Your Light Pollution

The Sky-Glow Story

November 2020

How Light-Pollution was Born and How it Evolves with the Lighting Industry

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Front cover: At center is a view of downtown Los Angeles, California, with its surrounding suburbs photographed in February of 2018. The background clear-night sky-glow spectrum (top and bottom) was obtained over Las Vegas, Nevada, in February of 2020.

Rear cover: Photographed with a wide-angle lens during the Perseid meteor shower of August of 2018, is a view of the night sky over Ottawa, Ontario, as seen from about 120 kilometers west of the city.

Your Light Pollution Series

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By George Liv

Figure 1.1 - The modern city, indifferent and contemptuous towards other life forms presents an unwelcoming and often a terminal environment for many types of mammals, fish, birds and insects. Altering the landscape and nightscape for the convenience of modern humans and their economic activities alone, the disharmony of a metropolis is disguised by a display of glitter and glare. Pictured here is downtown Montréal, Québec, in April of 2017, still largely with high-pressure sodium lighting.

CHAPTER - 1

LOSING THE NIGHT

The Perspective

For as long as people subsisted on animals and fish they could hunt, catch or trap, and on fruits, roots and nuts they could gather, practically all early human activity was limited to a shifting hunter-gatherer existence whose energies were almost entirely consumed by the business of staying alive. To secure reliable food sources and durable shelter, people began to settle in villages, domesticate animals and perfect agricultural practices. The trend in permanently altering earth's environments was subsequently set in motion.

Through thousands of years of cultural and agricultural advances, we unperceptively shifted farther from our very rudimentary beginnings. In the last one hundred years, a heightened shift away from our simple origins has placed most of the human population so far removed from nature that it is doubtful any person can survive a few days stripped of technology and civilization.

Although supported and surrounded with countless benefits and considerable leisure, modern people are burdened with various forms of environmental degradation and alienation, a few of which stand near maximum at present. This essay addresses a single such issue, a subject which had never been regarded as life threatening or even a challenge to people's well-being until relatively recently. This is ***Light-Pollution***.

For most of our earthly existence we have tried to banish the forces of darkness by any means possible. Night-time was man's first real and imagined terror, and dreading the night likely originates prior to the emergence of humankind. The gathering darkness reduced an essential sense of our early ancestors - that of vision. Deprived of proper sight, we were subjected to an uncertain, dark and cold period nightly. The control of fire and the first uses of primitive torches reassured us to endure and in time to explore the night.

Even within the security of villages and towns, night-time continued to instigate deep apprehension. Throughout much of written history, particularly in pre-industrial times, night-time was forever met with anxious fears of demons and evil spirits, mysterious nocturnal animals, marauding wolves, including thieves and murderers. Yet in cultures spanning the globe, as the night sky remained dark and the stars beckoned brightly, citizens sought answers to fundamental questions about their origins and place in the universe by contemplating a star-filled sky. The once bright stars ultimately became a vital source of information so that seafaring societies could safely navigate the vast oceans. Powerful agricultural civilizations also utilized the stars in the creation of calendars for all-important crop management.

The Price of Progress

At the start of the Industrial Revolution, near 1760 in the United Kingdom (UK), somewhat later for the rest of Europe, nights remained as dark as they were in ancient times. Even with widespread public gas-lighting throughout the 19th

century—a type of artificial illumination that reigned supreme for a hundred years—it remained quite dark in the cities, dark enough for planet Venus to cast distinct shadows.

Figure 1.2 - Two ancient forms of night-time illumination, the bonfire and moonlight, providing light and security for generations of people up through to the industrial revolution.

The United States had largely an agricultural and natural resource producing economy at this time. By the end of the 19th century, at the height of the prevalent form of outdoor illumination—that of gas-lighting—an uncomplicated and reliable source of light was devised here and concurrently developed in the UK. This second form of technological advance in illumination was the electric light-bulb, slowly spreading to become dominant for a short time.

The incandescent light-bulb cannot be said to mark the beginning of light-pollution, as the night sky remained nearly as dark as in the century before. A 3rd revolution in lighting technology may be rightly attributed to the true beginning; that of the high-intensity-discharge lamp. One more such light-tech revolution, a 4th, and the night sky succumbed to that mustard colored glowing aura we noticed over cities and towns as small as a few hundred people. How did this happen? What was the technology or the habits that allowed so much light to pour into the heavens setting aglow air particles many kilometers from the source?

A total of 6 lighting technology innovations will be described here, to which many regions are in the midst the 5th. The 6th technological advance in light delivery schemes was evaluated (twice) and this scheme appears unlikely to take hold. The 5th, of course, is the solid-state lighting or light-emitting-diode (LED) revolution. Being at an unprecedented position to correct or at least alleviate some light-pollution—or *sky-glow* as it is termed by most amateur astronomers—it appears that a correction period might have come and gone for some regions, although vast improvements have been realized in others.

Figure 1.3 - Incandescent filament lighting had a limited light output as seen here in a 1950s postcard of Hollywood and Vine in Los Angeles, California. Big changes were in store by 1960 and beyond with the introduction of HID lamps for general outdoor use. Credit: Colourpicture "Plastichrome" postcard, Boston 12, Mass., photograph by Frank Thomas.

Lighting the Streets Under Present-Day Conditions

Increasing High-Speed Traffic Requires High-Intensity Lighting

TEN or a dozen years ago illuminating engineers were seriously and emphatically debating whether the street-lighting intensity on residence streets should be equal to that of half-moon or quarter-moon, or at least about those relative values. The greater use of electricity for illumination was being urged. The small unit was just beginning to make inroads into what had been admittedly the arc lamp's field. While there was some inkling of the possibility of developing a scientific illumination of the average street at relatively high intensities, and while there had been several examples of "white ways"—largely for advertising purposes, however—rash indeed would the man have been who dared to predict street-lighting practices of the kinds which are now obsolescent.

Street lighting, or street illumination, has assumed a different character recently. In early days the principal object was to provide enough light to enable pedestrians to walk without colliding with obstructions or with other persons, and to find their homes, and to permit horse-drawn vehicles safely to navigate the more or less quiet thoroughfares and side streets. To-day the problem of handling with safety the ever-increasing auto traffic, the value of high illumination as a police safety precaution, the importance of well-lighted streets in forming public opinion regarding the desirability of certain districts, together with other modern factors, all serve to focus the attention of others besides illuminating engineers and central-station men on the problem of adequate street illumination. The result has been an awakening of interest which has brought about new ideas of proper illumination intensities, which has developed new methods of installation and of design and spacing of units, and which has made city authorities study street-lighting budgets on a basis other than that of a necessary evil.

—*Electrical World.*

The Americam City Magazine, November 1923, Page 500

Looking at the history of outdoor lighting throughout the last two centuries, there is the strong suggestion of a competitive escalation in illumination, not just for the requirement of copious quantities of light, but for revenue enrichment. In many cases unnecessary over-illumination, all too easily achieved by an installer, continues to be a key cause of light-pollution.

Well into the 21st century, we have now attained the ability to illuminate the great outdoors in such a manner that night-time activities can be carried out as easily as in the day; perhaps in greater comfort.

Since the invention of the high-intensity-discharge lamp (H.I.D. or HID), outdoor light-levels in most cities escalated much faster than their urban populations. An exaggerated rate

CHAPTER - 2

LIGHT-SOURCES

Oil and Candle Lanterns

Perhaps for tens of thousands of years, ancient people employed various fires and torches to see their outdoor night-time surroundings by simply exploiting resources at hand. It wasn't until the early 19th century, just over two hundred years ago, that standardized and marketable forms of street-lighting became commonplace in major cities as soon as flammable gases were made abundantly and economically available.

Street-lighting was first recorded centuries before gas-lighting in numerous cities of antiquity. Candle or tallow lanterns and torches were often used by members of a household to light up entrances and street facades. Candle making became a guild craft in England and in France by the 13th century. A guild is an association of artisans or merchants controlling the practice of their craft in an area or town.

In 1524, dwellings in Paris, France, were required to have lanterns lit in front of their homes at night. By 1594, the Paris police managed and controlled the installation of lanterns in the city. The earliest street lamps required a lamplighter journey around the city at dusk lighting each lantern.

Figure 2.1 - Even with large candles, the light provided by this classic-styled modern lantern, is near 10 to 20 lumens. This can be considered as the bare minimum to see with. The glass sides prevent any breezes from blowing out the candle flame.

In 1667, the royal government under King Louis XIV began installing candle lanterns on the streets. Three thousand lamps were installed by 1669 in Paris, and twice as many were in place 60 years later. An improved oil lantern was introduced in the 1740s, (the *réverbère*), which was attached at the top of lamp-posts. During the French Revolution of 1789-1799, revolutionaries found these lamp-posts a convenient place to hang aristocrats.

In 1716, by an Act of the Common Council, houses in London, England, that faced any street, lane, or passage, were required to hang out every dark night one or more lights to burn from six to eleven o'clock, under penalty of a fine of one shilling for failing to do so.

Through the 17th and 18th centuries, it was regular practice for wealthy travelers to hire a lantern-bearer to journey at night through moonless and winding city streets. Lantern-bearers were common in Paris until the French Revolution.

The inventor and postmaster of Philadelphia, Pennsylvania, Benjamin Franklin popularized the concept of street-lighting in the USA with a wax candle lit inside a four-sided glass lantern.

Gas Lighting

Candles, various oil lamps and soaked torches were the only sources of outdoor lighting into the late 18th century when lighting with gas became known. References to burning springs had been made since ancient times but the discovery of illumination with gas is generally attributed to the engineer and inventor, William Murdock, after he succeeded in 1792 to light his home in Cornwall, England, with gas he obtained from distilling coal. In 1798, Murdock used gas to light a foundry and later in 1802, lit the building's exterior in a public display of gas-lighting that astonished the local residents.

In 1799, a teacher in mechanical engineering, Philippe Lebon, obtained a patent in France for making gas by distilling coal or wood. To produce flammable gasses, coal was heated in a sealed oven with an oxygen-poor atmosphere.

The first occurrence of *outdoor* gas-lamp lighting likely took place in 1801 in France, when Philippe Lebon used the gas he obtained to light both his home and gardens.

Interest in gaslight grew among industrialists since it was found that the use of gas burners for lighting in factories resulted in some savings over the expense of lighting with candles. Only after 1834 did the manufacture of candles became an industrialized mass market product when pewterer Joseph Morgan, of Manchester, England, patented a machine that allowed continuous production of molded candles. This mechanized method of candle making could produce 1,500 candles per hour.

In just a few years of industrial gaslight applications the first English patent for distilling gas was obtained in 1804. The first occurrence of a public exhibition of street-lighting on record took place on January 28, 1807, on Pall Mall in London. This can be regarded as the beginning of the first revolution in standardized street-lighting technology.

Preston, Lancashire, was the first city outside of London to use gaslights in 1816. The Preston Gaslight Company was run by Joseph Dunn who formulated a better gas lighting process providing a brighter and more powerful gas flame. Such gas companies were soon formed in all UK cities.

As the costs for gaslights were found to be about 75% less than that for lamp oil or candles during this period, all major UK cities with populations greater than 50,000 had gaslight by 1821, and by 1826, just two towns over 10,000 remained without gaslight.

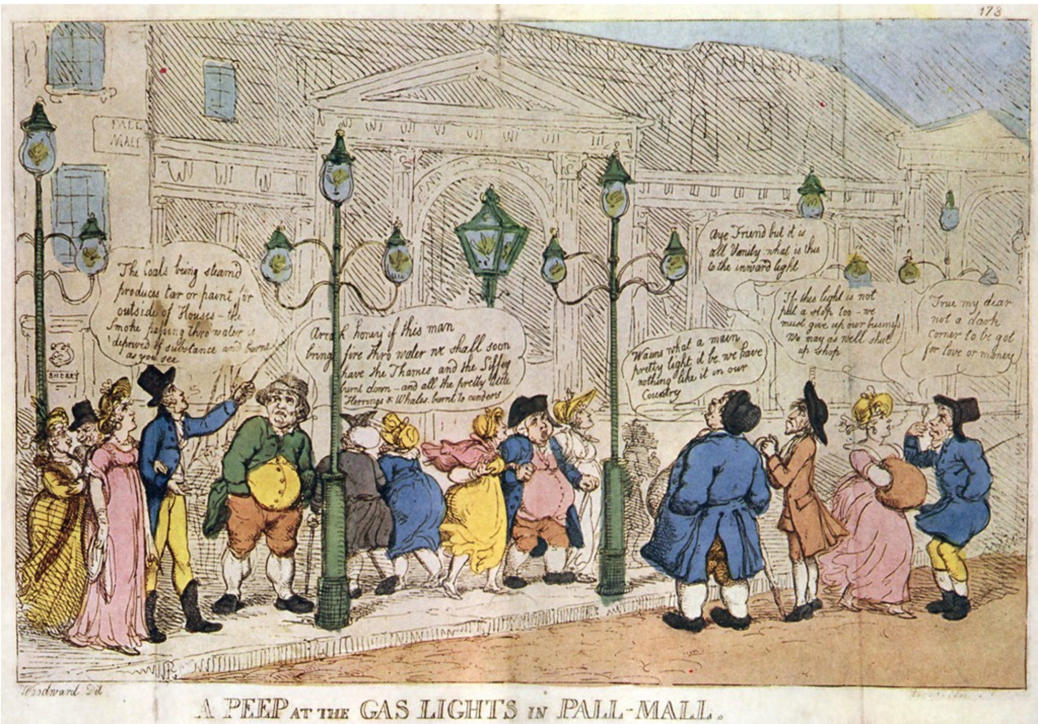


Figure 2.2 - "A Peep at the Gas Lights in Pall Mall" is a famous caricature engraving on the reactions to the new invention of gas burning street-lights on Pall Mall in London. Engraved by Thomas Rowlandson, in 1809, after a drawing by Woodward, this work is in the public domain in its country of origin and other countries.

Caricature dialogue from left to right:

- "The Coals being steam'd produces tar or paint for the outside of House - the Smoke passing thro' water is deprived of substance and burns as you see."

- "Arragh honey, if this man bring fire thro water we shall soon have the Thames and the Liffey burnt down - and all the pretty little herrings and whales burnt to cinders."

- "Wauns, what a main pretty light it be. we have nothing like it in our Country."

- "Aye, Friend, but it is all Vanity. what is this to the inward light?"

- "If this light is not put a stop to - we must give up our business. We may as well shut up shop."

- "True my dear not a dark corner to be got for love or money."

Following the successes in England, the need for gaslight on busy streets and growing cities spread quickly in many other areas. Gaslights were exhibited in Rembrandt Peale's Museum in Baltimore, Maryland, in 1816. The city of Baltimore is now regarded to be the first city in the United States to utilize gas for street-lighting in 1817. The city's gaslights were provided by Rembrandt Peale's Gas Light Company of Baltimore.

In 1821, in Fredonia, N.Y., the first well yielding natural gas was drilled by William A. Hart, a local gunsmith. In the following year, using at first bored logs, he piped the gas to illuminate some of the town's homes and stores, thus marking the start of the natural gas industry.

Naturally obtained gas was utilized for street-lighting primarily in the towns that happened to be near natural gas sources as it was difficult to transport it to distant markets. Frequently an unwelcome discovery in drilling operations, it was allowed to burn off in large torches or piped to street lamps in the town that liberally burned day and night.

By 1850, central stations providing gas to local street gas-lamps were common in scores of cities throughout the western world. Paris for example, had just a few of its streets lit in 1820. By the 1850s, all Grands Boulevards were lit with gaslight. Installed gas and arc-lights on the boulevards and city monuments bestowed Paris the nickname "The City of Light".

By 1860 there were 362 companies chartered in the USA for the manufacture and distribution of gas. Street-lighting was also the primary use of gas; not until the late 1860s did gas-lighting attain widespread and common use within homes.

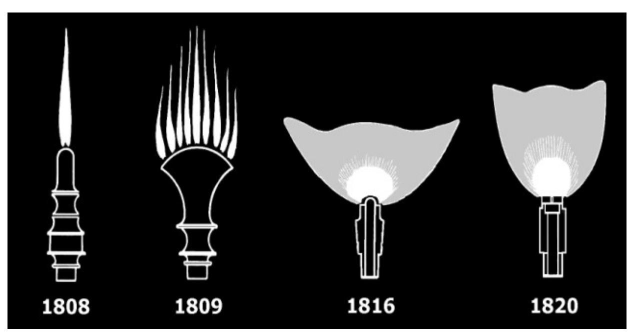


Figure 2.3 - The naked flames of early gaslights were named. With an increasing light output over some years, from left to right are the Rat-tail, Comb, Bat-wing and the Fish-tail.

At best, early gas flames were just about adequate and never powerful, similar to the light output of a few candles to a few dozen candles. Think of the old Bunsen burners cranked up all the way (air throat holes closed). By the middle of the 19th century the output may have reached many tens to a few hundred lumens. A standard candle provided about 10 lumens.

Compared to today's extended city where every side street, minor residential road and laneway is lit with bright sodium lamps or LED systems, gaslights were mainly installed on the main avenues, most boulevards and major streets. Very few contemporary astronomers would have been inconvenienced by sky-glow caused by gaslights. There's enough historical evidence, in fact, that astronomy was unaffected by gaslight throughout the nineteenth century with most astronomical research taking place from observatories within the core of large cities. Relocation of major observatories occurred comparatively recently in history. For example, the Royal Greenwich Observatory in Great Britain was relocated in 1954.

Figure 2.4 - Early gas lanterns had to be ignited manually. A naked-flame gas burner is lighted here by a lamplighter in Sweden, in 1953. By this time, such remaining gaslights were uncommon curiosities. This photograph is in the public domain in its country of origin and many other countries.

Visual research has demonstrated that eyesight becomes increasingly sensitive to brightness differences in a scene as the total level of light is raised. A very high ratio between the faintest and brightest lit objects was permissible in those days with little glare experienced by the naked flames, even though they were thousands of times brighter than their surroundings.

Near the time that the electric arc-lamp and incandescent lamp threatened to displace illuminating gas, the Welsbach incandescent mantle was invented, dramatically raising the efficiency of gas-lighting. First appearing in 1885, the mantle is a spherical or cylindrical hood of thorium-oxide which brightly glows when heated by a gas flame. Open flame burners consumed large quantities of gas and by the 1890s were widely replaced by mantled burners. The mantle essentially saved the gas industry and allowed the manufacture and sale of gas to remain competitive with more expensive electricity. This permitted the expansion of gaslights into the 20th century until the outbreak of the First World War and beyond.

Figure 2.5 - Dating back to 1892-93, these are some of the original double-mantled "Model Lamp" style gas-lanterns operating in Kreuzberg, Berlin. Converted now to run with 4 mantles, this image was obtained in 2018. Photo by C. Fraser.

Mantled gas-lighting (hooded gas burners) offered a better quality of light than the earliest incandescent lamps and provided much higher light levels than the open flames of gas burners. Up to 800 lumens could have been produced by a single mantled burner. This was as much as that provided by today's 60 watt incandescent lamp (or 11 watt LED lamp).

The economic impacts of both indoor and outdoor gas-lighting were enormous. It allowed for much longer work hours in factories with less cost. Industries could operate more economically over a 24 hour day, resulting in increased productivity. Compared to candle lighting, gaslights permitted a less expensive, more dependable and safer means to leisure time and theatre enjoyment. Shops could also afford to stay open longer. This was particularly important in northern countries such as the UK, where the duration of darkness on dreary winter months can be longer than 16 hours.

shown to be 30% to 60% more efficient than sodium, metal-halide and ceramic-metal-halide lamps. The powerful and compact electrodeless sulphur bulb lasted over 60,000 hours without a change in lumen output over its life and the spectrum was nearly continuous.

At the time of its invention the ballast life was limited to 15,000 hours and the parts were very expensive. Nevertheless, electrodeless microwave-excited sulphur-lamp systems were tested in a number of university growth chambers for greenhouse and hydroponics systems, the trials of which demonstrating excellent results.

The costs of the components made the lamp system a commercial failure by 1998, but by 2005, sulphur lamps were produced again. The magnetron of the system (similar to a microwave oven magnetron) was improved to match the 60,000 hour life of the lamp. The bulb itself, enclosed in a microwave-resonant mesh cage, could have had a light magenta filter coating to correct for the slight green tint which spectrally peaked near 510 nm. Adding other chemicals inside the bulb could improve color rendering further.

Lamp prototypes were of very high wattages and units lower than 1000 watts were impractical to construct. Due to the copious amount of light produced by the lamps, they were applied by means of a light pipe. This was a hollow, cylindrical transparent tube attached to the parabolic reflector of the bulb which distributed the light uniformly over its entire length via a prismatic surface. It was either capped by a mirror on the end or two lamps were placed at each end for longer pipes. A light pipe had the appearance and color of an outsized fluorescent tube and was designed to replace numerous HID lamps per light pipe.

These microwave sulphur lamps were used in a lighting demonstration project in the US National Air and Space Museum, in Washington, D.C. Three lamps, each with a 27 meter (89 foot) light pipe, reportedly replaced 94 HID lamps, while the amount of light they delivered was greater.

If costs of the microwave-sulphur lamp technology drop, and if efficacy and reliability further increase, it may very well become a viable alternative for lighting systems where profuse amounts of light are required. The technology could be also used outdoors for very long stretches of tunnels or bridges; however, this technology now appears to be dead in the water.

Light Emitting Plasma Lamp

Another emerging lamp technology developed in just the last two decades, again for higher illumination applications but this time mainly for outdoors, was the light-emitting plasma (LEP) lamp.

A solid-state radio frequency driver supplied energy to a tiny electrodeless light emitter consisting of a fully-sealed quartz pill-case (similar to an oversized tic-tac) embedded in a ceramic puck. As the supplied electromagnetic field was extremely concentrated, the blend of gases and halides contained in the electrodeless capsule became ionized creating a plasma which produced intense light.

The total lamp system efficacy was alleged to be better than that for HPS lighting. The lamp fill was proprietary while the spectrum was said to be continuous. The main halide fill chemistry, nonetheless, appeared to be indium which was at a high enough vapor-pressure to provide mostly a continuous spectrum. It also seemed that a small quantity of a rare earth halide was added (possibly holmium iodide) to balance the overall color. Visibly, the light had a distinctive blue-green tint.

The superiority of the system was with the small quartz capsule embedded in the optics which made the source highly efficient. The problem with such a halide lamp technology is that, in reality, the true efficacy was not much better than that of any other standard metal-halide lamp. Because of the significant infrared emission from the indium-halide plasma, it negatively affected its power conversion into useful visible light. For this reason, the true mean luminous efficacy remained near 85 Lum/W at best.

Figure 2.45 - On a stretch of Highway #417, in Kanata, west of Ottawa, Ontario, there were 4 masts with LEP lighting units that were being evaluated. The blue-green light they emitted (top image) was in stark contrast with the orange light from the HPS masts. By the end of 2017, these were replaced with new LED luminaires (bottom image).

LEP technology was considered complementary to LED lighting; LEP was suggested where higher levels of light were necessary while LED systems could handle lower levels. LEP lighting was therefore liberally encouraged for reducing costs and maintenance by installing them on high-masts and tower arrays. Their makers were also recommending them just about anywhere higher watt HPS and metal-halide lamps were used. These included growth-chambers and hydroponics, roadway and area lighting, as well as for outdoor industrial lighting.

A number of cities and municipalities around North America had installed and appraised the practicality and energy efficiency of LEP as early as 2010. Because of the very high cost and exceedingly blue-green appearance, the results seem to indicate that this type of lighting was not widely accepted as LED systems were.

Future Lighting

Rapid and instant-start compact-fluorescent bulbs became readily and economically available by the year 2000 and at that time, officials, budget planners, lighting companies and environmentalists were encouraging the switch from ordinary incandescent light bulbs to compact-fluorescent. With the advent of LED bulbs this practice quickly waned. The need to ban items containing mercury and rare earth coatings has promptly become a little more imperative now.

Since mercury vapor lamps for lighting purposes were banned in the EU in 2016, finding a replacement for mercury in fluorescent and HID lamps was necessary. Several low pressure systems containing various metal halides had been reported in generating ultraviolet and visible light. Instead of mercury, halides of indium or thallium were used with the peak emissions adjusted by the variation of plasma parameters. This also addressed the color of the lamp. With the ascendance of LED systems in the lighting industry for both indoor and outdoor lighting, all activity and developments in fluorescent and HID lamps have effectively ceased.

Continued research into lighting and its effects on people are driving lamp technology into new areas. Recent studies using colored tubes, originally developed to treat SAD (the medical condition of Seasonal Affective Disorder), featured very high color temperatures near 10,000°K. Apparently, the blend of new phosphors (*fourth generation* phosphors with very high *Color Correlated Temperature*) have been engineered to match what is currently believed to be a good balance between lighting for vision and for people's well-being. Tests carried out in offices and schools revealed a measurable increase in personal performance with subjects feeling alert and energized. These high color temperature lamps can be a positive influence in windowless offices or dull classrooms, where their enhanced blue light mimics the blue sky of natural daylight, however, they are completely unsuitable for fixed, all night, dusk-to-dawn lighting.

In the last decade, a period of darkness has been found crucial to our biological circadian rhythms of regular day-wake and night-sleep cycles. The part of the spectrum responsible for regulating this biological rhythm has been found to be blue light. The same wavelengths which are beneficial during daylight hours seem to be very disruptive at night.

The newly discovered melanopsin receptors in our eyes, which are distinct from rods and cones, generally sense blue light and suppress melatonin levels. They have a peak sensitivity that seems to span the blue wavelengths of 455–485 nanometers. Apparently, violet light which spans about 390-430 nanometers is excluded or was absentmindedly omitted in the studies. Except for some smart-phone and new laptop screens, few lighting systems are currently filtered in any way to prevent the suppression of melatonin.

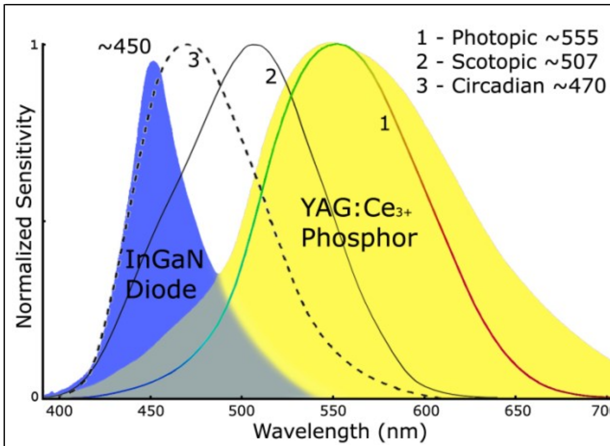


Figure 2.46 - The spectral distribution for a common indium-gallium-nitride (InGaN) LED system is superimposed on the spectral responses for the three photosensitive cells found in our eyes. Shown are the distributions for our photopic (1) and scotopic vision (2) along with a dashed line (3) representing the estimated spectral response for the photosensitive melanopsin found in our circadian regulating cells. The respective spectral peaks are marked on the top right in nanometers. The blue peak and the phosphor peak for a neutral balanced LED system (~4000°K) are nearly at the same height. For cool-toned systems (~6000°K), the blue peak is twice the height of the phosphor. The blue spectral peak (~450 nm) from all phosphor-based LED systems falls near the crest of the spectral response for melanopsin.

With or without adequately filtered blue wavelengths, white light sources will become steadily more dominant in street-lighting. This is clearly evident with the slow but steady trend towards inefficient and higher maintenance metal-halide over sodium lamps through the turn of the century, including the somewhat hasty deployment of cool-white LED and induction-lighting systems early in the 21st century. The orange and yellow color of sodium lighting is equally disliked by lighting consultants and the public, and since many HPS lamps include a little mercury, they are currently banned in a number of countries. Within the next few years, it appears that all sodium lamps will eventually be replaced by LED systems.

A few countries In the EU are experimenting with getting rid of street-lights altogether in favor of special luminescent road paint which will also serve self-driving vehicles of the future. Additionally, to reduce energy costs in outdoor lighting systems, a number of EU nations are moving away from traditional, fixed illumination by employing intelligent and adaptive lighting. This type of street-lighting adjusts to motion by pedestrians and vehicles, dimming when no activity is sensed, brightening when movement is detected. Intelligent

CHAPTER - 3

LIGHTING FIXTURES AND PRACTICES

Consequences of Application

Thus far we have looked a little at the history and electrical efficacy of all the light-sources available for outdoor use. Important in how much light-pollution any lamp will produce is the choice of the fixture, the brightness level of the lamp inside this fixture, and the manner in which the unit is installed outdoors. Therefore, the *application* of the illuminating source is of a central consequence regarding the amount of up-light, and hence, sky-glow it will produce.

No matter what type of light-source is used inside a lamp housing, if the lamp rays are aimed into the night sky, either directly from an inherently poor fixture or from excessive illumination on the ground, these rays will produce sky-glow according to the sky conditions and scattering laws at play. It turns out that in clear and dry air, the scattering process discriminates the bluer sources over the redder. The scattering processes are described in the beginning of Chapter 5.

Figure 3.1 - Two identical metal-halide throw lights are shown here having dissimilar up-light. This is largely achieved by the installer using an incorrect tilt angle for one of the luminaires.

The topics covered herein are by no means exhaustive. Overall general trends in common lighting fixtures and practices are discussed with many of these products and practices being common worldwide.

Maintenance, Relamping and Control

Central to our understanding of the type and method of illumination adopted for nightly, public street-lighting through the last two hundred years, is the all inclusive subject of street-light maintenance, relamping at or near a lamp's end-of-life (EOL) and nightly lighting control.

For the early years of gas lighting, gaslights were ignited manually one by one every evening. A lamplighter would either walk or use a horse driven carriage going from lamp to lamp, physically climbing a ladder or raise a lit wand to light the burner. The typical era lamp-post had a crossbar below the lantern against which the lamplighter's ladder was rested. When gas lamps were manually lit each night, they were put out the following morning by cutting off the flow of gas at the base of the lantern. Rarely were street lamps left burning during the daylight in that period as the cost of the gas was comparatively high.

Figure 3.2 - Gas-lights installed on Royal Avenue, Belfast, Ireland, circa 1895. By this time, the gas-lights of many cities were under central control with underground piping. From the Detroit Publishing Co., catalogue J foreign section, Detroit Photographic Company.

Very soon, a large effort was made by public gas companies to minimize the labor necessary to manage street lamps. Consequently, centralized control systems were developed with separate supply lines for streets. When the gas pressures became regulated, pressure or shock-wave ignition systems were developed to light gas-lamps automatically and remotely, thus, eliminating the lamplighter altogether. During the gas-mantle era, the pressure was also regulated at a central gas supply that greatly dropped during the daytime to maintain a pilot-light, increasing the pressure at dusk to fully illuminate the street.

The same concept was used for electric arc-lamp systems. Public street-lighting used separate power stations with a group of arc-lamps having one dynamo acting at the same time as necessary ballast. While street-lights were controlled by running or not the power generator, privately owned arc-lamps at factories, institutions and businesses were connected to dynamos with individual control. Timers were developed to enable switching the dynamo on and off from the main electrical grids of that era. The autonomous aspect of the timer meant that arc-lamps and soon incandescent street-lamps would be automatically lit at the same time nightly. This self-governing standard is still employed today for street-lighting.

At the end of the 19th century, after the initial successes with incandescent and arc-lamps, it was uncertain whether or not electricity would displace illuminating gas. Mantled gas-light was flourishing during this period for both indoor and outdoor lighting, at best providing somewhere between 300 and 800 lumens per mantled burner. The mantles were delicate if touched, shaken or attacked by insects, occasionally needing replacement with daily use. This depended on how well the lantern was sealed against the elements.

The first electric power systems for incandescent lighting used direct current (DC) generators with 100 volt DC light bulbs. The voltage in DC power wires steadily declined with increasing distance and the power plants needed to be within 1 or 2 kilometers of the lamps they served. The development of alternating current (AC) power transmission solved the voltage-drop problem by taking advantage of very high voltage transmission lines combined with almost silent transformers containing no moving parts. AC power generation enabled the growth of dependable and economical electrical networks that finally brought the gaslight era to an end.

Figure 3.3 - Many arc-lamps were installed on intersections on a mast with a winching mechanism. An arc-lamp is lowered here by a worker for maintenance. The earliest arc-lamps required daily cleaning and rod replacement. From a 1905 postcard, W. A. Reed, Stationer, Milton, Pennsylvania.

Since early incandescent light bulbs had a life of just 1000 hours, it meant that relamping was necessary every 85 days with nightly use. Later into the 20^{th} century, the life of series incandescent lamps was 1400 hours or about 4 months. Blackening of early incandescent bulbs was a severe problem, therefore, street-light fixtures were simply *mass-relamped*. The scheduled replacement of all the lamps in a district was an accepted form of preventative maintenance.

Bulb replacement of a few months was ordinary and not thought as inconvenient. On the contrary, it was considered a luxury as the gaslights decades earlier had a shorter mantle life (vibrations and wind-gusts being the leading cause of mantle failure), and arc-lamp rods had a life of just one or two days at first. A bulb with a life of three months was a tremendous improvement. Additionally, the earliest discharge lamps of the 1940s didn't have the present rated life spans; 1500 hours was common for fluorescent lamps while medium pressure mercury-vapor discharge lamps had a rated life of about 3000 hours, slightly *lower* than that for the series and extended life incandescent lamps available by the 1940s.

Early into incandescent lighting, some areas decreased the line voltage in order to extend the life of the lamps from half a year to a year. To the delight of residents, lowering the voltage made street-lamps appear more amber, similar to turn of the century gas-lamps. Additionally, incandescent lamps were made with low voltage, high-Ampere filaments, 6.6 Amps being the most common. These circuits were regulated by constant-current series regulators that adjusted the voltage to properly operate the number of working lamps in a string. A 2500 lumen series-lamp on a 6.6 Amp series circuit operated at 24 Volts.

Figure 3.4 - For easy maintenance and relamping, the earliest series incandescent lamps were also installed on masts with winching systems. Rope tied near the base of the post was released to lower the lamp. Severn Hall hotel in Wildwood, New Jersey, circa 1907, part of an 8x10 inch dry plate glass negative, Detroit Publishing Company.

A street-light maintenance contract would typically be negotiated between a town and a utility that provided and maintained series street-light fixtures. For example, under a 4150 hour annual lighting schedule (about 365 days x 11.4 hours per night), it was required that every light bulb be replaced twice a year within a few days of two specified dates.

NIGHT SCENE IN SOUTH BEND WHEN FIVE-LIGHT CLUSTERS WERE USED

Street Lighting in South Bend, Ind.

By Eli F. Seebirt
Mayor of South Bend

STREET lighting is being given serious study by the officers of every progressive city. The aim is to furnish efficient light to make the streets safe, to show off the buildings and store windows of merchants, and to give an attractiveness to the streets. Correct conclusion as to the best type of installation can be formed only by seeing a system in actual use.

South Bend, Ind., presents to-day a very well lighted business district. Until last year the business district was lighted with cluster lights, five on a pole, with a combined wattage of 340 to the cluster. The contract with the lighting and power company expired in 1924 and the city negotiated a new ten-year contract seeking the best possible lighting equipment. A lighting engineer was employed and inspection of installations in other cities was made.

NIGHT SCENE IN SOUTH BEND AFTER SINGLE-LIGHT STANDARDS WERE INSTALLED

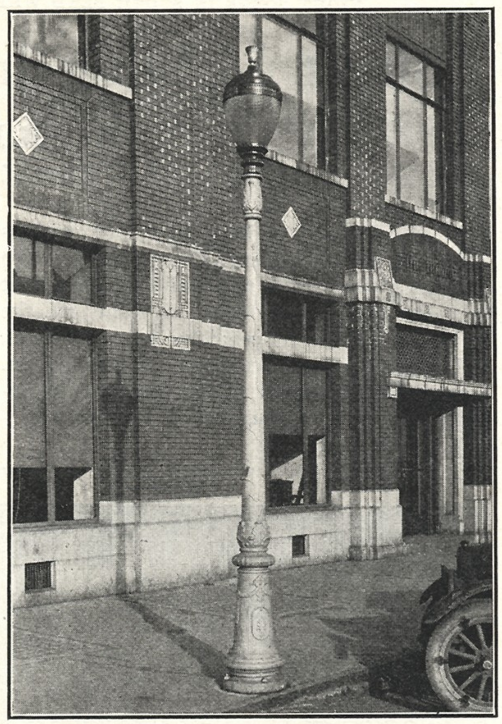
Figure 3.7 - Promoting ample and standardized forms of street-lighting continued throughout the 20th century each time a contract with a lighting and power company expired. From the March 1926 issue, page 291, of The American City magazine.

ONE OF THE FIVE-LIGHT CLUSTERS

The most modern types of lights manufactured by the Westinghouse Electric & Manufacturing Company were installed. South Bend now has in its business district an efficient and beautiful system of lights consisting of 7,000-lumen incandescent lamps, Egyptian Senior opalescent units, mounted on iron posts about 12 feet high, placed so that there are from ten to twelve lamps in each city block. A block is from 344 feet to 410 feet in length.

The lamps have demonstrated that they throw a much brighter light per unit than was obtained from five of the old lamps formerly in use, and that they throw the light, not upward, but outward into the street, and into store windows and onto the sides of buildings. They place the light where it is needed. There are 84,000 lumens provided to light one block, which is a greater quantity than that provided in most cities. But while more light was obtained than under the old system, it was found that it could be supplied cheaper, as the maintenance, repair, and cleaning of one lamp instead of five effected a large saving in cost.

On the boulevards there were installed incandescent lamps of 1,000 to 2,500 lumens, with octagonal tops and refractors, mounted on iron posts. All old arc lamps are to be removed from the remainder of the residence district before January 1, 1927, and are to be replaced by 6,000-lumen incandescent lamps with pendent fixtures and dust-proof bowl refractors, which will greatly improve the intensity of lighting. The cost of lighting in South Bend is about $1.10 per capita, based on the census of 1920; and upon the present actual population it is about $1.00 per capita.



ONE OF THE NEW SINGLE-LIGHT ORNAMENTAL STANDARDS

STREET AND HIGHWAY LIGHTING IN 1926 MUNICIPAL INDEX

Section 15 of the 1926 MUNICIPAL INDEX, devoted to the subject of street and highway lighting, has been prepared through the cooperation of C. H. Shepherd, Consulting Engineer, Engineering Service Corporation, Chicago, Ill. In his discussion of this important subject, Mr. Shepherd takes up the promotion of a street-lighting system, its financing, construction, types of circuits, overhead and underground wiring, typical installations, and highway lighting.

Figure 3.8 - In the roaring twenties, there was a desire for much stronger lighting, achieved here with single post-top luminaires with 7,000 lumen (near 500 watts) incandescent lamps. From the March issue of 1926, page 292, of The American City magazine.

Figure 3.44 - An American Electric Lighting (AEL) FCO (flat glass) luminaire with a manufacture date of 06/2014. Refurbished with S68 ANSI ballast for a 50 watt HPS lamp (a rare wattage for any North American street-light) it was photographed with a used 50w HPS lamp installed. Good spreading of the light is achieved by the internal reflector alone. Compare the light output with Figures 3.32 through 3.34.

Figure 3.45 - NuVue Lighting (now defunct) NV-RL-RT70W FCO luminaire with a manufacture date of 09/2008. The maker's sticker says "for Induction Lamp RT70W" and was also photographed with the same camera settings while using the factory installed 70 watt 6000°K induction-lamp. Due to the donut shaped lamp, the reflector here has no true provision for spreading the lamp light sideways.

Figure 3.46 - An American Electric Lighting (AEL) FCO luminaire, a second one but identical to the AEL fixture in Figure 3.44, is retrofitted here using a 60 watt induction-lighting system with a torus-shaped lamp rated at 6500°K. It appears that it's more difficult to focus the light from an induction-lamp, but this time the light is spread somewhat better than the NuVue fixture just above in Figure 3.45.

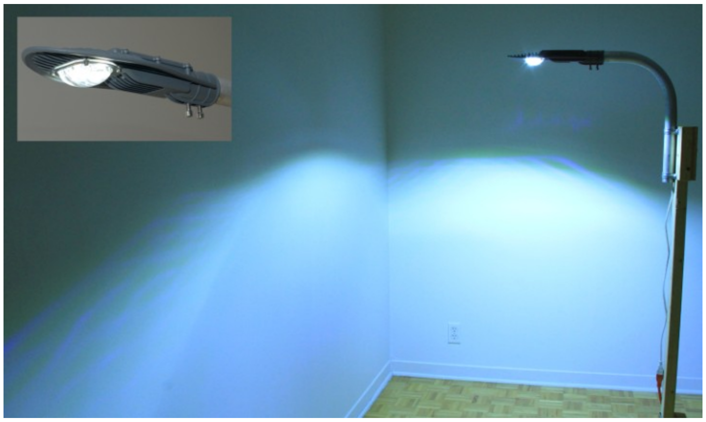


Figure 3.47 - Here is an inexpensive and widely available Chinese made LED street-light. Rated at just 30 systems watts with a color temperature at 6500°K, it was also photographed using the same camera settings as for the rest of the luminaires on this page. Although a lens is situated below the LED assembly, (see insert), very good dispersal of the light is achieved while still retaining a cutoff design.

All images on this page were photographed using the same camera settings: 1/10", F11, ISO 1250 at 3200°K.

New LED and induction-lighting systems take advantage of the increased luminaire efficiency of a FCO design to enable the use of lower system wattages. Despite the *lower raw lamp efficacy* of these new LED and induction sources over higher watt sodium lamps, the FCO design is one of the reasons for the reputed improvement over fixtures of the past. Other reasons would be their longer life and lower maintenance.

Figure 3.48 - This tiger-stripe lighting pattern on the roadway due to the FCO induction street-lighting in Brockville, Ontario, would have been unthinkable more than a decade ago. Such are the powers of the lighting industry that anything can be marketed in support of a supposed cost-cutting measure.

A number of companies made glare-shields for the common cobra-head with sag lens, including the NEMA-type area lights, turning these units into good cutoff systems. However, they were rarely installed by a municipality outside eco sensitive regions. On the most part these were adhoc solutions for astronomical interests rather than economic, and sometimes shields were installed after a resident complained.

Figure 3.49 - In certain sensitive areas, such as on some Hawaiian islands, old cobra heads were shielded making them into cutoff heads from semi-cutoff and non-cutoff type.

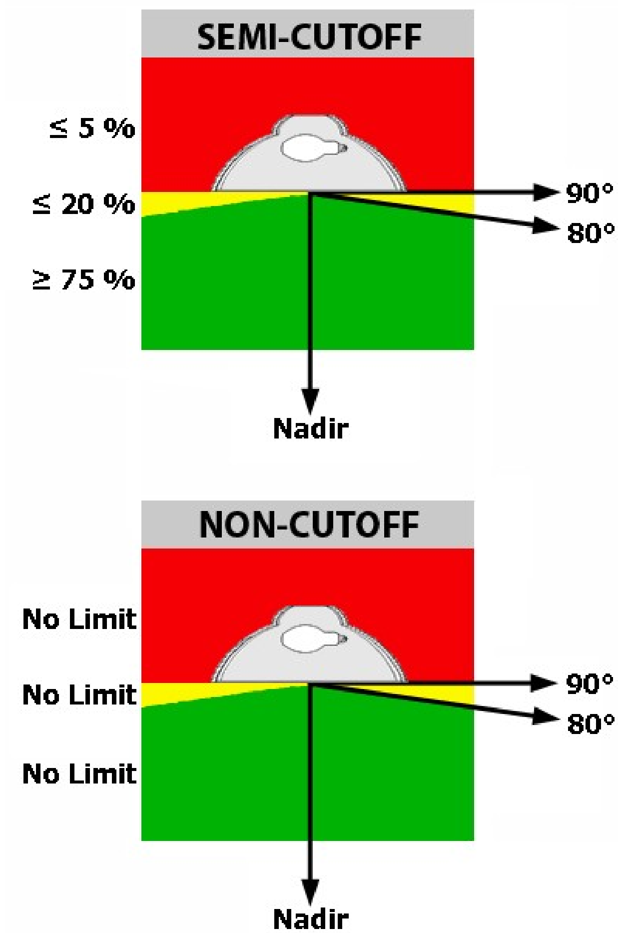


Figure 3.50 - The lighting budget and IESNA classification for the designations of "Semi-Cutoff" and "Non-Cutoff" fixtures.

Figure 3.51 - Low pressure sodium (LPS) street-lighting using semi-cutoff type heads with 55 watt lamps. These have nearly the equivalent mean lumen output as 100 watt HPS lamps.

To reap the benefits of the most efficient raw lamp system available, numerous municipalities had installed LPS lamps with FCO systems. Some were housed in shoe-box styles with

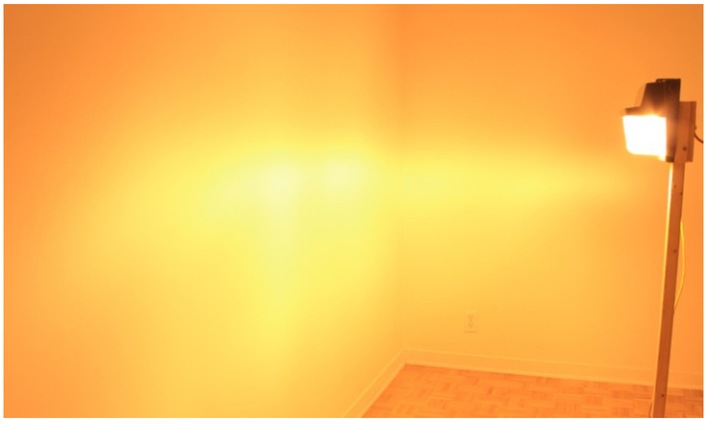


Figure 3.66 - Here is an older HPS wall-pack made sometime in the 1980s by Holophane. A used 70 watt mogul sodium lamp is installed. The wall-pack employs a thick glass refractor cover and the lighting pattern shows that a significant portion of the light is thrown at an angle of 65° to 80° above the nadir.

Figure 3.67 - A typical mini HPS wall-pack or side-pack made by numerous companies, these utilize medium socket lamps of between 35 and 150 watts. This one contains a ballast for a 70 watt lamp and a well used HPS lamp is installed. A rather poor lighting pattern is shown for the light distribution, much of it being shed straight out horizontally.

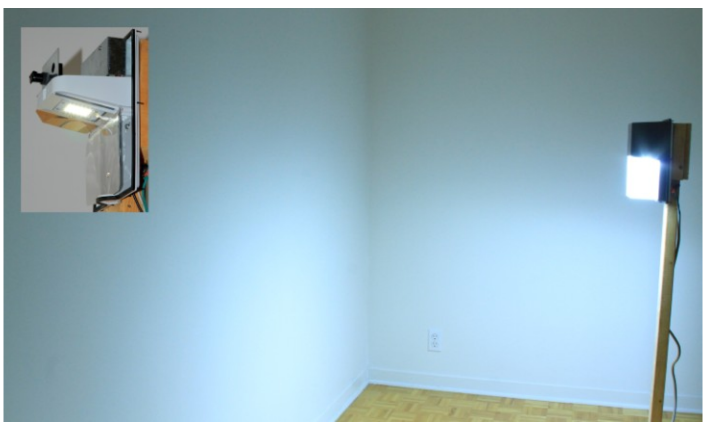


Figure 3.68 - This typical LED mini wall-pack, rated at 20 system watts with a 5000°K color temperature, is meant to replace 70 to 150 watt metal-halide/HPS wall-pack systems. It has the correct LED console orientation pointing the light down (see insert) and the cover appears to be a simple diffuser, so it achieves a slightly better downward spread of the light than a typical HPS mini wall-pack.

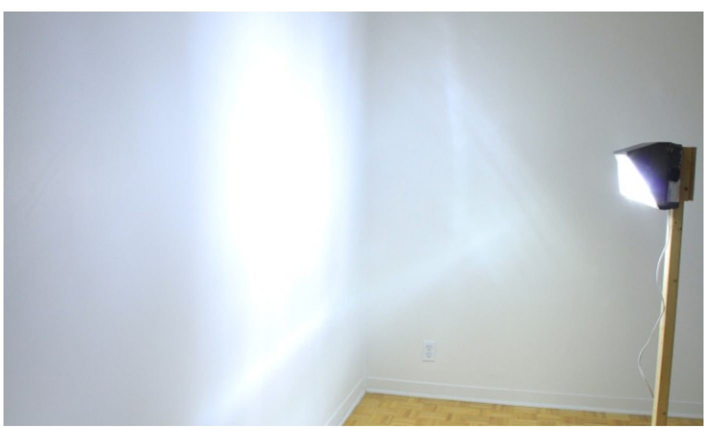


Figure 3.69 - A Stanpro wall-pack with a 100 watt metal-halide lamp is shown here. The aged 100 watt lamp was rated at 3200°K, the same temperature as for the camera setting. The glass refractor for this wall-pack bends the light much too high, refracting the light straight out with a sizeable amount of up-light.

All wall-packs on this page were photographed using the same camera settings: 1/10", F11, ISO 1250 at 3200°K.

Lamps are also pointed up on tall skyscrapers mounted at some higher point on the building. Rarely are lamps installed from above pointing down, which is likely to occur with buildings set flush on sidewalks without lawns to mount units onto. The inclination has been with the ease in the installation method with an eye out for the serviceability of the lamps without concern for waste. The same polluting practices have continued into the LED era. Lamps are also used on the ground to light up flags, fountains, statues, logo products, promoted automobiles, etc., the list is endless.

Figure 3.70 - A large one meter squared (3' x 3') fixture with a kilowatt MH lamp is pointing upwards. The insert shows the lamp's etch. This fixture is also shown in Figure 3.71.

Some of these lamps, either on the ground or higher up on skyscrapers, are turned off at some point of the night to ease consumption costs. Some reductions in sky-glow for these areas will occur afterward. Lighting regulations restricting overnight facade lighting effectively reduce sky-bound levels in a similar but forcible manner.

Figure 3.71 - The 1000 watt MH floodlight shown in Figure 3.70, one of six such fixtures, is illuminating a column of a building. This was photographed in March of 2019 and the fixture appears to have one third of its light sky-bound.

Figure 3.72 - Excellent down-lighting with metal-halide lamps judiciously conceived when this building was constructed, the lamps supplying light for pedestrians and for the parking lot.

Another disturbing trend since the 1980s has been the increased use of wall-packs to light entrances or the grounds of commercial and industrial establishments. Wall-pack fixtures, originally with mercury, then HPS and MH lamps, recently with LED, have also spread on the facades of private homes where light-levels in a residential context can be obnoxious. Peer pressure can be seen here where one fixture causes another and another to be installed all within a radius of a few homes. Wall-pack output can be variable depending on the maker.

Figure 3.73 - Wall-packs on the rear of a building confounding the viewer as there are no exits or entries, nor a parking lot or landscaping, except perhaps for a single emergency exit.

The wall-pack somehow became conventional application to industrial building design to provide security and perceived occupancy as well as general lighting over exits. This type of lighting, which was in addition to any adjacent lot lighting, was abhorrently over-applied. Wall-packs on empty building walls are currently executed in a similar manner with LED systems.

For many applications, wall-pack lighting is not tied to any real security or exit-entry concerns. In such cases the lighting simply serves as a sense of spatial and corporate presence for

TABLE 3.4

TYPICAL WATT SIZES FOR ROADWAYS

The typical lamp wattages utilized inside North American street-lights throughout the last seven decades are shown here (without ballast consumption for HID systems). Higher wattages than what is listed here were sometimes used when a street-light was adjacent to a railroad crossing, was in a school zone, or located at a pedestrian crossing.

DISTRICT / ERA	Commercial and Major Arterial	Industrial Zones	Residential Inner City	Residential Suburban
Incandescent* (~1945 to ~1960)	500 to 1500 watts	300 to 1000 watts	300 to 500 watts	100 to 300 watts
Mercury-Vapor (~1960 to ~1985)	400 watt, through 700 and 1000 watts	250 and 400 watts	250 watt	175 or 250 watts
Low-Pressure Sodium (LPS) (~1970 to ~2000)	(180 watts for freeways)	55 to 135 watts	55 watt	35 or 55 watts
High-Pressure Sodium (HPS) (~1985 to ~2015)	250 and 400 watts	150 or 250 watts	100 and 150 watts	70 or 100 watts
LED systems (~2010 to present)	101 to 220(?) system watts	35 to 120 system watts	52 to 101 system watts	22 to 52 system watts

*Series incandescent street-light lamps, rated for lumens, had odd wattages such as 115, 275, 525 and 635 watts, etc.

Evolution of the typical *mean lumen* lamp output inside street-lights for residential roads:

	Incandescent	Mercury	HPS	LED
Inner City	4000 (305 watts) (?)	10400 (250 watts)	14400 (150 watts)	8736* (101 watts)
Outlying Suburban	1600 (115 watts)	7200 (175 watts)	5400 (70 watts)	4115* (52 watts)

* For 4000°K LED models. A mean *system* lumen output is shown published by the company.

Invariably, 150 watts HPS were used for busier residential intersections and 100 watts along the remainder of the street. 150 watts HPS were indeed sited on collector roads and school zones, while it was common to find 250 watts on inner city residential avenues and boulevards and up to 400 watts HPS on roadways adjacent to railroad crossings or school zones. For many recent implementations, LED system heads often remained identical for an entire neighborhood (same wattage) regardless if it were an intersection, a side street or a collector type road. LED lights were sometimes added on intersections.

Even near the year 2015, the predominant lamp-size for an inner city North American residential district was the 150 watt HPS system inside older cobra-heads. These might have been half of all street-lights for residential city roads, typically yielding about 190 watts with ballast. The remaining half in the same districts were the 100 watt HPS, yielding about 130 watts consumption. All these roadways formerly lit with HPS could have received one type of LED head, such as the Cree XSP2 with 101 system watts.

Between 100 and 150 watt HPS or MH lamps had been installed in most ornamental housings, and 70 watts inside luminaires for paths and public parks. 50 watt HPS lamps could easily have been utilized, but since these lower sodium wattages were never mass-produced until the 1990s, they were a tad more expensive, consequently they were rarely employed; 70 as well as 100 watts were utilized instead.

Many EU nations have lowered the levels provided onto residential roads, currently utilizing 36 watts PL fluorescent tubes (tri-phosphors) or more recently 18 through 35 watts for LED systems. These practical and pleasing lumen level standards are often half those for many North American residential roads.

CHAPTER - 4

THE CASE FOR UP-LIGHT

Surface Reflections

Sky-glow is a fairly complex process with locally variable interactions that are linked to large scale evolving physical features. We shall attempt to thoroughly straighten things out.

Because most surfaces change with the seasons, including concrete and asphalt when it snows, the topic of reflections from surfaces due to outdoor lighting must be covered first.

To a great extent, sky-glow from poor fixture design and bad lighting application is entirely reversible when smart lighting practices are used. Unfortunately, a portion of sky-glow can never be reversed and will always be present with any amount of widespread outdoor lighting. This irreversible portion is due to reflections from lit surfaces and it's the reason why it's important to maintain the least amount of lighting necessary.

To get a proper grasp of the total up-light from each fixture or a group of fixtures of the same type, the total amount of light reflected off the ground has to be known or at least estimated. Various surfaces below street lamps will reflect different amounts of light depending on the type of surface, from a minimum off of calm water to a maximum off of freshly fallen fine snow. Table 4.1 summarizes reflectance values that were found for various surfaces.

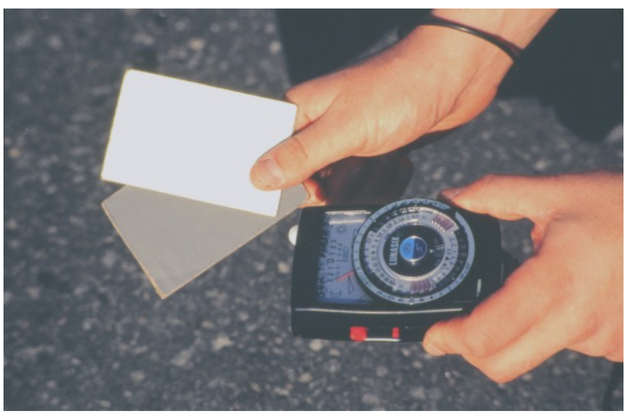


Figure 4.1 - Cut pieces of Kodak's Gray Card, colored grey on one side and white on the reverse, for measuring various surfaces in different areas using a good light-meter.

The amounts in Table 4.1 are based on easily obtainable measurements using **Kodak's Gray Card** (American spelling) and a good light-meter but a spot-meter was best. The Gray Card is a sturdy piece of 8 X 10 inch cardboard with a specifically manufactured neutral grey color on one side and white on the other. The grey side reflects 18% of the light falling onto it and the white side reflects 90% when new. Any surface can be compared to these standardized values under any light source. Measurements of the surface taken with and without Kodak's Gray Card on the same spot are independent of any height or brightness level (or wattage) of a light source.

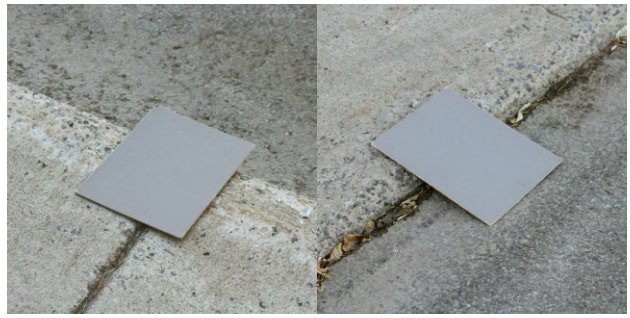


Figure 4.2 - Two views of Kodak's 8x10 inch Gray Card, with the grey side up, showing a reflectivity of 18%. The card is placed between an asphalt roadway and a concrete sidewalk.

There are numerous published tables with values for a coefficient of diffuse reflectivity for many manmade surface materials. The values, however, do not represent actual and real-world surfaces that can be encountered. All surfaces, whether they are concrete, asphalt or snow, have a layer of fine dirt and dust (and sometimes pollen) on top. The values in Table 4.1 are real measurements (with some estimates also included) of representative outdoor surfaces below street-lights, checked and confirmed by this author.

Figure 4.3 - The two sides of Kodak's Gray Card. The white, slightly aged side has a reflectivity of about 85%, and the grey side is 18% reflective. Part of an over-coated black asphalt driveway is on the right, while a concrete sidewalk is at left.

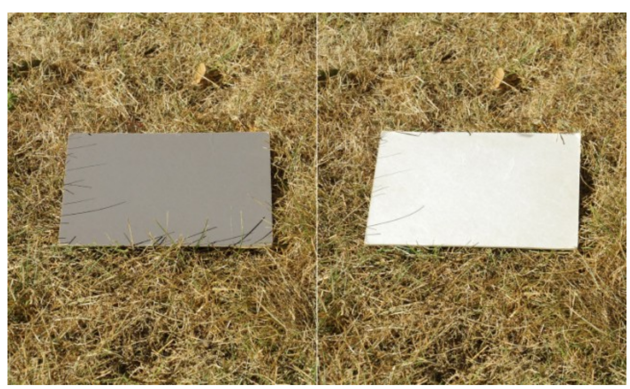


Figure 4.4 - Kodak's Gray Card, with the grey side up at left and the white side up on the right, is placed on a dead lawn.

Some of the entries may seem surprising and even a little controversial. For every sector, including for industrial, the difference in up-light between the older cobra-heads and FCO heads is statistically nil. Increasing the skybound light to 10% for classic cobra-heads in Table 3.2, yields similar results.

Assuming our reasoning has been accurate throughout, the greater useful light of FCO heads has a higher reflection component resulting in nearly equal up-light. The glaring light of the classic cobra-head is spread so widely at large distances from the source that it becomes lost, diminished by the inverse square and cosine laws and by surface features. These heads indeed cause local trespass and sky-glow by spreading light below the horizontal at extremely shallow angles above backyards, but in terms of widespread sky-bound light, they are practically as offensive as any sharp or semi-cutoff optic. Consequently, converting classic cobra-head street-lights to any FCO type luminaires merely for light-pollution reduction reasons should be considered as a waste of time.

Figure 4.33 - For whatever reason, when a classic cobra-head was replaced with a FCO one, the watts often remained the same. Compared to the former light levels, the new levels below a FCO street-light (second from right in this image) became double or more. The measured lux values are marked below four HPS heads, all of which showed a "25" NEMA tag.

The significance of FCO fixtures (HPS, LED or Induction) is that they enable municipalities to utilize ***lower wattages*** to accomplish the same lighting task; hence, up-light is reduced because of the lowered lumen output. As noted previously, lower wattages were rarely employed for HPS FCO heads. Cutting the lumens for new FCO fixtures is essential, and on the most part, happily, this is current practice for new LED systems.

Street-Lighting vs. Private-Lighting

Since we have an approximate up-light for typical street-lights, we can compare them to privately owned commercial and industrial fixtures. In the following, let's examine some typical lighting situations which do not pertain to street-lighting at all. Ballast and fixture glassware losses are nearly a wash for private or street-lighting and are not considered.

- A 250 watt metal-halide billboard luminaire can have two-thirds (67%) of its lamp light (11390 mean lumens) directed upward. This single fixture pollutes the night-sky like ***twenty-six*** 100 watt HPS cobra-heads in a summer urban setting (having 5% total up-light).

Figure 4.34 - Typical lot lighting fixtures have about 25% direct up-light. This single 400 watt flood-light pollutes like thirty-two 100 watt HPS older cobra-heads for urban settings.

- A 400 watt directional HPS luminaire flooding a large parking lot from atop an industrial building can have a quarter (25%) of its lamp-light directed above the horizontal (Figure 4.34). With about 6% of the remaining (75%) ground-ward light being reflected up (all asphalt: .13 x .571 x .75), this results in about 14000 mean lumens of total up-light [(25%+6%) x 45000 lumens]. This is the equivalent polluting power of ***thirty-two*** 100 watt older HPS street-lights for an average summer urban residential site with 430 mean lumens of up-light each (.05 x 8600).

Figure 4.35 - A lighting contractor had free reign to illuminate a company's flags in this small town in upstate New York in the mid 1990s. The ground-mounted HPS lamps were an incredible 400 watts and each one polluted like twenty 400 watt FCO street-light counterparts (5% for urban summer).

Figure 4.36 - The five 400 watt metal-halide billboard lamps (~67% up-light) that are facing us, pollute like forty-three 250 watt FCO HPS luminaires located on the very same highway (with 10% up-light for an industrial setting and no canopy).

- Even if only ***half*** of the light from one 400 watt metal-halide advertising lamp is sky-bound (14400 mean lumens up-light), this solitary luminaire can pollute the night sky like ***ten*** 150 watt FCO HPS luminaires in an industrial setting (no canopy) in summer (.10 x 14400 = 1440 lm).

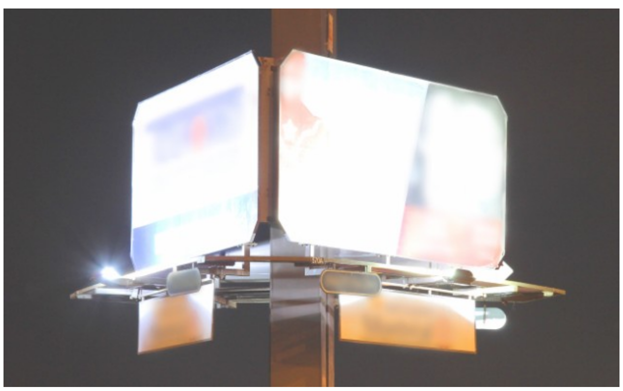


Figure 4.37 - Up-turned billboard lamps shed most of their light directly into the night sky. Therefore, the metal-halide spectral signature from these billboards (or LED for modern billboards) must be apparent in the night sky spectrum.

- A 400 watt HPS architectural lamp on the ground might have half its total light (22500 lumens) sky-bound while illuminating a building. Incredibly, this one fixture pollutes like ***fifty-one*** Cree XSP2 FCO LED 101 watt heads in a summer urban setting (about 437 lumens total up-light).

This entire number crunching exercise culminating in the values derived in Table 4.3 might appear meaningless; on the contrary, it demonstrates the difference between up-light due to public street-lighting and up-light due to private lighting. It should be painfully obvious that compared to typical public street-lighting situations, ***far greater up-light is caused with private lamp units*** which are pointed up or with any amount of upward spill**.** If significant numbers of these offensive fixtures enclose metal-halide lamps, their spectral signatures, notably the unique scandium lines, which can only be radiated by metal-halide lamps, (or thallium and indium lines for Asian and European cities), should be conspicuous in sky-glow spectra.

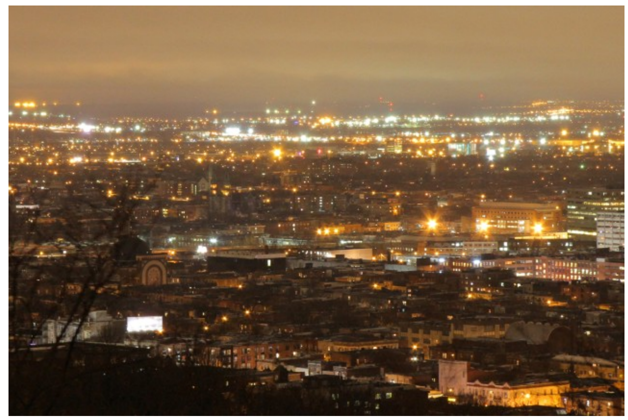


Figure 4.38 - It appears that a large proportion of urban light-pollution is caused by private outdoor commercial-industrial lighting. Unlike public street-lighting, privately owned high lumen output luminaires have greater amounts of light shinning directly into the night sky. The proportion of the sky-glow contribution from such lighting, potentially, might increase with any lower light levels implemented for street-lighting with new no-spill LED systems.

Examples of such volumes of light pouring directly into the night sky from commercial-industrial private lamps are plentiful. At least half of our urban light-pollution (but probably $2/3^{ds}$) could have been caused by these non-public luminaires. This can be proven by having obtained the spectrum of urban sky-glow over some decades. The question remains: will this situation improve or worsen with LED systems?

Crunching out the numbers has shown that ***upward pointed luminaires*** are the fixtures astronomers need to target in any light-pollution abatement efforts. If not, it is unlikely that urban and suburban sky-glow will ever decrease in a significant manner.

GE redesigned the HPS lamp in 1967, greatly improving lamp performance and life, but the lamp had to be produced for base-up or base-down operation only. Universal lamps became available again when GE developed special crimps to keep the sodium in a reservoir outside the arc-tube at its ends. Practical lower powered lamps were also developed during the 1970s.

Figure 5.20 - With a manufacture date of April 1979, this 250 watt HPS cobra-head served an industrial road for 38 years. Incredibly, when retired in 2018 it was replaced with a warm-toned GE Evolve LED FCO head with just 31 system watts.

Near the end of the 1970s HPS lamps had become quite reliable. With a life expectancy of 24,000 hours this was as long as for the mercury-vapor lamps; however, the raw lamp or system efficacy was at least twice that of mercury lamps. Supplying extra light, a 250 watt HPS lamp could replace a 400 watt mercury lamp. To match the 400 watt mercury lamp's output, the 200 watt HPS lamp was created. Such lamp powers were typically installed on boulevards and collector roads.

Figure 5.21 - Fresh and intense HPS cobra-head lighting of the past, associated with glare, light spill and a bright overcast.

Starting around 1979, most newly constructed streets were receiving HPS lighting standards. HPS and mercury lights on older roads would be seen side by side for well over a decade until municipalities decided to save on energy costs associated with running dusk-to-dawn mercury lighting. An equal mixture of sodium features and mercury lines would have been apparent in the spectrum of sky-glow up until full conversions to HPS occurred for an area. Full-blown conversions from mercury to HPS (or to SOX lighting in some cases) generally occurred in the period between 1983 and 1995. A few towns declined to modify their mercury lights, several installations of which lasted well into the 21st century.

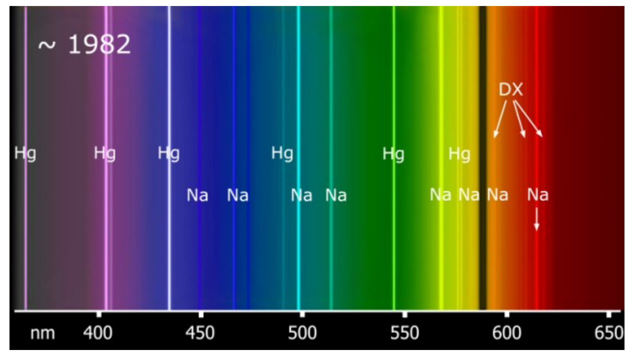


Figure 5.22 - The spectrum of urban and suburban sky-glow as it may have appeared over major North American cities around 1982. Cities adopting SOX lighting (low-pressure sodium) had the sodium doublet lines appearing inside the dark self-absorbed band. In urban settings, natural airglow emissions and the DX phosphor lines were ostensibly obscured by HPS's powerful yellow-orange continuum. No scandium lines (from metal-halide lamps) had appeared yet.

HPS lamps were applied extensively in the next few decades for the majority of outdoor lighting worldwide. For most lighting upgrades, light levels on the ground from the new HPS installations soared; two exceptions being for conversions from 250 watt mercury to 100 watt HPS, and those from 175 watt mercury to 70 watt HPS. Typical wattages of outlying suburban residential areas, these upgrades would have yielded equal or greater levels initially, particularly from lumen depreciated and dirty mercury luminaires, eventually dropping to slightly less than the former mean mercury levels.

With added lines and a good continuum in the yellow through to the red, the spectrum of urban sky-glow (shown in Figure 5.22) quickly became difficult to manage. Amateur astronomers scrambled to find good LPR (light-pollution) filters that adequately blocked the new spectrum; otherwise, many amateurs arranged to acquire their own portable scopes and vehicles to flee the brightening cities. Some urban amateur astronomers simply abandoned the hobby.

Night skies suffered immensely with HPS lighting. Remote locations ultimately became contaminated as the less scatterable orange wavelengths from HPS penetrated deeper into the atmosphere.

Light levels for intersections and on major thoroughfares were generally increased and numerous laneways were lit for the first time. Facade lighting using sodium lamps significantly contributed to orange hot spots, but by the start of the 1990s

Figure 7.6 - An inner city street in Montréal, Québec, received new 2700°K FCO LED systems at the end of 2018. The old HPS cobra-heads had significant spill, as seen at the marked green Xs, while the LED systems show very little. The wattages are unknown but the lux levels on the road appear nearly equal.

Figure 7.7 - Most industrial roads in the Montréal area and its suburbs had 150 and 250 watt HPS street-lights. The obvious drop in light levels in these districts with new LED systems points to a definite reduction in up-light, at least for street-lighting. The scene had been photographed to show the effect of the increased light levels on the ground with FCO heads.

The DSLR body temperature can influence the brightness, contrast and color output of an image, but being considerate of the previous imaging conditions, these effects can minimized.

A number of scenes had originally been photographed to show the increased light levels from FCO HPS heads, with lux levels on the ground having been recorded. The readings were repeated using the same lux meter with the new LED lighting.

By utilizing identical camera equipment and settings, acquiring before and after images has been as informative as in obtaining sky-glow spectra. In the least, numerous new LED public street-light installations appear to have lower lighting levels on the ground than the former street-lights. The direct up-light portion is unquestionably lower from all new LED street-light heads.

Figure 7.8 - Many residential and minor streets are receiving greater lux levels due to the initial output of the new LED systems. This is normal for neglected and underserviced HPS street-lights. A failed HPS street-light appears in the distance (top image). The rise in light levels would have been greater if all the former installations were relamped (in the region of 12 to 17 lux for new 100 watt HPS lamps in classic cobra-heads).

For the latest outdoor lighting transition in and around the area of Montréal, Québec, lighting levels on some roads have clearly decreased, notably for the over-lit HPS boulevards. On the other hand, for minor streets that received LED systems, the levels appear to have increased. It's not clear if the total up-light arising from public street-lighting has increased or decreased; large roadways with elevated light levels have now decreased, while for the far more numerous residential and minor roads, levels have increased. Given many of the past practices and current (2020) light levels for FCO LED systems, a decrease in up-light may not be in the offing. This will remain valid for several years before LED lumen output declines.

Figure 7.9 - Many older metal-halide perimeter lights are now being replaced with new and powerful LED systems. The same lot was photographed nearly three years apart with the same camera settings. The newly installed LED wall-packs are more polluting than previously with just two luminaires.

Figure 7.10 - With a pair of LED system units replacing failed units in the distance (at right), light levels soared when all the metal-halide flood lights for this industry lot were replaced. According to the exposure settings, a fourfold increase in the light level was estimated: to match the two histograms of the images the ISO had to be changed from 1250 to 320 ISO.

Significant early improvements in LED lighting levels had been realized for parking lots, industry wall-packs and for side lighting. These levels increased alarmingly by the summer of 2017, for a few reasons. The cost of an LED luminaire is directly proportional to the power (or watts) of the unit. With HID lamp technology of the past, the cost for the higher or lower watt versions differed little; with LED systems one actually pays for each watt installed. Today, the availability of high-powered LED luminaires offers all lighting companies the opportunity for the greatest profits possible by installing the highest powered units onto business properties. Another reason for the increased levels would be that businesses naturally consume more of a product as it becomes comparatively less expensive with time.

The newest LED systems for wall-packs and security lighting now have higher levels and sometimes a great deal higher than previously (Figures 7.9 and 7.10). FCO LED systems for parking lots might have less upward spill than preceding metal-halide or HPS fixtures, but current upgrades with lower lux levels on to commercial and industrial properties are rare. Again, this is partly due to the initial output of new LED systems compared to formerly neglected installations.

A Few Calculations

Since higher lux levels on the ground are required or desired for many areas, up-light should rise at first as LED conversions take place. This may not appear definite, but doing the math confirms that up-light can very easily increase with FCO heads. For the following calculations there are no Rayleigh scattering considerations favoring the shorter wavelengths of LED output.

First, ignoring reflections for now, let's consider only direct up-light from heads. If FCO LED systems are used in converting the many hundreds if not thousands of cobra-heads with sag-refractor in our cities, then:

FCO LED heads = 0% direct up-light;
Classic-cobras with refractors = 5% direct up-light.

A 5% drop in the up-light should result in a 5% drop in the light-pollution. Needless to say this will be difficult to notice by most people. However, if we accept that older cobra-heads had 10% direct up-light, there should be a 10% drop in the light-pollution, in which case it should be apparent.

For any type of fixture, the correct **Total Up-Light** formula is:

Total Up-Light = [Skybound + Reflected] • [1 - OL]
= [Skybound + ASR(CL)Useful] • [1 - OL]

…where **Skybound** and **Useful** are the fractions for a fixture's light budget; **ASR** is the average surface reflectance estimated for typical street-light situations; **CL** is the Cosine Law factor for reflectance and **OL** is a fraction for obstructed light. All these parameters were defined in Chapter 4 and appropriate values were assigned. Why a glaring portion is not part of the formula was clarified in detail in Chapter 4. Nonetheless, for *local up-light* considerations, let's add the **Glaring** portion to the formula into a **Useful** part. Without making an allowance for obstructed light (as for an open area, i.e., asphalt parking lots in industrial zones), the above formula simplifies to: