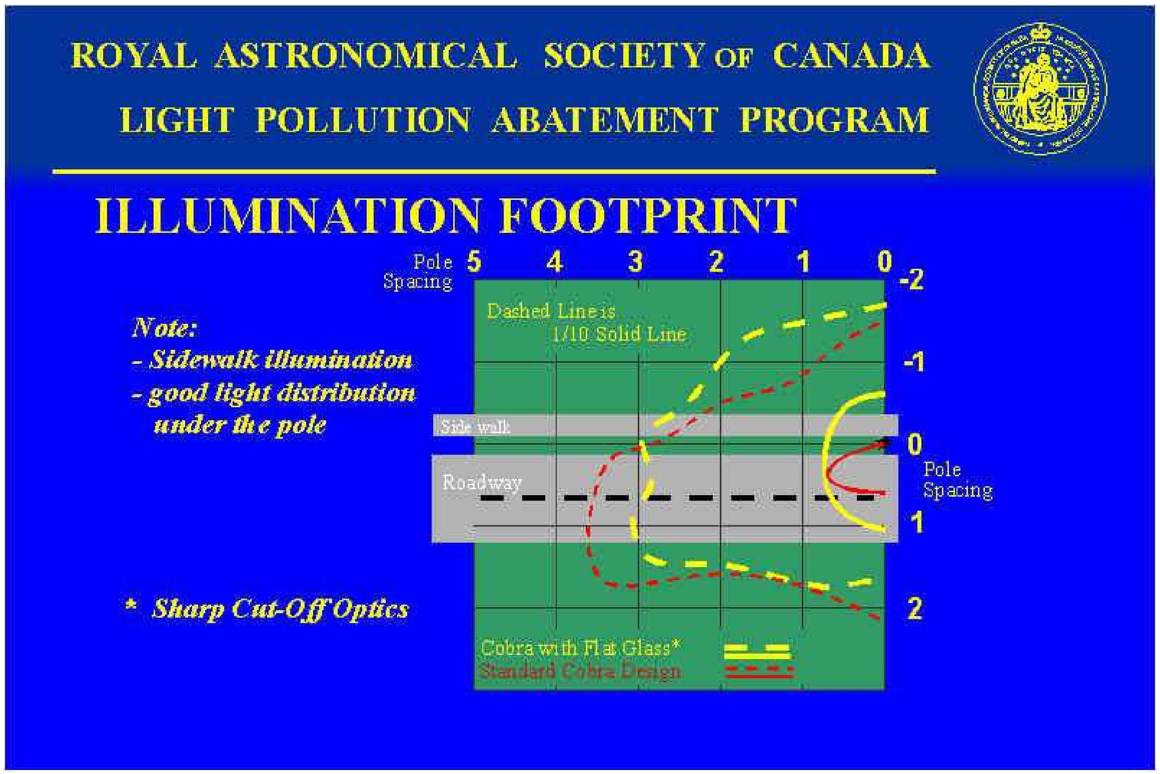


Figure 7 - The illumination footprints for two popular luminaire designs. Both are cobra-type luminaires, however the larger distribution corresponds to a standard ovoid refractor and the smaller distribution is for a cobra with reflective optics and a flat glass cover ("cobra on a diet").

The dashed line in the figures outlines the area illuminated by a standard cobra-type luminaire (GE M-250A2 with a 35-232548-1 reflector, refractor 593 with the socket in position 2A). The solid line is the light distribution of a flat glass cobra (GE M-250A2 with a 35-232436-03 reflector, clear globe 35-232436-03 and the socket in position 1A). The more expansive isophotes show the extent of the ground illumination that is one-tenth of the inner isophote. The light scattering property of the ovoid refractor produces an expansive ground illumination at the cost of horizontal light (glare) and upwards-directed light. The constriction of flat glass optics inherently reduces the illumination from the near horizontal light and results in a perceived need for closer pole spacing.

Cost

Of paramount importance to municipalities is cost! The cost of an installed pole with concrete footings and electrical wiring ranges from about $2,000 to over $4,000. The actual cost depends on the details of the footings and whether the wiring is buried or strung between the poles, as well as details of the pole design The cost of the cobra-type luminaire is about $70 (rated for 100 watts or less) to about $150 (rated for up to 200 watts). The premium cost for a flat-glass cobra ranges from zero to about $25 per luminaire. Municipal engineers therefore focus on the number of poles required to produce the specified level of illumination. The cost of the luminaire has a minor effect on the economics.

The energy saved by focusing all the light on the ground, and potentially reducing the wattage, is approximately 5%. Even over a life of 20 to 30 years the savings are only about 5 watts per luminaire. Economics point to the need to minimize the number of poles. The only way to get around the argument is to retrofit existing luminaires with sharp cut-off luminaires as part of infrastructure renewal, and to illuminate the ground to lower levels with less glare. The phase-in period of the sharp cut-off luminaires will be about 20 to 30 years.

Since the sharp cut-off luminaire eliminates direct upwards-directed light, limits the amount of horizontal and near horizontal light, and minimizes glare and light trespass, we decided to promote that design fixture in our program. The luminaire of choice for the LPAP consists of a HPS or MH lamp, with well-controlled light distribution properties, in a fixture with sharp cut-off optics.

Lessons Learned

Based on feedback during our meetings with municipal officials and with lighting engineers under contract to the municipalities, we have come to appreciate better the job of municipal engineers and lighting contractors. To amateur astronomers and many citizens, reason does not seem to apply when dealing with governments. It is not that they make irrational decisions, but that they are subject to constraints of which most people are unaware. For example, published guidelines and specifications are paramount in these days of litigation. Good design can be biased by guidelines.

Light that does not shine onto the ground seems to be a waste of energy that should be eliminated. That is easily done with sharp cut-off luminaires.

Is the LPAP playing a pivotal role in the development of lighting policy in eastern Ontario? We will know in twenty years when the last of the old lighting fixtures are finally retired and lower levels of quality lighting are used. We hope that the Ottawa Centre is witnessing the development of a long-term policy leading to less glare and a reduction in light trespass.

The City Lights Conference held in Ottawa in October 1996 gave us hope that the lighting policy for the National Capital Region will reduce the effects of light pollution on astronomy. The single voice of the conference should have a continent-wide impact through the illumination Engineering Society of North America. If correct then the future of astronomy, not just in Ottawa but for all of North America, will be bright -- err, good.

Robert S. Dick is an amateur astronomer heavily involved in astronomy education and in light pollution abatement. He has worked on a wide variety of engineering projects for both the military and commercial interests, and has also taught astronomy courses to students and people of all backgrounds. In his spare time he has built several telescopes, the last of which is housed in the observatory at his country place at Rideau Landing, Ontario.

Richard Arnold (Arnie) Weeks has worked in both astronomy and in systems analysis. In the last twelve years he has established two companies to provide systems solutions to corporate clients and, more recently, legal, financial and planning services to businesses. He has been a member of many organizations, including the Royal Astronomical Society of Canada's Light Pollution Abatement Committee.