PRACTICAL GUIDE FOR LIGHTING

to reduce light pollution and save energy
"My star will be just one of the stars, for you. And so you will love to watch all the stars in the heavens."

— The Little Prince, Antoine de Saint Exupéry
Until the 19th Century, people only used the full moon, torches and simple lanterns to see at night. With the advent of gas and later electricity, night lighting has become more permanent and widespread, with the result that light pollution has slowly emerged. Light pollution can be defined as any modification of the natural light environment, especially that which causes some sort of nuisance. The most well-known forms of light pollution include sky glow, light trespass and glare.

Inefficient and excessive night lighting causes significant loss of energy globally. In North America, the energy wasted in illuminating the sky costs about a billion dollars. Here in Quebec, more light is produced per inhabitant than anywhere else in the world. It has thus been estimated that over 50 million dollars could be saved annually in this province by improving lighting management and cutting energy consumption by over 700 GWh/year.

Because of the multiple problems deriving from light pollution, astronomers, engineers, architects, designers and luminaire manufacturers have all come together to redefine requirements and draft solutions for outdoor illumination. Several municipalities near Mt. Megantic have adopted innovative regulations to combat the growing concerns over light pollution.

This practical guide follows that trend and is based on recent trials in the Mt. Megantic region. Although it is primarily intended for lighting professionals and suppliers, the general public will also find advice for simple actions that will reduce light pollution and energy consumption. The first part of the guide explains basic ideas regarding efficient management of exterior lighting and offers useful tips on how to determine the level of illuminance required and how to select an appropriate luminaire.

The second part provides examples of different lighting applications so that the reader can design a lighting system that not only offers excellent visibility but also limits over-illumination. The document ends with a glossary of technical terms used.

LIGHT POLLUTION AND STAR GAZING

Stars are less visible when the sky is illuminated and only 3% of stars can be seen today from most cities and suburbs. One must now travel several hundreds of kilometers from an urban centre to witness a clear, starry sky. This is one of the major consequences of light pollution, which not only affects the work of astronomers but also deprives city dwellers of the possibility of enjoying the beautiful night sky.

A dark sky is essential to astrophysicists for the observation of celestial objects, particularly those of faint luminosity. Light pollution in the Eastern Townships seriously threatens studies at the Mt. Megantic Observatory, the most important astrophysical research centre in Canada. This pollution also restricts educational and tourist activities at the ASTROLab in the Mt. Megantic provincial park.

These two photos were taken in a Toronto suburb during a widespread electrical blackout (on the left) and after electricity was restored (on the right). The Milky Way is clearly visible in the dark sky but completely obscured with light pollution.

Source: Todd Carlson
PLANNING AN EFFICIENT LIGHTING SYSTEM

Today there exists a vast choice in luminaires that have been designed to reduce both energy consumption and light pollution. To fully benefit from the newest technologies, however, a radical change in everyday habits is required.

I. ASSESS YOUR REQUIREMENTS

Night lighting fulfills the dual needs of seeing and being seen. This is the first question you should ask yourself: Is lighting really needed?

If so, then go on to define your requirements:
- **What** areas or objects should be illuminated?
- **How much** illuminance is needed?
- **When** is the lighting necessary?

By following the recommendations in this guide (and by respecting the regulations in force in your municipality), you can determine the appropriate illumination for your requirements.

II. DIRECT LIGHT WHERE IT IS NEEDED

Remember that only certain areas need to be illuminated. Concentrate lighting in these places only. Following this simple principle has several positive consequences. It:

1. saves energy,
2. decreases light pollution,
3. reduces light trespass,
4. increases safety.

Casting light upwards to the sky or onto adjacent areas is a waste of energy. If we were to think of luminaires as taps and leaking light rays as drops of water, we would never tolerate such an extravagance!

III. AVOID GLARE

Glare occurs when the eyes are exposed to a relatively bright source of light compared to background lighting levels, which results in contraction of the pupils. Visual perception is greatest when illumination is uniform and so contrasting glare significantly reduces visual performance and visibility. Avoid producing glare by noting levels of ambient lighting and carefully controlling how beams of light are directed.

A luminaire that emits a concentrated beam of light offers better visibility than one that shines light in all directions. In certain cases, the effects of glare can compromise safety.
Uniform lighting of an area is not always necessary. In some cases, it is possible to manage the night environment by placing visual markers to orient travellers.

IV. PLAN YOUR LIGHTING SYSTEM ACCORDING TO PRE-DEFINED NEEDS

Once you have defined your lighting requirements, you are ready to plan your lighting system:

- First, assess the environmental lighting level (roadway luminaires, signs etc.) to see how it could help fulfill your needs;
- Next, determine whether complete illumination is necessary or whether a series of accent lights could suffice;
- Find the best locations for installing luminaires;
- Choose luminaires according to their photometric report;
- Determine the minimum bulb strengths required, taking into account the surface area to be illuminated and the number, type, height and location of luminaires to be used.

You can check your lighting plan using point-by-point illuminance calculations. These values are generally available from manufacturers, distributors, engineers and architects.

Feel free to use the examples in this guide as inspirations!
CHOOSING THE RIGHT LIGHTING COMPONENTS
Several lighting devices (bulbs and luminaires) can be utilized to build the lighting system you have planned. Once again, you should let the economizing principle be your guide.

I. CHOOSING THE RIGHT BULB

Sky glow above cities is mainly caused by white light. That is why it is recommended to reduce the use of bulbs that emit white light and to utilize low-power bulbs whenever possible. In addition, certain types of bulbs consume more energy than others with the same light output. You should therefore choose bulbs with a high lamp efficacy.

Table 1 shows a classification of the different types of light bulbs available with respect to lamp efficacy. Recommended uses according to the regulations in force in the region of Mt. Megantic and the City of Sherbrooke are also included. Table 2 demonstrates the relationship between input power and luminous flux for these bulbs.

<table>
<thead>
<tr>
<th>TYPE OF BULB</th>
<th>Usage</th>
<th>Lamp luminance (lm/W)</th>
<th>INPUT POWER (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-pressure sodium (HPS)</td>
<td>Yes</td>
<td>100</td>
<td>15-20 35 50 70 100 150 250</td>
</tr>
<tr>
<td>Metal halide (MH)</td>
<td>No, some exceptions</td>
<td>85</td>
<td>- 2,000 4,000 6,000 9,600 16,000 24,000</td>
</tr>
<tr>
<td>Compact fluorescent (CFL)</td>
<td>Yes, if less than 20 W</td>
<td>60</td>
<td>900-1,200 - - -</td>
</tr>
<tr>
<td>Mercury vapour (MV) (1)</td>
<td>No</td>
<td>40</td>
<td>- - 2,000 3,000 4,000 6,000 10,000</td>
</tr>
<tr>
<td>Incandescent/ Halogen</td>
<td>Yes, if less than 100 W</td>
<td>15</td>
<td>100 - 600 1,000 1,500 2,300 -</td>
</tr>
<tr>
<td>(1) The luminous flux of the mercury vapour bulb deteriorates very rapidly compared to other types of bulbs.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Classification of the main types of bulbs according to lamp efficacy.

Table 2. Relationship between input power and luminous flux for the main types of bulbs.

WHITE LIGHT POLLUTES!

Light in the sky is visible due to reflection off airborne particules (dust, aerosols, humidity) and diffusion by the atmosphere. Diffusion increases as the wave length of light decreases. Thus blue light is more diffused than yellow light, which is more diffused than red light. This explains why blue light contributes disproportionately to concealment of the stars.

The relative intensity of the different colours that make up light varies from one type of bulb to another. The figures above represent the light spectra of a mercury vapour bulb (on the left) and a high-pressure sodium bulb (on the right). Light emitted by the mercury vapour bulb is very white and contains much more blue than the sodium bulb, which is more yellow. This means that the mercury vapour bulb pollutes more than the sodium bulb.
Choose devices with the highest energy efficiency and durability possible. These components will not only provide improved quality of lighting but also respect the night environment.

II. CHOOSING THE RIGHT LUMINAIRE

Avoid lighting up the sky
Remember that light directed towards the sky does not improve night vision. Choose luminaires emitting less than 1% of luminous flux above the horizon. This can be verified in the photometric report. Examples of good choices include those:

- having a flat lens and a shield that completely shades the upper surface of the bulb;
- classified as full cutoff (FCO) by IESNA;
- installed under balconies, eaves, etc.

Choose a luminaire with a high efficiency
The efficiency of a luminaire is the ratio of the luminous flux of a luminaire to the luminous flux of the bulb, expressed as a percentage. You should thus choose the most efficient luminaires. Table 3 shows typical efficiencies of luminaires that direct minimal amounts of luminous flux to the sky.

However, don’t forget that only some of the light produced by a luminaire falls on the ground, since the rest is either lost in space or as heat. Take, for example, a wall sconce having an efficiency of 60% and a bulb of 6,000 lm. If 15% of the luminous flux is directed upwards, then 45% of the flux is directed downwards. Thus, of the 6,000 lm originally emitted by the bulb, 3,600 lm leave the luminaire and only 2,700 lm are actually available for lighting the ground.

Aim the light where it is needed most
Use the photometric report to determine the distribution of the luminous flux on the ground around the luminaire and then choose a luminaire that fits your specific requirements.

<table>
<thead>
<tr>
<th>TYPE OF LUMINAIRE</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional roadway luminaire</td>
<td>75% to 85%</td>
</tr>
<tr>
<td>Decorative roadway luminaire</td>
<td>60% to 80%</td>
</tr>
<tr>
<td>Wall sconce</td>
<td>60% to 85%</td>
</tr>
</tbody>
</table>

Table 3. Typical efficiencies of good luminaires.

When choosing a roadway luminaire, maximize the proportion of light emitted along the street side of the road and minimize the proportion emitted on the house side.
CHOOSING ILLUMINANCE ACCORDING TO THE APPLICATION

Excessive illuminance constitutes light pollution and a waste of energy. It is always preferable to produce a moderate yet uniform illuminance. This allows the eye to adapt to ambient light levels while ensuring the required visibility.

Minimize illuminance

Table 4 indicates recommended illuminance levels for the main types of exterior lighting applications. These recommendations for rural and urban milieus have been approved by the IESNA and correspond to regulations adopted by the region of Mt. Megantic and the City of Sherbrooke to preserve research activities at the Observatory.

Extinguish lights when not in use

Darkness is incorrectly associated with crime. Artificial lighting, especially when very intense, creates a false feeling of security.

For this reason, non-residential lighting should be switched off after 11 p.m. or when not in use. Public spaces that are frequented at night, however, should stay illuminated.

The full moon provides very low but uniform illumination (~0.1 lux) that does not generate glare.

Source: Éric Ladouceur

The table below indicates recommended illuminance levels for the main types of exterior lighting applications.

<table>
<thead>
<tr>
<th>LIGHTING APPLICATION</th>
<th>Rural or semi-rural situation</th>
<th>Urban situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial display areas</td>
<td>50 à 75</td>
<td>100</td>
</tr>
<tr>
<td>Automobile dealerships</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Other sales areas</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Storage areas</td>
<td>40 à 50</td>
<td>50</td>
</tr>
<tr>
<td>Loading, handling or work areas</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Pedestrian and cycling zones</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Building entrances</td>
<td>10 à 15</td>
<td>15 à 25</td>
</tr>
<tr>
<td>Roadways1 (According to use)</td>
<td>4 à 12</td>
<td>6 à 17</td>
</tr>
<tr>
<td>Parking lots</td>
<td>10 à 15</td>
<td>15 à 25</td>
</tr>
<tr>
<td>Service stations</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Pumping areas</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Surrounding areas</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*No road should be lighted outside city limits, except at intersections.

Table 4. Recommended illuminance for main exterior lighting applications.
ILLUMINANCE CALCULATIONS

To design a lighting system that is efficient and respects the night environment, one needs to determine the specific illuminance pattern that will be produced. This information may be found in the detailed, point-by-point illuminance calculations, which produce a plot of illuminance onto a surface area. Once the components of the system have been installed and turned on, the actual illuminance can then be measured using a light meter.

Don’t forget that the performance of luminaires decreases with time due to numerous factors, such as wear, dirt deposits, leaking of the seal, type of bulb, etc. This phenomenon is accounted for through the inclusion of a maintenance or light loss factor.

Look for the following information in the point-by-point calculation summary:

- maintained illuminance on the ground: average, minimum and maximum (Eavg, Emin, Emax);
- uniformity of the lighting, as determined from Eavg/Emin;
- number and input power (W) of the bulbs;
- the light loss factor used.

The figure below shows a typical point-by-point layout and summary.

Example of a point-by-point layout with two roadway luminaires along a street. Each point on the grid corresponds to an illuminance value in lux.
ROADWAYS
The lighting of a roadway must be designed to protect the safety of all users. Quality of illumination is extremely important in the following situations: busy pedestrian zones, places where pedestrians come into proximity with vehicles and intersections. In order to create good visibility, illuminance should also be uniform, that is, the ratio of average to minimum illuminance should not exceed 6.

URBAN AREAS
Streets in city centres typically contain high densities of both cars and pedestrians. Illuminance of these roadways should correspond to the greatest recommended average illuminance, i.e., 17 lux.

HYDRO SHERBROOKE AND THE UNIVERSITY OF SHERBROOKE TRANSFORM THE CAMPUS SECTOR

Before the conversion

The campus exit from the University of Sherbrooke connects to the University Boulevard. These two roadways each contain four lanes and are lighted by double-headed luminaires from a height of 9 m. The lampposts are spaced 25 m apart on the exit highway and 40 m apart on the boulevard. Before conversion (photo on left), the campus exit was intensely illuminated (75 lux) by 400 W high-pressure sodium lamps. The University Boulevard (photo on right) received less illuminance (17 lux), but the 250 W high-pressure sodium bulbs emitted a high proportion of luminous flux towards the sky and in the glare zone.

After the conversion

Installation of new Helios luminaires allowed for maintenance of the standardized 17-lux illuminance level using only 150 W high-pressure sodium bulbs. Replacing all 90 luminaires along the routes adjacent to the university led to an energy saving of about 100,000 kWh/year.
THE TOWN OF LA PATRIE ALTERS THE ROADWAY LIGHTING SYSTEM

Before the conversion

The town of La Patrie is situated at the foot of Mt. Megantic. The main road, which is approximately 12 m wide, used to be illuminated by a series of luminaires that were 8 m high and 30 m apart. These luminaires did not control any of the distribution of the luminous flux and supplied an excessive illuminance of 15 to 20 lux on the ground using 150 W high-pressure sodium lamps.

After the conversion

Thanks to the lighting conversion program of the Mt. Megantic ASTROlab, Helios type luminaires fitted with 70 W high-pressure sodium lamps were used to replace the old luminaires. The careful control of luminous flux now assures that the luminaires do not illuminate the sky or the walls of nearby houses. Also, the roadway is more discretely illuminated at 8 to 10 lux.

The Helios roadway luminaire by Lumec is classified as cutoff by IESNA. The sag lens permits a downward efficiency of 83% and restricts less than 1% of the luminous flux from reaching the sky.
BUILDING FACADES AND SURROUNDINGS

Building facades and surrounding areas are often illuminated at night. This type of lighting serves several purposes. It can illuminate commercial signs, building entrances and adjacent parking areas.

High-power wall sconces or floodlights are often utilized to this end. However, these fixtures are inefficient, produce glare and usually direct over 15% of the luminous flux to the sky. In order to decrease light pollution and save energy, choose a moderate lighting system that will allow clients to safely enter buildings without producing over-illumination.

The entrance to this school is sufficiently illuminated by a full cutoff FPM luminaire by Keene that utilizes a 35 W high-pressure sodium bulb. Here we see all the characteristics of an appropriate lighting fixture: good visibility, energy efficiency, concentrated light and pleasing design.

The illumination of the front facade of this bakery makes for a safe entrance. It is therefore not necessary to install extra luminaires in the parking area. The discrete lighting provided by the recessed luminaires in the eaves adds lots of style to the building. This example shows that one need not over-illuminate a business to promote it.
After the conversion

Following the lighting conversion program of the Mt. Megantic ASTROlab, the same business only uses 70 W bulbs, which reduces energy consumption by 1,500 W. Also, certain wall sconces were repositioned to be above, rather than below, the areas to be illuminated. This stopped directing light to the sky.

The FPM luminaire by Keene is classified as full cutoff by IESNA. No luminous flux is emitted towards the sky and downward efficiency is 60%.

This funeral home in Lac Megantic was illuminated by 13 wall sconces fitted with 150 W (11 bulbs) or 400 W (2 bulbs) high-pressure sodium lamps.
Replacing the 21 luminaires in the parking lots of the University of Sherbrooke reduced the total power consumed by a factor of four. Each fixture used to contain four high-pressure sodium bulbs and was replaced by a single floodlight of the same power (400 W). The illuminance on the ground was maintained at 15 lux and savings add up to 120,000 kWh/year.

Source: Guillaume Poulin
This gas station provides adequate lighting without glare, by using recessed luminaires in the ceiling of the roof.

A SERVICE STATION THAT DOESN’T ILLUMINATE NEIGHBOURING PROPERTIES!

This dealer displays the rows of cars with luminaires that take 400 W metal halide lamps. The luminaires supply an average illuminance of about 60 lux to the ground. This is four times less than that normally generated for this type of application using floodlights of 1,000 to 1,500 W. In addition, it is strongly recommended to extinguish at least some of the lighting outside business hours. Reducing illuminance levels and occasionally turning off the lights in a dealership with 32 such luminaires could save 115,000 kWh/year, which would result in a difference of about $10,000 per year. The initial investment will be quickly returned!

A DEALER WHO SETS A GOOD EXAMPLE!

These two photos demonstrate good planning for urban lighting. In both cases, the lighting fixtures do not direct light to the sky nor beyond the limits of the commercial property.
LOADING AND HANDLING ZONES

Although it is generally preferable to use moderate lighting, certain circumstances require increased illuminance levels. This applies notably to agricultural and industrial situations and businesses having exterior loading zones. It is necessary, however, to be careful not to exceed actual requirements.

Now the new high-performance RW-115 luminaires illuminate the sawmill with 150 W bulbs. The company gains through energy savings and improved safety.

The high-performance luminaires of the series RW-115 by AEL are classified as full cutoff by IESNA.
The use of security lighting and floodlights is currently widespread for this type of application. These luminaires waste energy because not only do they create glare but they also direct up to 50% of the light output towards the sky. Floodlights typically utilize 400 W mercury vapour bulbs or 1,000 W halogen lamps. Mercury vapour bulbs have an efficacy that is one fourth that of high-pressure sodium bulbs. Also, mercury vapour bulbs have high lumen depreciation over time.

Before converting the lighting system, this factory produced glaring and polluting light with its 21 mercury vapour lamps (400 W each).

The factory currently illuminates its buildings with luminaires that offer improved control of the luminous flux and utilize 70 W high-pressure sodium bulbs. This conversion reduced energy consumption by 32,000 kWh/year. Given that electricity costs $0.08 per kWh in Quebec, this represents an annual saving of $2,500.
The rapid and constant increase in light pollution in the region of Mt. Megantic led the Observatory and ASTROlab to search for solutions to this important problem.

Thus it was in 2003 that the ASTROlab established a light pollution abatement project. This project involved sensitizing the public, encouraging regulations and converting luminaires.

Significant media coverage has promoted a greater awareness in the general public of the Eastern Townships and Quebec. Exterior lighting regulations are now in effect in 34 municipalities of the Haut St. François and Granit MRCs, as well as in the City of Sherbrooke. In addition, all three levels of government and several related organisms have supported the project, in order to encourage new expertise in energy efficiency and sustainable development. These financial contributions have allowed the ASTROlab to launch an ambitious public and private lighting conversion program, which has resulted in:

- an approximate 25% reduction in light pollution at Mt. Megantic;
- an energy saving of 1.5 million kWh/year;
- a unique showcase of how efficiency works in the management of night lighting.

The combination of all these actions has borne fruit. Not only has the region of Mt. Megantic begun to rediscover the stars, but also it has been designated as the first International Dark Sky Reserve in the world!
IESNA CLASSIFICATION
The design of a luminaire determines how the light will be emitted into the environment. Since designs vary widely, the distribution pattern of luminous flux around the luminaire can also vary greatly. The IESNA (Illuminating Engineering Society of North America) has established a cutoff classification system of luminaires according to the proportion of light emitted towards the sky and also in the potential glare zone (in the 10° angle below the horizon). The different classifications are full cutoff, cutoff, semi cutoff and non cutoff.

ILLUMINANCE
The ratio between luminous flux and the illuminated surface area in lux (lumens per square meter) or footcandles (lumens per square foot). Illuminance can be measured with a light meter or calculated according to characteristics of the lighting system.

INITIAL AND MAINTAINED ILLUMINANCE
Initial illuminance is the light output rating of a lamp before applying the light loss factor. This rating applies when the lamp is first installed. Maintained illuminance is the light output rating of a lamp after applying the light loss factor and corresponds to the average illuminance level expected over the long term.

LAMP EFFICACY
The ratio between luminous flux and the electrical power consumed by a lamp, expressed in lumens per watt (lm/W).

LIGHT LOSS FACTOR
This factor is used to calculate average maintained illuminance, or simply the “average illuminance”. This factor accounts for the various effects and processes that alter luminous flux over time: lumen depreciation of the bulb, dirt deposits on the luminaire, leaking of the seal, decay of the ballast, etc. For real world measurements, the light output of a lamp is set to the expected long-term output value by multiplying the initial light output by the light loss factor to obtain the average illuminance. Light loss factors typically range from 0.6 to 0.9.

LIGHT TRESPASS
A condition in which undesired light is cast on a property or a dwelling. Light trespass is harmful when it negatively affects the well-being or activities of individuals at that place. All lighting that spills outside a property, even if it does not directly bother someone, must be considered a waste of energy.

LUMINOUS FLUX
The total amount of light emitted by a bulb in all directions as perceived by the human eye, measured in lumens (lm). This value is marked on bulb packages as “light output”.

PHOTOMETRIC REPORT
A technical report describing the principal characteristics of a luminaire, especially how the light is emitted. The report contains data relating to the manufacture of the luminaire, including:
- percentage of luminous flux emitted above the horizon;
- percentage of luminous flux illuminating the ground;
- distribution of luminous flux in a horizontal plane around the luminaire;
- IESNA classification.
In acting against light pollution, we help promote the nocturnal landscape.

Let’s light up the night discretely, to preserve its natural beauty!

The Mt. Megantic ASTROLab thanks the following partners who actively work to preserve the starry sky in an era of sustainable development: