Attachment 1

THE CITY OF Edmonton

Light Efficient Community Policy



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Executive Summary

The goal of this project was to develop technical and background information for a “Light Efficient Community Policy” for all city-owned lands and properties. This document defines new and proven methods and practices, reviews relevant research, presents new technologies and concepts, and assesses existing lighting in the city.

The report reviews specific technologies and concepts and their potential to save significant power in and money for the city. The report also includes significant information on visibility, health, safety, power reduction, and the reduction of light pollution.

The city operates over 97,500 outdoor lights, the vast majority of which are streetlights. Therefore, the majority of the focus is on street lighting. Research shows a high safety value for street lighting in urban collector and arterial roadway applications, along with both urban rural intersections. Lighting also is shown to provide a feeling of security, though it does not make one safer.

In recent years the city has been proactive in assessing new technologies and has retrofitted over 13,000 existing streetlights to LED. The city currently follows industry lighting standards from the Transportation Association of Canada. In its most recent residential lighting recommendations, the city has given extra attention to minimizing over-lighting, to avoiding changes to existing pole locations, and to maintaining historic lighting levels in established residential neighborhoods. A very limited assessment of existing lighting in Edmonton reveals a range of old and new lighting. The quality of design varied. Some areas of over-lighting, particularly in arterial roads, were identified.

A review of medical and biological research suggests that exposure to light at night, such as from outdoor lighting could pose some health risks. The evidence could be considered inconclusive, although the American Medical Association and the World Health Association have taken strong stands against exposure to light at night.

The city currently spends over $11M dollars annually for the power and maintenance of outdoor lighting. This cost could be dramatically reduced along with the city’s overall carbon footprint by retrofitting to LED lighting with an adaptive lighting (dimming) technology. The cost of installing these systems on a city-wide basis would require a very large capital investment of well over $50M dollars. However, the Return on Investment could be in the range of 50% based on possible power and maintenance savings.

Some of the energy saving recommendations and concepts presented are on the leading edge and will require small-scale pilot deployments to review and monitor impacts and public acceptance.

It is recommended that the city develop a strong promotional campaign, as was undertaken with the City of Calgary’s 2005 Envirosmart™ streetlight program.

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1 Introduction

The goal of this project is to develop technical information for a “Light Efficient Community Policy” for all city-owned lands and properties. The main objectives are to define where lighting best serves the community and defining ways to reduce energy consumption, greenhouse gas generation, and light pollution.

Key elements include research, investigation, and recommendations of best practices for the efficient use of outdoor lighting. Also included is a review of potential health and safety issues/benefits related to outdoor lighting.

The report is broken down into the following sections:

1. Introduction
2. Lighting and Vision
3. Purpose and Justification for Lighting
4. Potential Lighting Impacts and Mitigation
5. Existing Conditions (Benchmarking)
6. Energy Saving Concepts and Technologies
7. Policy Recommendations
8. Future Direction

The contents of this document are heavily focused on street and roadway lighting, since they constitute the largest amount of outdoor lighting owned by the city. Other city-owned lighting that is covered here includes that of walkways and multiuse paths, building exteriors, parking facilities, transit facilities, waste management facilities, parks and natural areas, special places, temporary lighting, and digital signs.

1.1 Stakeholders

A list of the main stakeholders and their roles with respect to this report and lighting is as follows:

1.1.1 City of Edmonton

The City of Edmonton owns and manages the design, installation, and maintenance of various outdoor lighting equipment within the city boundaries. The city’s role in developing this policy is to manage and oversee the consultant undertaking this work and provide support and direction. Based on the information provided and agreed upon, the city will prepare and distribute the Outdoor Lighting Policy.

1.1.2 Edmonton Federation of Community Leagues (EFCL)

The role of the EFCL is to speak on behalf of all community leagues. EFCL assists and supports the work of community leagues through program development and delivery, workshops, regular communications, advice on issues and opportunities, joint purchase of supplies, and attraction of sponsorships. The EFCL provided information and comments throughout the process.

1.1.3 Light Efficient Communities Coalition (LECC)

The Light Efficient Community Coalition (LECC) is a group focused on reducing energy consumption and light pollution while enhancing safety. The LECC provided information and comments throughout the process.

1.1.4 Urban Development Institute (UDI)

The Urban Development Institute (UDI) is a national, non-profit association representing the development industry. Members are development companies and professionals involved in the industry such as planners, surveyors, architects, landscape architects, engineers, contractors, lawyers, and a variety of municipalities and utility companies. The UDI provided feedback throughout the process.

2 Lighting & Vision Principals

Light and vision are the core elements of outdoor lighting and therefore require in-depth explanation and discussion. In defining visibility, many mechanisms and components comprise our ability to detect an object or hazard while driving, cycling, or walking at night.

The concepts of light and vision are, however, very complex and are explained in this document as they relate to new lighting concepts and the methods listed. For those who require further information on light and vision, please refer to the Illumination Engineering Society (IES) Lighting Handbook (10th Edition).

2.1 Structure of the Eye as it Relates to Vision

In order to understand the basic principles of vision one must understand how the human eye works. The human eye is very complex and, for the purposes of this document, only a basic overview of the principles that relate to vision is provided. Basic principles covered include the structure of the eye, function of the pupil, adaptation, accommodation, and function of the retina. Many of these principals are referred to or discussed in other parts of this document so a basic understanding is therefore required. The key elements of the human eye are shown in Figure 1 - Structure of the Eye and are explained below.

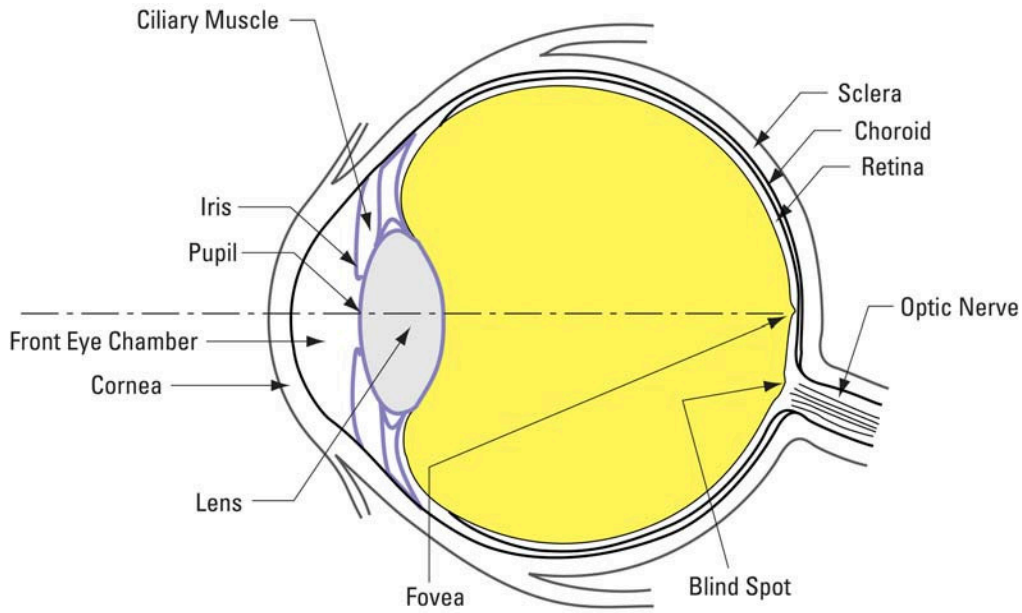


Figure 1 - Structure of the Eye

Light passing through the cornea traverses the front eye chamber and it's transparent aqueous filling. It is then either imprinted upon on the iris, which is the opaque coloured portion of the eye, or it passes through the pupil, the black circular orifice surrounded by the iris. The iris is able to expand and contract, altering the diameter of the pupil, and thereby providing a means of regulating the amount of light entering the interior of the eye.

The light then passes through the lens, which has a variable focal length. The thickness and curvature of the lens is controlled by the ciliary muscles. The lens focuses an image on the retina, which via the light-sensitive optic nerve is connected to the brain. The retina contains two types of photoreceptors: rods and cones. Rods, which are the most numerous in the retina are more sensitive and function at a lower light level than the cones. Rods are also not sensitive to colour. Cones are sensitive to colour and are divided into red (64%), green (32%), and blue (2%) cones.

Adaptation is a retinal process by which major changes in eye sensitivity are achieved. Feedback from the brain to the retina causes the sensitivity of the retina to adapt to the prevailing brightness. The retina undergoes localized adaptation and one area of the retina may be adapted to a high light level because it is receiving the image of a bright light source, while another part of the retina may be adapted to a low light level because of a dimly lit area of the nighttime scene. However, such adaptation is not perfect. An eye fully adapted to darkness cannot easily adapt to high light levels and glare sources. The goal of good lighting design is, therefore, to limit the presence of very bright sources, and to ensure adequate uniformity by eliminating areas of excessively low light level where vision may be overwhelmed by high brightness areas.

States of eye adaptation are defined as photopic, scotopic, and mesopic vision as defined in Figure 2 - States of Eye Adaptation.

Cones	Rods	Both Cones and Rods Functioning
"Day" Vision	"Night" Vision	"Dim Light" Vision
Photopic Vision	Scotopic Vision	Mesopic Vision
Operating Range: $\approx$3.4 cd/m^2 to +100,000 cd/m^2	Operating Range: $\approx$3.4 × 10^{-6} cd/m^2 to .034 cd/m^2	Operating Range: $\approx$.034 cd/m^2 to 3.4 cd/m^2
Very Good Visual Acuity	Very Poor Visual Acuity	Diminished Visual Acuity
Color Vision	No Color — B & W Only	Driving a Vehicle at Night
Light Adaptation	Dark Adaptation	
Maximum Concentration in the Fovea	Maximum Concentration at the Edge of the Macula	
Number Decreases in Periphery	No Rods in the Fovea	

Figure 2 - States of Eye Adaptation

This distribution of receptors and "wiring" of the retina to the brain accounts for the very high resolution obtained in the fovea. This is also the reason that the direction of view constantly changes, as this brings images from different parts of the field of view onto the foveal region for high-resolution viewing. The eye movements occur roughly five times per second, and the eye is said to "fixate" on different points in the field of view. Much lower resolution occurs in the peripheral field due to the receptors being grouped. Peripheral vision is less acute than foveal vision under most circumstances. Peripheral vision, however, is highly important to roadway users. When a hazard appears, it will very often first appear off the roadway. For example, a pedestrian running towards the roadway or another vehicle is approaching from a side road. It is unlikely that the axis of the eye is directly pointed to such objects at the moment they appear.

Only all-cone foveal vision enables the detection of small details, which explains why nighttime drivers might not be able to identify details in a scene. Scotopic vision tends to allow object detection until the object is illuminated by the vehicle's headlamps and the identification of more details is possible through photopic vision.

Because peripheral vision at night relies heavily on the rods of the retina, providing lighting to stimulate the rods is beneficial. Furthermore, because the light level affects the relative extent to which rods and cones are active, it can be seen that there is a complex interrelationship between light level, retinal activity, and visibility.

2.1.1 Spectral Properties

Light is radiant energy in the visible part of the electromagnetic spectrum between 380–770nm. Within this range different wavelengths are seen as different colours. Figure 3 - Electromagnetic Spectrum shows that radiation from the shorter wavelength end of the visible spectrum is perceived as "violet" while the longer wavelength at the other end is perceived as "red".

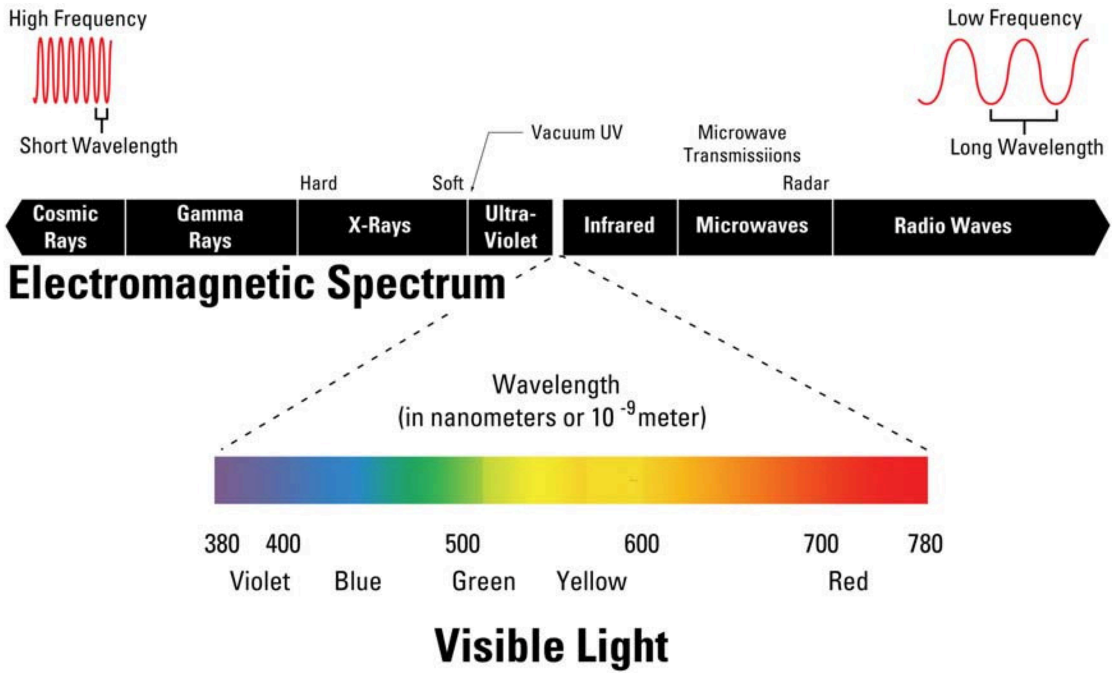


Figure 3 - Electromagnetic Spectrum

The eye has varying sensitivity to different wavelengths within this visible spectrum depending on the state of adaptation. The measure of eye sensitivity to light is represented by the V Lambda curve (shown in Figure 4 - V Lambda Curve). Scotopic (rod vision) and photopic (cone vision) have their own specific curves to represent the relative spectral luminous efficiency of the visible light at various wavelengths (i.e., colours). The solid curve represents the eye response when using photopic vision and shows that at well-lighted areas, light sources in the yellow range (such as high-pressure sodium lamps) would be rated at a higher power value (lumen output) than a source with the same amount of more blue content like metal halide and LED sources. The dashed curve representing the eye response when using scotopic vision shows that at very low light levels (e.g., starlight), light sources with more blue content would be allocated a higher lumen value. The peak scotopic wavelength is 505 nm and the peak photopic wavelength is at 555 nm.

There is a varying biological sensitivity to different portions of the visible light spectrum. In particular the response curve for basal ganglion cells in humans is sensitive to the high-frequency end of the visible light spectrum (blue, violet, ultra-violet). There is an increased sensitivity for most animal and some plants to this spectrum. In terms of spectral effects reference section 2.4.8 Correlated Colour Temperature should be referenced as it is a significant measure.

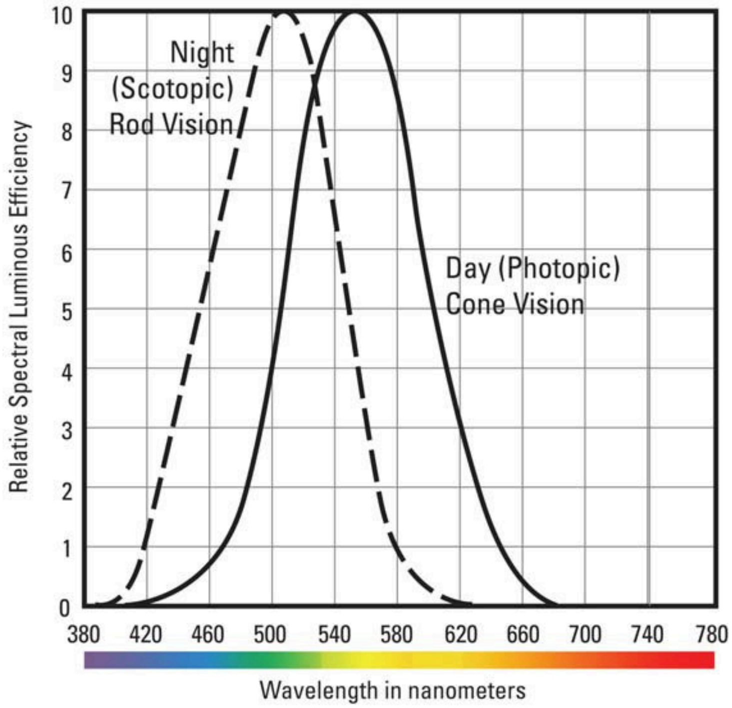


Figure 4 - V Lambda Curve

Essentially, the rated lumen outputs of light sources are based on the photopic luminous efficiency. If, however, the eye were operating in the scotopic range, a different curve would be used and a different wavelength or colour of light would be more effective. Roadway lighting levels are in the mesopic range, and are much closer to the photopic range than the scotopic range as defined in Figure 5 - Light Levels as Related to Visibility. This figure also draws a comparison to roadway light levels commonly used in North America, namely the Illuminating Engineering Society (IESNA) and the Transportation Association of Canada (TAC) standards, and those used in other parts of the world (defined by CIE[1] designation) which are significantly higher. This is discussed further in Section 5 Existing Conditions (Benchmarking).

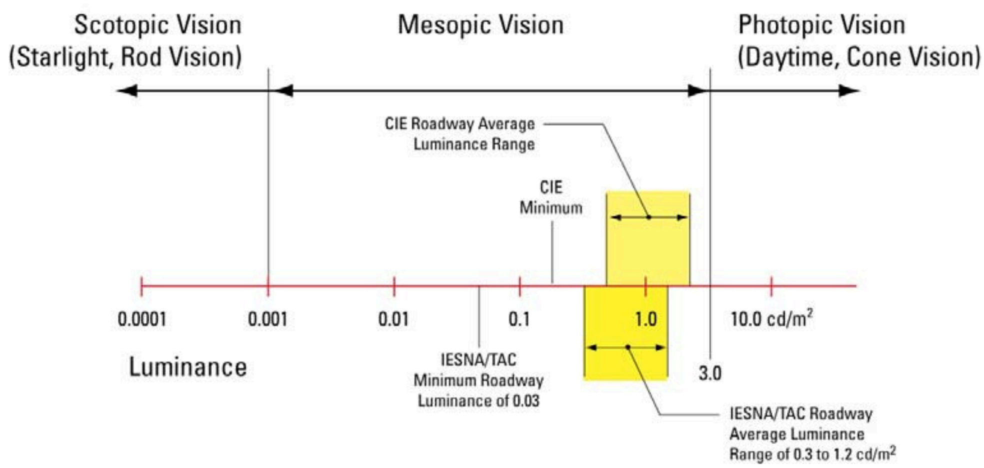


Figure 5 - Light Levels as Related to Visibility

Some lighting manufacturers promote the use of scotopic lumen multipliers if a white light source, such as metal halide or LED, is used. There is no solid basis for the use of scotopic multipliers and they should not be used for any outdoor lighting.

Models have been developed in recent years suggesting modifying factors which can be applied to adjust the calculated photopic values to the expected mesopic values. These are based on defined scotopic/photopic (S/P) ratios. S/P ratios for various light sources have been developed by LRC ASSIST[2]. S/P ratios are approximately 0.65 for high-pressure sodium, 1.5 for metal halide, and 2.0 for LED sources.

Research projects to establish mesopic models include MOVE[3] and the Unified System of Photometry[4] (USP). As an example using the MOVE model, if a luminance requirement of 0.3 cd/m^2 (local road with low pedestrian activity) is achieved using photopic photometry, the adjusted mesopic luminance levels achieved using the following light sources would be:

- high-pressure sodium - 0.27 cd/m^2;
- metal halide - 0.33 cd/m^2;
- LED - 0.37 cd/m^2.

When considering the MOVE mesopic adjustment factor, the LED source is 27% more efficient than the high-pressure sodium source.

The Unified System of Photometry was developed by conducting a field study on a test road where subjects were asked to identify the orientation of variously sized Landolt rings (a standard system for testing vision) displayed on small targets in the center of the roadway. Their reaction time was measured as well as the subject's impressions of visibility. These results were then compared with various models for photometry in the mesopic region. The results of the USP model show an impact of using higher S/P ratio sources of moderate impact for most recommended roadway lighting levels with no difference in the visual efficacy multiplier of approximately 0.6 cd/m^2. There is, however, a significant improvement of over 20% in LED sources over high-pressure sodium sources at lower light levels of 0.3 cd/m^2.

In 2010, the CIE issued the publication CIE 191 - Recommended System for Mesopic Photometry Based on Visual Performance, which essentially combines the USP and MOVE research understood as the basis for the "Effective Luminance Multipliers" (as defined in the soon to published 2012 version of IES RP-8 American National Standard for Roadway Lighting). This document lists various lighting levels taking into account the mesopic factor and establishing multipliers that can be applied to account for the mesopic factor. The document recommended that these mesopic multipliers should only be used in "applications for street lighting where the posted speed limit is 40 km/h or less" which would exclude most roads in the city. The document defines the reason for this as being "due to the heavy dependence of the mesopic research on peripheral vision and the fact that driving tasks at higher speeds may be more heavily dependent on foveal vision". The use of the 40 km/h speed limit, however, is based on opinions that are being further reviewed as part of a multi-year Spectral Effects study being conducted by the Virginia Tech Transportation Institute (VTTI). The study will evaluate spectral power distribution effects on nighttime driving tasks under dynamic conditions. The study is significant as it consists of the evaluation of a variety of spectral power distributions in both headlamps and overhead lighting in a controlled environment. A variety of objects will be used to evaluate the detection distance and visual performance under various light sources. This study will also include the evaluation of the lighting level in each of these conditions.

If we consider the multiplier listed in the draft 2012 version of RP-8 for a local road with low pedestrian activity (i.e., within a residential subdivision), the use of a LED multiplier of 0.834 could reduce the required minimum luminance from 0.3 cm/m^2 to 0.25 cd/m^2. In addition, other off-roadway areas such pathways and sidewalks, roads with posted speeds of 40km/h or less, and cul-de-sacs could use this factor. The use of this multiplier is, however, still under research and review.

With respect to foveal (i.e., looking ahead) vision, light sources like high-pressure sodium show much better. Recent research by the late Dr. Werner Adrian entitled "Transmission of the Aging Human Lens for Light of High Pressure Sodium and Metal Halide Gas Discharge Lamps" presents data showing that a high-pressure sodium (HPS) light source reflects approximately 21–25% better off asphalt pavement than white light sources, such as metal halide (MH) or LEDs. This is a significant finding as it relates to visibility. This research is based on foveal vision as opposed to peripheral vision. In effect, when looking straight ahead, as is the common task when driving, one's ability to recognize objects and shapes may be better under a high-pressure sodium light source than a white light source. One's foveal vision is, therefore, more critical for object detection straight ahead on higher speed roads such as freeways or highways where pedestrians or cyclists are not present.

2.1.2 Conclusions

Light and visibility are complex issues. There are distinct benefits to both LED (white) and high-pressure sodium (orange) light sources. LED lighting provides benefits to one's peripheral vision, which is most significant in urban environments where pedestrians, cyclists, and motor vehicles all interface. On high-speed freeways, expressways, and highways where foveal (ahead) vision is dominant and where pedestrians and cyclists are not present (thus reducing the importance of peripheral vision), high-pressure sodium lighting shows distinct visibility benefits.

Based on the information noted above, a mesopic multiplier of 0.834 can be considered for low light level applications such as walkways and sidewalks with low pedestrian activity, for pathways and plaza areas, on low-speed roads, and cul-de-sacs. This will reduce the required lighting levels by approximately 17% in these applications. Research is being undertaken to further define and clarify specific benefits and factors. As research develops, the city should update and consider refining lighting levels to suit emerging research findings.

The mesopic multiplier will not be applicable for light level applications above 0.6cd/m2 (9 Lux). This would rule out most heavily-traffic parking lots, transit centers, and the lighting of urban public spaces which require higher lighting levels. The multiplier can be applied to sidewalks, walkways, and alleys, as well as to low traffic parking lots and low use parks.

2.2 Contrast

Objects are seen in contrast and, therefore, it is a very important part of visibility. Contrast is essentially the difference between an object and its background. For example, if you held up a white object against a white background it would be far more difficult to see the object than a black object held against the same white background. The black-on-white scenario would have a much higher contrast than the white-on-white scenario and it would therefore be much more visible.

Normally a visual task, such as seeing a person or an object on the roadway, will have a different luminance contrast from that of the surrounding pavement. An object that is brighter than its background will be seen by positive contrast and an object that is darker than its background will be seen by negative contrast. In Figure 6 - Luminance Contrast the object shown in the left side of the figure is in negative contrast (i.e., a darker object silhouetted against a brighter background) whereas the right side demonstrates positive contrast (i.e., a brighter object against darker background). From a visibility perspective, creating positive contrast is the goal. It is also worth noting that contrast may also vary across an object.

Figure 6 - Luminance Contrast

How much contrast you will need to see an object depends on numerous elements. These include: the size of the object, how it's in your view, one's eyesight, and one's adaptation luminance (determined by the luminance of the road, glare from lights, approaching headlights, and ambient lighting levels). This is referred to as threshold contrast and is based on the probability of detection of an object 50% of the time.

The purpose of a roadway lighting system is to produce contrast of an object on the road greater than the threshold contrast required by the driver. Good visibility of objects can be achieved if the actual contrast is 3–4 times the required threshold contrast. Applying contrast metrics to roadway lighting, however, is situational and depends on many variables and is therefore not practical. Designers should be aware of the key elements under their control such as reducing the glare generated by the roadway lighting system. This is discussed further in Section 2.3 Glare.

Luminaire placement significantly impacts contrast. As shown in Figure 6 - Luminance Contrast above, a light source placed in front of a person results in positive contrast whereas a light source placed behind a person results in negative contrast. The positive contrast benefits can be significant at such applications as mid-block crosswalks and intersections. From a safety standpoint, this is significant as there is a high potential of vehicle to pedestrian collisions at mid-block crosswalks and intersections.

A project undertaken by the Virginia Tech Transportation Institute titled FHWA-HRT-08-053 Informational Report on Lighting Design for Mid-block Crosswalks defines significant visibility benefits when achieving high positive contrast which is achieved with a vertical illuminance level of 20 lux or greater at mid-block crosswalks and intersections. Figure 7 - Mid-block Crosswalk Pole Placement shows pole placement for mid-block crosswalks that has been shown to significantly improve pedestrian visibility to drivers. This is covered in the *TAC Guide for the Design of Roadway Lighting* that is followed by the City of Edmonton.

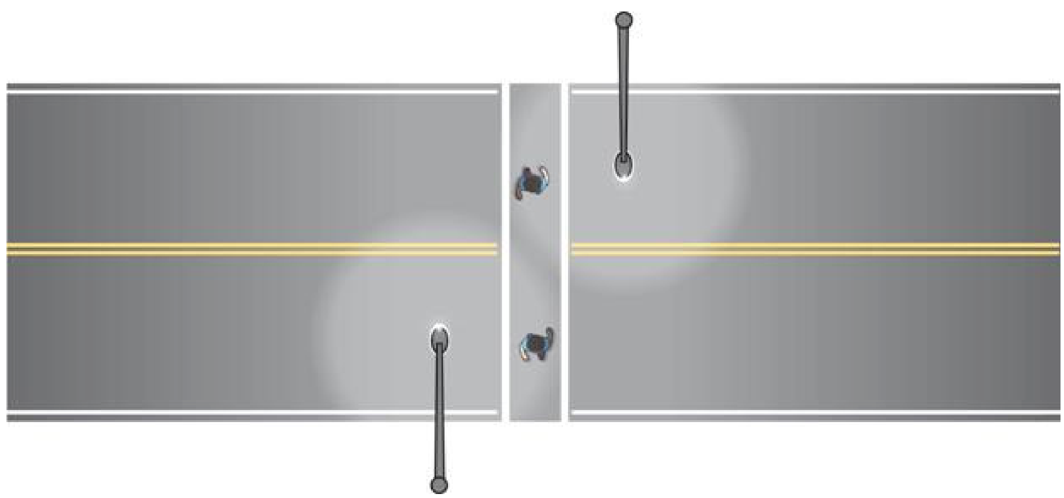


Figure 7 - Mid-block Crosswalk Pole Placement

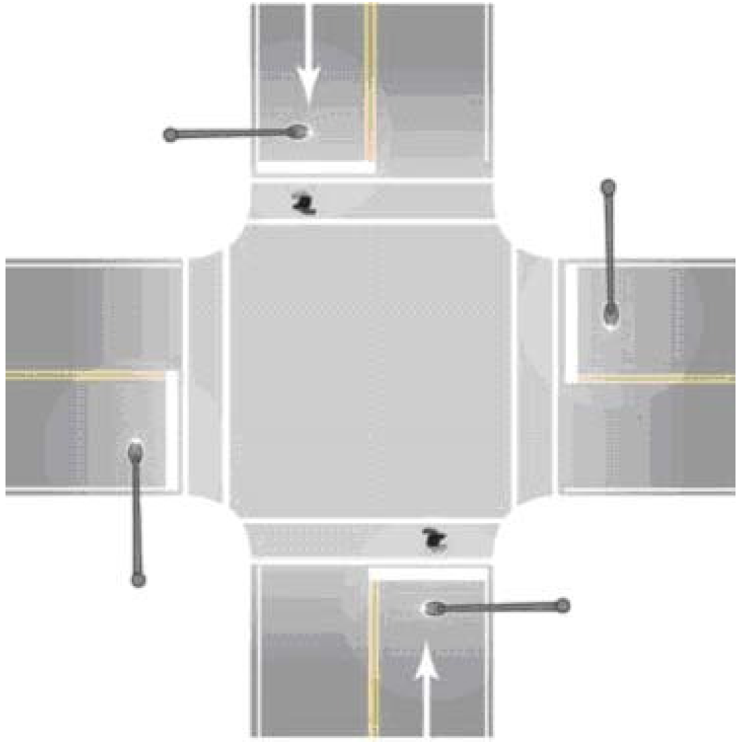


Figure 8 - Intersection Pole Placement

Figure 8 - Intersection Pole Placement defines the placement of poles for intersections that will create similar positive contrast as with the mid-block crosswalk. This may require additional luminaire poles and luminaires to supplement the luminaires typically placed on the signal poles. This is covered in the *TAC Guide for the Design of Roadway Lighting* that is followed by the City of Edmonton.

2.2.1 Conclusions

During the hours of darkness, significant visibility benefits can be gained by creating contrast with street lighting. This is most important at mid-block crosswalks, intersections and roundabouts where risk is the highest. By creating high levels of vertical illuminance through pole placement, mounting height and luminaire wattage one can significantly improve visibility and thus improve safety. How this is achieved is referenced in the city's current Road and Walkway Lighting Design Standards.

http://www.edmonton.ca/transportation/on_your_streets/street-lighting.aspx

2.3 Glare

Glare can be a major factor in reducing visibility. Glare is the sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted. It can cause annoyance, discomfort, or loss in visual performance and visibility. The magnitude of the sensation of glare depends on such factors as the size, position, and luminance of a source, the number of sources, and the luminance to which the eyes are adapted. It is a sensation that can vary greatly between observers.

Bright sources of light in the visual field create glare. When glare is present, light is scattered in the eye resulting in a phenomenon known as “veiling luminance.” This results in a visual haze within the eye, reducing vision that is a result of glare. We have all experienced veiling luminance when bright oncoming headlights significantly reduce one's vision. By blocking the bright source or looking away from the visual field, the haze associated with veiling luminance is reduced, and vision is partially restored.

When glare is present and the intensity fluctuates as the driver proceeds, the adaptation level is constantly changing. This is referred to as transient adaptation.

Roadway lighting thus aids the eyes in adapting to an increased level of luminance than can be provided by headlights alone.

Figure 9 - Glare Examples gives examples of the effects of glare from car headlamps. In the top image, a car is present on the road with no headlamps. In the second image, headlamps are turned on low beam and visibility is reduced. In the lowermost image, headlamps are increased to high beam and visibility is further reduced. Street lighting does provide significant benefits in reducing glare from ongoing vehicle headlamps.

Glare can also be produced by poor street lighting. This glare can be assessed and mitigated.

Figure 9 - Glare Examples

Glare typically falls into the sensation of disability or discomfort. Disability and discomfort glare are very different phenomena. Disability glare depends on the quantity of light falling on the eye and the angle from the line of sight, whereas with discomfort glare the source intensity is a major factor.

Disability glare is the presence of an amount of glare so significant that it prevents an individual from seeing adequately. An example of disability glare is the driver's reduced visibility caused by the headlights of an oncoming car as shown in the lower photo of Figure 9 - Glare Examples. Disability glare can also result from a luminaire with poor optics. An example of discomfort glare would be an overly bright outdoor light shining in one's window at night.

To assess disability glare from streetlights, a numerical ratio (the veiling luminance ratio) has been developed as defined in the *TAC Guide for the Design of Roadway Lighting* adopted by the city. Veiling luminance is therefore a key criterion when undertaking lighting design. The effect that veiling luminance has on visibility reduction is dependent upon the level of lighting present. A higher level of veiling luminance can be tolerated if the lighting level is high. Veiling luminance is therefore calculated in terms of a ratio of the maximum veiling luminance experienced by the observer to the average pavement luminance.

The impacts of disability glare increase with age due to yellowing of the cornea and lens. The veiling luminance ratios defined in *TAC* and used by the city is based on a 25-year-old driver. As defined in the soon to be published 2012 IES RP-8, the calculated veiling luminance can be multiplied by a factor to account for normal physiological changes in the eye due to increased age. This factor is referred to as the "Aging Factor." The effect of incorporating this age factor is to reduce the ratios of the calculated veiling luminance. Figure 10 - Age Factors for Veiling Luminance Ratios shows ages with the corresponding age factor.

AGE	AGE Factor
25	1.0
35	1.1
45	1.2
55	1.4
65	1.7
75	2.3
85	3.2

Figure 10 - Age Factors for Veiling Luminance Ratios

If we consider a 65-year-old as our basis rather than a 25-year-old, we should be reducing the veiling luminance ratios of 0.3:1 and 0.4:1, typically applied for roadway lighting, by a factor of around 1.7. This would bring the requirement to under 0.2:1.

Discomfort glare is the presence of glare that may over time cause a sense of pain or annoyance, and may increase blink rates or even cause tears. An example of this is shown in middle photo in Figure 9 - Glare Examples.

Discomfort glare is a further result of overly bright light sources in the field of view, causing a sense of pain or annoyance. While its exact cause is not known, it may result from pain in the muscles that cause the closing of the pupil. Disability glare and discomfort glare normally accompany one another, and beneficial luminaire light control that reduces one form of glare is likely to reduce the other. Discomfort glare, which can cause effects from an increased blink rate to tears and pain, does not reduce visibility. While discomfort glare does not affect vision, it should be noted that the associated blinking, squinting, tearing, and avoidance (turning away) may create distractions which disrupt viewing and thereby create a hazard.

It is generally accepted that reducing disability glare will reduce discomfort glare. It is possible, however, to reduce discomfort glare and increase disability glare. North American roadway lighting standards do not specify numerical limits for discomfort glare. Methods exist to quantify discomfort glare for roadway lighting, but these are mostly subjective. Also, no instrument has been developed for the measurement of discomfort glare. The International Commission on Illumination (CIE) uses the Glaremark Rating System, which is a graphical method using a scale of 1 to 10 to rate lighting systems. However, there is no practical use or application of this method.

A study entitled Predicting Discomfort Glare from Outdoor Lighting Installation[5] reviewed measurements and ratings of discomfort glare but it does not go so far as to define a specific method or rating system.

2.3.1 Conclusions

Disability glare from streetlights can be calculated with most lighting design software. It is defined as a veiling luminance ratio (VL). As a design practice, VL ratios should be reduced from 0.4:1 or 0.3:1 to 0.2:1, or better where possible. This is usually accomplished through the evaluation and selection of luminaires with glare-reducing optical systems. In some cases, the pole spacing may have to be tightened or wattage increased to raise the maintained average luminance level on the roadway. This may be in contradiction to other areas of this document where over lighting is discouraged. However, reducing the VL ratio should be a design consideration. The standards for the city should be developed not with average drivers and pedestrians in mind, but with the full range of people affected, especially those disproportionately affected by glare.

With respect to street lighting applications when a lower VL ratio is applied, on roadways the glare impacts off site will also be lessoned. Therefore, for roadway lighting, a lower VL ratio will benefit drivers with improved visibility and it should also reduce the impact of glare on local residents in close proximity to the roadway.

The impacts of discomfort glare are typically more of an issue to residents off site (i.e., light viewed through a window). The impacts and mitigation of discomfort glare from outdoor lighting are further discussed in Section 4.3 Light Pollution.

2.4 Significant Lighting Measurements

Listed below are key lighting measurements that are used for outdoor lighting. Also listed are recommendations and comments related to lighting scenarios covered in this document.

2.4.1 Lamp Lumens

A lamp generates radiant energy in the form of light referred to as luminous flux and it is measured in units of lumens. As with most lamps, light is emitted in all directions so the lumen output of the lamp is normally the total amount of light emitted in all directions.

When defining lamp lumens, it is critical that the proper lamp be selected and that the appropriate quantity of lumens for that lamp be used as the basis for lighting calculations. Published values for lamp lumens will typically vary slightly from one manufacturer to another.

Lamp efficiency is typically measured in lumens per watt when comparing traditional bulb type lamps that were installed in similar luminaire optical systems. However, LED luminaires have a much more efficient optical system than typical refractor type luminaires. Therefore, using lamp lumen output as a measure of light source efficiency in regards to comparing LED sources to metal halide or high-pressure sodium sources does not make for a fair comparison.

2.4.1.1 Conclusions

Values for lamp lumens are required to undertake lighting calculations but it is not always a suitable measure of luminaire efficiency. A better measure is the total performance of the luminaire based on its unit power density, measured as the wattage required for lighting a defined area. This is further discussed in Section 6.1 Unit Power Density (UPD).

2.4.2 Intensity (Candlepower)

Intensity (candlepower) refers to the concentration of light in a particular direction, while lumens represent a total quantity of light emitted. Intensity is expressed in candelas (cd). The concentration of light will normally change for each direction of light emission. While this is not required for a given lighting calculation, it is, however, an important lighting fundamental when assessing light pollution impacts.

2.4.2.1 Conclusions

The intensity of the light source (brightness) is significant when assessing light trespass impacts on local residents. This is further discussed in Section 4.3 Light Pollution.

2.4.3 Photometrics

Photometric testing of a luminaire involves gathering data that characterizes its candlepower distribution. Once the intensity values for all directions are known, software that reads the data can generate photometric test reports. The measurement device used in a laboratory is called a goniophotometer. Light readings are taken at numerous points throughout an angular grid, in fine angular steps so that the full light distribution is accurately quantified.

Data processing software reads the collected candlepower arrays and it can then produce test reports in a digital file format. This file can be used as input for numerous other application programs that are available to aid in computerized lighting design. Photometric files are available from luminaire suppliers for the various luminaires they supply.

Typically luminaire photometric files are based on a lamp that can vary from the actual lamp used in the test, provided it is similar. This is referred to as "relative" photometry. As for LED photometric files, they must be "absolute" which means the file must be for the exact luminaire being tested.

2.4.3.1 Conclusions

Only use "absolute" photometry for LED lighting. This practice is currently followed by the city.

2.4.4 Illuminance

Light is incident upon a surface and will create "illuminance" on that surface. Illuminance is a measure of the light landing on a defined area. The more lumens projected onto a given surface area, the higher the level of illuminance.

Typically, illuminance is a poor measure of visibility. As an example, imagine a half-white/half-black surface being measured by illumination. The appearance of the white surface would be totally different from that of the black surface, even though each may be receiving identical illuminance. This is due to the better reflectance of light on a white surface than on a black surface. Our eyes do not see illuminance or the light incident on a surface. One only sees the proportion of the light reflected towards the viewer.

Illuminance is measured in units of lux. On a bright and sunny day, an outdoor area receives about 100,000 lux of illumination. Under bright moonlight, the figure is about 0.2 lux, about a millionth as much light. As defined in *TAC Guide for the Design of Roadway Lighting*, the city uses illuminance for most lighting applications. The exception for this is on roadways and within tunnels, where luminance is used.

2.4.4.1 Conclusion

Continue to use illuminance where defined in *TAC* (ie; intersections, roundabouts, pathways, sidewalks, parking lots, etc). Where possible, use luminance as it is a superior measure of visibility. The upcoming edition of IES RP8 will remove illuminance as a calculation metric for roadway. Illuminance will still be used for field measurements due to the complexity of luminance measurements. The 2012 version of RP-8 also noted that curved roadway sections (less than 160 meter radius) or roads with steep and variable grades (6% or greater) are calculated using the horizontal illuminance method.

Avoid over-lighting and never reach lighting levels more than 15% above recommended levels. Adaptive lighting can be used to "fine tune" lighting levels to meet design criteria and to accommodate changes in performance and traffic over the lifetime of a luminaire.

2.4.5 Luminance

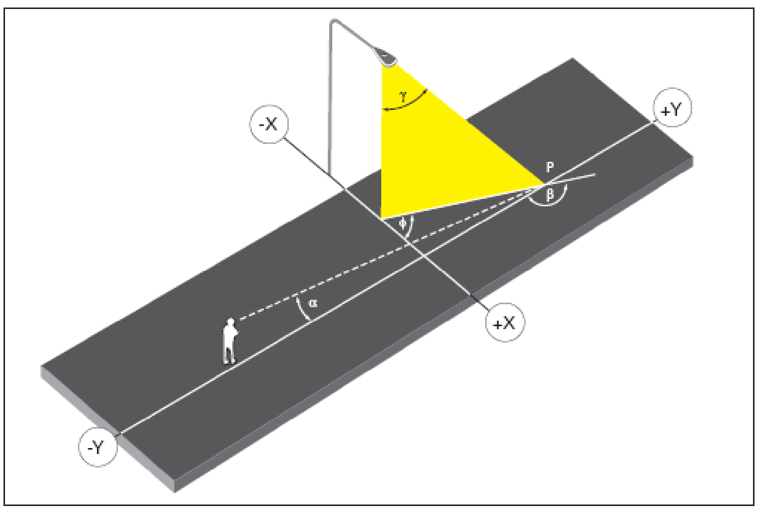
Luminance is the concentration of light (intensity) reflected towards the eyes per unit area of surface.

As road surfaces do not reflect light uniformly, reflectance varies depending on the angle of the incident light in both the vertical and horizontal planes, and on the angle that the driver views the pavement. For a luminance calculation, the driver's viewing angle is fixed at one degree below the horizontal and an observer distance of approximately 83 m.

The actual discernment of an object at night comes from the relative brightness of the surface and the object, or the contrast of the object against its background. Luminance represents the amount of illumination reflected into the eyes of the driver (or pedestrian). A small amount of roadway brightness reflects back into the driver's eyes from the driver's headlights, although most is reflected away, down the road, where it is of little value to the driver. At close distances (about 30 meters or less), the low beam vehicle headlights will also begin to effectively reflect back from the darker (but not black) clothing of a pedestrian.

Luminance is measured in candelas per square meter (cd/m^2). The calculation of luminance is a very complex mathematical calculation (undertaken using computer lighting software) which is limited to only a few lighting applications.

As defined in *TAC Guide for the Design of Roadway Lighting* luminance is used by the city only for straight sections of roadways and tunnels. It is not used for sidewalks, intersections, parking lots, etc. as there are no published recommendations and no software specific to these cases has been developed.



Graphic Reproduced with Permission of the IESNA

Figure 11 - Luminance Calculation Geometry

2.4.5.1 Conclusions

Luminance is the most suitable method for roadway lighting. *TAC* defines minimum levels, however, it does not define maximum levels that can often lead to over design. To reduce over lighting levels, those levels defined in *TAC* should not be exceeded by more than 15%.

2.4.6 Veiling Luminance (VL)

The effect is termed veiling luminance (also referred to as disability glare) and it may be numerically evaluated. Veiling luminance must be considered as a design criterion along with illuminance or luminance levels and uniformity. This is discussed further in Section 2.3 Glare.

2.4.7 Uniformity

Uniformity is the evenness of the light over a given area. Even (uniform) lighting throughout an area has a uniformity ratio of 1:1. A high degree of uniformity of roadway lighting has generally been accepted as desirable. As lighting calculations consist of a series of grid points with calculated luminance or illuminance levels, uniformity is expressed as the ratio of the average-to-minimum levels and/or the maximum-to-minimum levels.

New technologies such LED's offer improved uniformity through efficient optical systems. Making even uniformity (1:1 ratio) possible. This even uniformity results in a decrease in contrast which can reduce visibility (ref Section 2.2 Contrast). The Small Target Visibility (STV) design method actually focused on contrast which resulted in reduced uniformity. STV however had a number of shortcomings and is no longer used.

There is however no research to support reduced uniformity ratios however the range within the uniformity ratio may have a specific low and high end (ie: instead of 3:1 ratio or better it maybe a ratio of 1.5:1 to 3:1)

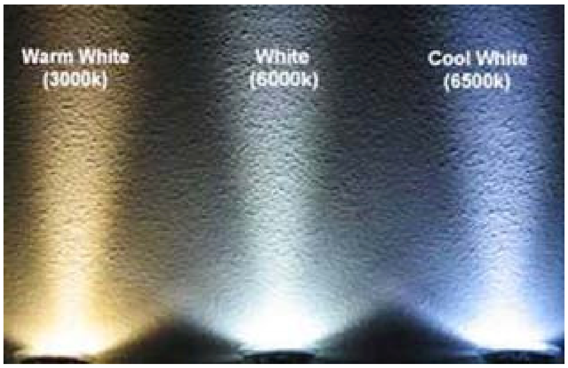
2.4.7.1 Conclusions

The City should follow recommendations from the *TAC Guide for the Design of Roadway Lighting*, or from RP8 - Roadway Lighting, depending on which is the most current and applicable, as design guidelines.

2.4.8 Correlated Colour Temperature

Colour temperature is a description of the warmth or coolness of a light source. By convention, yellow-red colours (like the flames of a fire) are considered warm, and blue-green colours (like light from an overcast sky) are considered cool. Confusingly, higher kelvin temperatures (3600–5500 K) are what we consider cool and lower colour temperatures (2700–3000 K) are considered warm.

Figure 12 - Correlated Colour Temperature gives examples of the colour temperatures range.



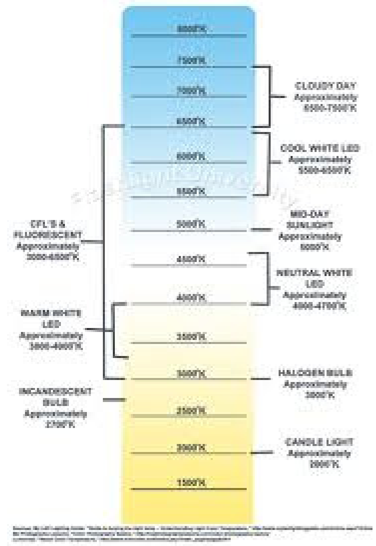


Figure 12 - Correlated Colour Temperature

Figure 13 - Scene with Different Light Source Colour Temperatures
Unit Power Density

Figure 13 - Scene with Different Light Source Colour Temperatures give examples of how correlated colour temperature can impact the colour rendering index of objects. In each image, the scene is shown under the same light source with different colour temperatures. The image on the right uses a light source with a far cooler temperature than the image on the left.

2.4.8.1 Conclusions

Colour temperature is an important consideration with respect to LED luminaries, as the higher the colour temperature the higher the efficiency of the luminaire. To reduce colour temperatures, chemicals (phosphors) are added to the LEDs that reduce their efficiency. Supplier will often push the higher colour temperatures to gain a performance advantage. The higher colour temperatures offered such as 6000, and 7000 kelvin tend to be very blue in the colour spectrum and when viewed against a dark background (night) can be annoying to the eye. For LED outdoor lighting, the industry is moving toward a 4200 or 5000K temperature limit however for most outdoor lighting applications however no common standard exists. The rationale for the lower colour temperature was 4200-4300 kelvin simulated moonlight. At this stage the industry is fragmented with respect to a defined standard of say 4,200 or 5,000 kelvin. Supplier offer a variety of colour temperatures however often push the higher color temperatures to gain efficiency.

The city currently use sources of 5000 kelvin or less and in residential areas and have used sources with 4100 kelvin in some neighborhoods.

3 Purpose and Justification for Lighting

In general, the purpose of lighting roadways is defined as follows:

- Provide an adequate visual environment for road users to safely use the road system during hours of darkness.
- Reduce the impacts of disability glare from approaching headlights thus improving visibility.
- Reveal objects and markings on the roadway beyond the range of vehicle headlamps.

The main benefits of street lighting are generally defined as follows:

- Reduce nighttime motor vehicle collisions and personnel injury.
- Provide an increased level of comfort for those using the roadway at night.
- Enhance local commercial development.

Beyond the general historical definitions of the “purpose” and “benefits” listed above, the questions that remain are: why do we need street lighting and where does it serve us best? Lighting some roads may have a much higher benefit than lighting others.

Presented below is information aimed at defining the benefits, including studies and information to support the safety benefits. Also, there are issues such as the effects that age has on visibility along with other human factors such as driver reaction times, security, and livability. The point of this section is to explore the benefits of lighting for various applications and define what applications may be of the most benefit.

3.1 Safety Benefits

Driving or walking on or across a roadway in the darkness has proven to be more dangerous than during the day. Though the number of fatal crashes in daylight versus darkness is about the same, only 25% of vehicle-miles travelled occur at night. Because 55% of fatalities occur at night, the nighttime fatality rate is three times the daytime rate. Figure 14 - Fatal Crash Rates for Day and Night (Source: US National Safety Council) provides a graphic illustration of this.

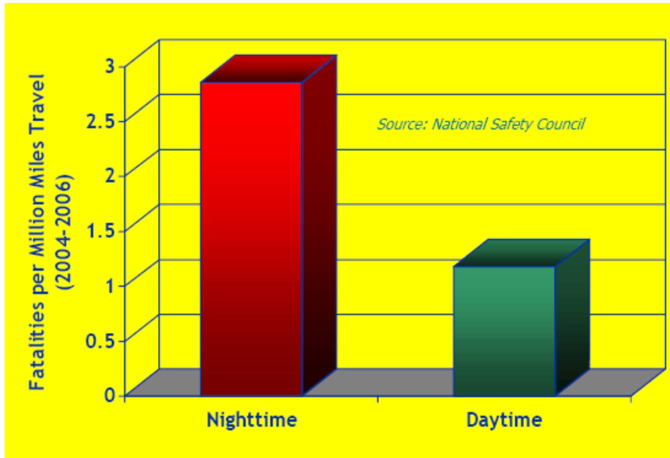


Figure 14 - Fatal Crash Rates for Day and Night

Over the last 50 years, studies undertaken throughout the world have analyzed the before and after effects of lighting, and related those findings to collisions. In most cases the results are positive as they show a reduction in the number of collisions and fatalities when lighting is installed.

Different types of roadways and areas will have different benefits. To define benefits we have broken down studies and recommendations into those concerned with urban roadways, rural roadways, urban intersections, and rural intersections, as the research gathered and reviewed falls into these categories. The purpose of this section is to define the value of roadway lighting based on research and studies and then define where it best serves the community.

The research listed is heavily based on roadway lighting. It is, however, important to consider lighting off of the roadway. Although fewer than 6% of trips are undertaken on foot, 13% of all traffic fatalities occur among pedestrians. In 1997 and 1998, 13% of all traffic fatalities in the US were pedestrians[6]. It is not known what percentage of sidewalks had lighting. Conclusions cannot be drawn on the value of lighting from these statistics. However, the facts show that walking outdoors during hours of darkness is less safe than in daylight hours.

The *TAC Guide for the Design of Roadway Lighting* does define a warrant system in order to apply roadway lighting where it will provide the most benefit. To the best of our knowledge, few other lighting warranting systems exist. The TAC warrant system is based on research undertaken in the 1970s by the US National Cooperative Highway Research. The science and research behind this system is unknown. The TAC roadway warranting system is dated and ineffective in determining whether to light or not. The TAC Guide for the Design of Roadway Lighting also has a warranting system for intersections which is current and an effective way to determine and define lighting of an intersection. The cities that don't use the TAC roadway lighting warranting system do use the intersection lighting warranting system which is a sound practice.

Research related to personal and property security (crime related) is covered in Section 3.4 Security and Livability.

3.1.1 Urban Roadways

What follows is a list of significant lighting studies, analyzing the safety benefits of lighting on urban roadways:

- As part of a widespread study on Long Island, New York, five comparisons were made of collisions on roads on three unlighted sections totaling 10 km and on three lighted sections totaling 5 km. A total of 539 collisions were tabulated during approximately four years. From the data, it was calculated that the night-day rate per million kilometres on the unlighted sections was 1.5 times higher than that on the lighted sections[7].
- A Syracuse, New York study used data based upon approximately 7,500 collisions on approximately 170 km of major and collector streets. Those streets with little or no illumination were found to have substantially higher night-day collision ratios and collision cost ratios than the average for streets with lighting and the same roadway classification and abutting land use. Also, the type of street (local, collector, or arterial) appeared to be more of a factor in the collision-illumination relationship than the type of abutting land use[8].
- The 1996 US Federal Highway Association Annual Report showed that lighting had the highest cost-benefit ratio based on fatal and injury related collision data collected over a 21-year period. The costs to benefits were viewed within a comparison of various safety improvements and not as an actual cost-benefit ratio (i.e., the various safety improvements that were compared included geometrics, signing, markings, channelization, etc.). This study showed that lighting has excellent value as a safety improvement to reduce collisions and injuries. This information was also published in the New York Times[9].
- A study in Naperville, Illinois used two years of “before” data and two years “after” data to study the effects of lighting a 2.8 km length of a 5 lane major traffic route. The collision sample exceeded 800. The reduction in nighttime collisions per million vehicle km was 36%, corresponding to a reduction in the total (day plus night collisions) of 14%[10].
- For the period up to 1987, the International Commission on Illumination (ClE) reviewed over sixty studies from 15 countries with respect to the significance of street lighting as a collision countermeasure. They identified 40 studies that they calculated to have statistically significant results. Overall, it was determined reductions in nighttime collisions, following installation of roadway lighting, ranged from 9–75%. Their findings also reflect the Kansas City, Missouri experience that urban street lighting most benefits the pedestrian. This kind of collision was reduced by 45–57% by lighting versus 21–23% reductions for other types of collisions[11].
- The approximate overall safety effects of fixed roadway lighting are a 65% reduction in nighttime fatal collisions, a 30% reduction in nighttime injury collisions, and a 15% reduction in nighttime property damage collisions[12].
- A study in Davidson County, Tennessee covered four suburban highways totaling a length of 51 km. The collision records for one year prior to lighting in 1965, and two years after, involved 2,528 collisions. With lighting, the nighttime collisions were reduced by 22% and injuries were reduced by 39% during the after period. However, daytime collisions were also lower, and the night/day ratio of collision rates per million vehicle kilometres showed an overall benefit of a 15% reduction[13].

In summary, the research clearly shows that properly designed roadway lighting aids in improving urban road users’ visibility and helps the viewer to locate objects on the roadway as well as other vehicles, pedestrians, and cyclists. The end result is increased safety for motorists, cyclists, and pedestrians.

Much of the information related to safety was extracted from a document no longer in production: IESNA CP-31-1989 Value of Public Roadway Lighting. The fact that this document was taken out of production by the IESNA due to low demand indicates that many take the value of roadway lighting at urban roadways for granted and feel that its benefits require no further research.

As all the research listed above shows, reducing the number and severity of collisions is a key benefit of urban roadway lighting. The benefits achieved through the installation of roadway lighting will vary depending on the type of roadway. For high volume multi-lane urban arterial and collector roadways, the benefits are shown to be the greatest in reducing vehicle to vehicle, as well and vehicle to pedestrian/cyclist injuries and fatalities.

There is now added pressure to more selectively choose where lighting may provide the best value. The IESNA is in the process of publishing a document referred to as DG-22 Design Guide for Residential Street Lighting which has a section that defines “When Street Lighting May Not Be Needed.” In the final draft it states:

“While the purpose of the street light is to improve the driver’s visual performance, there are conditions where street lighting may not be necessary, and, under certain conditions, poor lighting design may actually make vehicular travel less safe. Vehicular headlights may provide adequate illumination to allow the driver sufficient time for reaction and stopping at speeds less than 50 km/h. Streetlights may not be necessary for driver vision on such roads, except in commercial areas with high levels of ambient or stray light, or other areas with higher traffic volume, pedestrians or cyclists. This recommendation may provide for safe vehicular traffic but does not address lighting intended for pedestrian needs.”

This statement is significant if applied to lower speed applications such as residential subdivisions. To further validate this statement none of the research listed above (or that we could find) analyzes the safety benefit of lighting in residential subdivision applications. The research listed is entirely based on collector, arterial, freeway, and highway applications as it is typically funded by organizations like the US Federal Highways.

In summary, lighting has a proven high-safety benefit on collector, arterial, highway and freeway applications; it is, however, of less value where there are low speeds and low pedestrian activity levels (e.g., residential subdivisions).

3.1.2 Rural Roadways

What follows is a list of significant findings from lighting studies that analyzed the benefits of lighting of rural roadways:

- When driving at night, motor vehicle headlamps are the primary means for improving driver visibility. By law, all motor vehicles must have operating headlamps. When considering the benefit for fixed roadway lighting, the advancements in vehicle headlight systems and how they impact safety must also be considered. The University of Michigan Transportation Research Institute analyzed fatal crash trends on rural roads in the United States between 1990 and 2006. Changes in the ratio of crashes in darkness to crashes in daylight were assessed to determine whether recent improvements in vehicle headlights influenced the day to night crash ratio. The report noted that sharp declines were observed in rural crashes as a result of improved vehicle headlamps, while no significant changes were observed in levels of urban crashes. The research therefore indicates that advancements in vehicle headlights have had the biggest benefit on un-lighted rural roads[14].

- The Region of Waterloo, Ontario, tracked collisions on regional (rural) roads over a 4-year period. A summary of collision data provided by the Region showed that for mid-block roads between intersections, the night-to-day collision ratio without lighting was 0.65:1. The ratio with lighting was 0.26:1, a reduction of nearly 50%. This was based on nearly 10,000 collisions on roads with lighting, and 3,500 without lighting.
- Some municipal regulations allow streetlights for rural areas to be spaced two to three times further apart than the distance required in achieving the minimum recommended level of uniformity ratios (this is sometimes referred to as “half code” lighting). Another municipal streetlight practice that often creates a uniformity problem involves luminaires mounted intermittently on existing utility poles to reduce installation expense. Utility pole spacing is determined by wire distribution considerations, and often prevents achieving the minimum recommended level of uniformity for street lighting. Any street lighting practice failing to use the necessary spacing to achieve recommended illumination levels and uniformity ratios will inevitably result in mediocre to adverse lighting conditions, forcing the eye to adapt to very pronounced shadows and very high contrast in the field of view. Reductions in the lighting levels stated in this recommended practice, or meeting some of the criteria and not others, will not result in "slightly less" visibility. Simply put, providing half the criteria will not result in half of the benefit. In fact, reductions in uniformity or increases in the allowed veiling luminance ratio may produce results that are more detrimental to minimum visibility than not providing any lighting[15].

Based on a recent survey undertaken by DMD, most major cities in Canada do not light rural roads. In rural areas, lighting is usually only installed at intersections only, unless otherwise deemed warranted by high crashes and/or high pedestrian activity. Therefore, lighting on rural roads has a much lower value than lighting on urban roads. Advancements in reflective pavement markings and delineators can aid in vehicle guidance. Reflective safety wear can also be used by pedestrians and cyclists to improve their safety.

Partial lighting placed on utility poles is deemed as having poor value.

3.1.3 Urban Intersections

What follows is a list of significant lighting studies analyzing the benefits of urban intersection lighting with respect to pedestrian safety:

- Based on research in Switzerland, it was found that a level vertical illumination of 20 lux or greater in crosswalks reduced nighttime vehicle-to-pedestrian crashes by 66%[16].
- Although fewer than 6% of trips are undertaken on foot, 13% of all traffic fatalities occur among pedestrians. In 1997 and 1998, 13% of all traffic fatalities in the US were pedestrians[17]. It is not known what percentage of intersections had lighting. Conclusions cannot be drawn on the value of lighting from these statistics. However, the facts show that walking through an intersection during hours of darkness is far less safe than in daylight hours.

- The University of Michigan Transportation Research Institute used information from the US Fatality Analysis Reporting System (FARS) to show that the added safety risk in darkness versus light is much higher for pedestrians in intersections than for any other road users. The use of alcohol by pedestrians appears to strongly magnify the effect of darkness for the risk of being killed. The comparative risk of a pedestrian crash is much higher in darkness than in daylight (by a factor of over 4 times), but the annual number of pedestrian crashes in darkness is large enough to suggest that lighting targeted toward pedestrian visibility would save nearly twice as many lives as would be saved in collisions with other motor vehicles. Thus, the greatest lifesaving opportunity for lighting countermeasures appears to be in areas such as urban arterial intersections, where both speed and pedestrian density are high[18].
- The University of Michigan Transportation Research Institute analyzed 11 years of traffic data from the US Fatality Analysis Reporting System (FARS) to investigate the sensitivity to light level at fatal pedestrian crashes at intersections[19]. One method of analysis examined the abrupt light changes associated with the annual transition to and from daylight savings time. Significant information related to lighting is as follows: pedestrians may be 3 to 6.75 times more vulnerable in the dark than in daylight; the most practical means to extend the available time for avoiding pedestrian collision seems to lie in the improvement of lighting to illuminate objects farther ahead of the vehicle to extend available time to react; one clear conclusion from roadway lighting research shows that it reduces crash rates and particularly those crash rates involving pedestrians.
- Providing high levels of vertical illuminance is critical in enhancing public safety by improving visibility in marked crosswalks. A mid-block crosswalk can potentially be less safe for pedestrians than a crosswalk at an intersection because drivers may not expect pedestrians on the roadway. Historically, the use of silhouette or negative contrast for the detection of a pedestrian was recommended. However, new research shows that positive contrast has many advantages, particularly when considering the reinforcement of positive contrast with headlamps. A study[20] was undertaken by Virginia Tech University to provide information, lighting parameters, and design criteria that should be considered when designing fixed roadway lighting for mid-block crosswalks. The information is based on static and dynamic experiments on driver performance with regard to detecting pedestrians and surrogates in mid-block crosswalks. Experimental condition variables included lamp type (high-pressure sodium and metal halide), vertical illuminance level, colour of pedestrian clothing, position of the pedestrians and surrogates in the crosswalk, and the presence of glare. The researchers found that a maintained average vertical illuminance of 20 lux or greater in the crosswalk, measured at a height of 1.5 m (5 feet) from the road surface, provided adequate detection distances in most circumstances. Although the researchers only looked at mid-block placements of crosswalks, the report includes similar recommendation for intersection crosswalks. The TAC Guide for the Design of Roadway Lighting defines recommendations for both mid-block and intersection crosswalk lighting based on the Virginia Tech research.
- At intersections in urban areas, the greatest benefit of lighting is in the saving of pedestrian lives. Reductions of 45–80% have been found in various cities, following the modernization of lighting. In general, reductions in the range of 21–36% have been found for all types of nighttime collisions[21].
- According to the US Federal Highway Administration (FHWA) more than 40% of intersection fatalities occur during the late-night/early-morning hours. Further, the

probability of being killed in a crash during late-night/early-morning hours is as much as three times greater than during the day. A primary reason for this difference in crashes is poor intersection visibility, where drivers are not able to see conflicting traffic and other road users.

What follows is a list of significant lighting studies analyzing the benefits of urban intersection lighting with respect to motor-vehicle collisions:

- For the period up to 1987, the International Commission on Illumination (ClE) reviewed over 60 studies from 15 countries with respect to the significance of street lighting as a collision countermeasure. They identified 40 studies that they calculated to have statistically significant results. Overall, it was determined that the reductions in nighttime collisions, following installation of roadway lighting, ranged from 9–75%. Their findings also reflect the Kansas City, Missouri experience that urban street lighting most benefits the pedestrian. This kind of collision was reduced by 45–57% by lighting versus 21–23% reductions for other types of collisions. The approximate overall safety effects of fixed roadway lighting are a 65% reduction in nighttime fatal collisions, a 30% reduction in nighttime injury collisions, and a 15% reduction in nighttime property damage collisions[22].
- A study in Iowa assessed three-year before-and-after data at 47 locations and 568 collisions. Overall, the night collision rate of 1.89 per million entering vehicles (before) dropped to 0.91 after lights were installed: a reduction of 52%. The lighting was of greatest benefit at urban intersections having raised concrete channelization, with a route turn, and having four legs. Also, intersections with the largest number of lights installed had the greatest collision reduction[23].
- A study in Illinois analyzed collision data from 18 unlighted intersections and 263 lighted intersections. The night/day ratio of collisions per million entering vehicles was reduced by 25% wherever lighting was present. The night collision rate alone was reduced by 45%. Furthermore, intersections with channelization but no lighting had higher ratios than those with both lighting and channelization[24].

As the research indicates, lighting can reduce late-night/early-morning crashes at urban intersections. A high level of vertical illumination can improve pedestrian safety at mid-block crosswalks. Thus, lighting at urban intersections has a very high value.

3.1.4 Rural Intersection Lighting

The City has few rural intersections so less focus has been applied with respect to rural intersections. In recent years, research projects have been conducted to define the benefits of lighting rural intersections. The benefits of lighting are typically much greater in urban areas than in rural areas, with the exception being lighting at rural intersections where the studies and benefits are well proven. The studies show that roadway lighting has significant collision reduction benefits at rural intersections. Rural intersection lighting has shown to reduce overall late-night/early-morning crashes across these intersections by a weighted average of 35%[25]. Most research indicates providing overhead lighting where necessary, can reduce late-night/early-morning crashes at rural intersections.

In general the research indicates lighting has very high benefits at rural intersections.

3.1.5 Conclusions

The research shows a high safety benefit for lighting urban collector and arterial roadways, rural and urban intersections and pedestrian crosswalks. We are aware of no safety-based research to support lighting on local roads in residential or industrial subdivisions where night-time pedestrian activity and speeds are low. It is however common practice to light urban residential roads based on a survey of major Canadian cities undertaken by DMD.

The TAC roadway warranting system is not an effective method in determining whether to light or not to light urban residential roadways and should, therefore, not be applied. We understand the use of the TAC warranting system is not a current practice for the city. The city's June 13, 2011 policy C564 Residential Neighbourhood Street Lighting Renewal Policy notes "Maintain or reduce existing light levels where possible while ensuring pedestrian, cyclist or motorist safety". So where existing levels are lower than what TAC suggests, the policy suggests maintaining these existing lighting levels unless deemed unsafe to do so. The option also exists to dim or turn off lighting during late night hours when activity is nearly non-existent. This covered further in Section 6 Energy Savings Concepts and Technologies.

Though the research listed above is somewhat conflicting in terms of the general benefits of lighting on rural roads, pedestrian activity is much lower in rural areas than in urban areas and this makes lighting of less benefit with respect to pedestrians. With minimal pedestrians, driver guidance becomes the key factor. Retro-reflective delineators, pavement marking and clothing will serve as less expensive option than lighting with respect to driver guidance and pedestrian safety. Improvements in motor vehicle head lighting has also led to a reduction in crashes in rural areas thus the need for lighting on rural road is far less than on urban roads.

3.2 Aging Population

Our visibility is reduced at night. Daytime vision of 20/20 can be reduced to 20/40 at night. Age also has a significant impact on our visibility at night. As we age, visibility is further reduced. Over time, the lens of our eye discolours, allowing less light to penetrate the eye as shown in Figure 15 - Age Effect on the Human Eye.

As we age, we are more susceptible to glare. Diseases such as glaucoma can also reduce peripheral vision. This is significant as our population ages and life expectancy continues to increase.

It has been found that the eyes deteriorate considerably in their ability to adjust the pupil opening in proportion to the available light. The eye gate becomes smaller and smaller even in the daytime, but the critical feature is the inability to open up at twilight and in darkness to let in whatever little light might be available, particularly past the age of 60. A vital factor is the ability to see the movement of objects representing a potential hazard out of the corner of the eye. It has been found that the ability to see movement 40 and 80 degrees away from the line of sight, is reduced as much as 60% for those over 60 years old. A younger person can typically see in the presence of very little light, but this sensitivity to low brightness is reduced to approximately one half at 80+ years of age. It has been found that it can take up to 30 minutes for an 85 year-old person to adapt to lower outdoor night- time brightness after having been adapted to the higher interior brightness[26]. This long eye adaptation can be greatly reduced with roadway lighting.

The visibility factors noted above also applies to pedestrians, as reduced visibility reduces the pedestrians' ability to see motor vehicles and avoid collisions. Reaction time for both the driver and pedestrian is also reduced as we age[27].

The fact that our visibility is reduced with age is significant as Statistics Canada estimates the percentage of Canadians 65 and older will increase from 14.4% to 23.4% from 2011 to 2031. As the general population age increases, roadway lighting becomes of greater value in improving driver visibility. This lighting will be critical, as the percentage of Canadians over 65 on the roads at night will also significantly increase over the next 20 years.

Visual acuity and contrast sensitivity both decline with age. The decline generally begins slowly after the age of 40 followed by an accelerated decline after age 60[28,29,30]. Lens opacity increases and the pupil diameter also decreases with age. The maximum area of the iris in eyes of people aged 60 is about half that of those aged 20[31]. These factors allow less light to reach the retina in older persons. Weale determined that there is a 50% reduction in retinal illumination at age 50 compared to age 20, and this reduction increases to 66% at age 60[32]. Hills and Burg indicated no significant correlation between vision measures and crash data for participants under the age of 54, but for those 54 and older, acuity showed significant correlations with crash data[33].

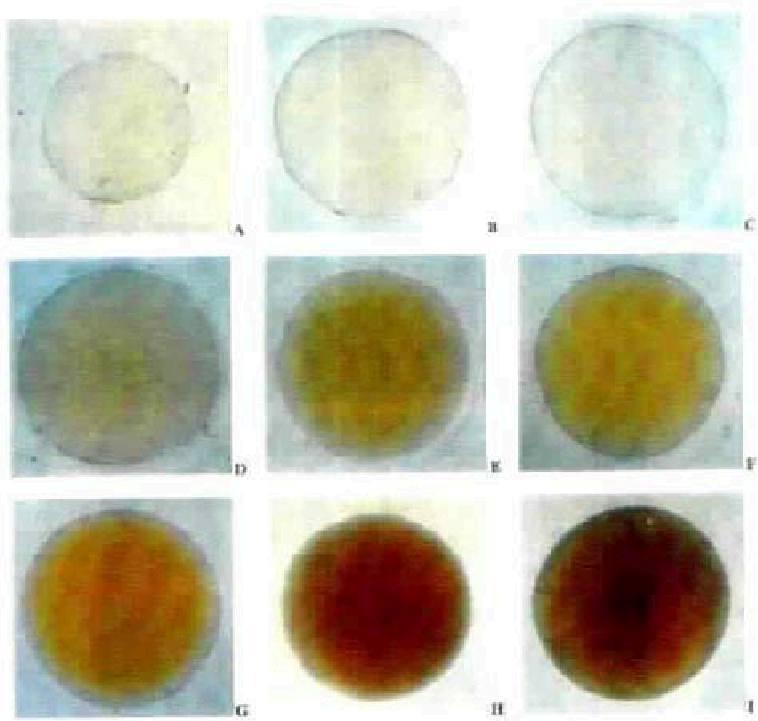


Fig 3 Yellowing and transparency of the Human Lens from 6 month (A) to 8 years (B), 12 years (C), 25 years (D), 47 years (E), 60 years (F), 70 years (G), 82 years (H) and 91 years (I) of age.

Figure 15 - Age Effect on the Human Eye

Figure 15 - Age Effect on the Human Eye shows as we grow older the lens discolours (darkens) thus reducing visibility.

3.2.1 Conclusions

As we age, our eyesight worsens which reduces visibility at night. By the year 2031 it is estimated that over 23% of the population will be greater than 65 years old.

With a significant and increasing population over age 65, the quality of outdoor lighting design is especially important as our senior population is large enough to justify lighting design with them in mind today. Based on this, outdoor lighting has significant benefit. The value and benefits of roadway lighting will increase over time as the population both increases and ages.

It is however important to consider that it is far less likely for someone over 65 years old to be driving late at night than someone much younger. In terms of those over 65 years old, it is important that proper lighting levels, uniformity, and VL ratios on the roadways, as well as proper sidewalk lighting levels, be maintained during peak travel periods. It is far less critical during off-peak periods where travel is far less likely.

For transit facilities reducing glare should be a key design consideration at entrance and egress points, where visual impairment can be especially hazardous.

3.3 Driver Perception-Reaction Time

Many components make up perception-reaction time. A motorist, in order to stop or avoid a hazard or person on a roadway, must first detect that an object is there, recognize what the object is, react based on that determination, enact the mechanical functions of braking/steering mechanisms, and then react to road/tire/vehicle performance conditions.

From a reaction time perspective, these elements can include whether a situation is expected, the extent of cognitive load and distractions, personal physical response attributes, age, and other factors.

The American Association of State Highway and Transportation Officials (AASHTO) Policy on Geometric Design of Streets and Highways includes a method for determining stopping distance based on a number of factors including reaction time. Figure 16 - Vehicle Stopping Site Distances (Wet Pavement) shows estimated Safe Sight Stopping Distance (SSSD) based on that AASHTO method. This is significant as it shows there is a significant difference in stopping distance based on speed and grade.

Table 1: AASHTO Stopping Sight Distance (Wet Pavement)							
Stopping Sight Distance M (Ft) by Percent Grade (%)							
		Downgrade			Upgrade		
Traffic Speed km/h (mph)	0	3	6	9	3	6	9
35 (20)	35 (115)	35 (116)	40 (120)	40 (126)	35 (109)	35 (107)	35 (104)
40 (25)	50 (155)	50 (158)	50 (165)	55 (173)	45 (147)	45 (143)	45 (140)
50 (30)	60 (200)	65 (205)	65 (215)	70 (227)	60 (200)	60 (184)	55 (179)
60 (35)	80 (250)	80 (257)	85 (271)	90 (287)	75 (237)	70 (229)	70 (222)
65 (40)	95 (305)	95 (315)	100 (333)	110 (354)	90 (289)	85 (278)	80 (269)
75 (45)	110 (360)	115 (378)	120 (400)	130 (427)	105 (344)	100 (331)	100 (320)
80 (50)	130 (425)	135 (446)	145 (474)	155 (507)	125 (405)	120 (388)	115 (375)
90 (55)	150 (495)	160 (520)	170 (553)	180 (593)	145 (469)	140 (450)	135 (433)
100 (60)	175 (570)	185 (598)	195 (638)	210 (686)	165 (538)	160 (515)	150 (495)
105 (65)	200 (645)	210 (682)	220 (728)	240 (785)	190 (612)	180 (584)	170 (561)
115 (70)	225 (730)	235 (771)	250 (825)	275 (891)	210 (690)	200 (658)	195 (631)
120 (75)	250 (920)	265 (866)	285 (927)	305 (1003)	235 (772)	225 (736)	215 (704)

Source: A Policy on Geometric Design of Streets & Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design.

The speed and distance columns only correspond to their metric or English equivalent, i.e., if determining the SSSD for a posted speed in kilometer per hour (km/h), use the value shown in m, if using miles per hour (mph), use the value shown for ft.

Figure 16 - Vehicle Stopping Site Distances (Wet Pavement)

Although stopping distances are not applied to roadway lighting, with the exception of tunnel lighting systems, the distances for stopping various travel speeds and road grades are significant. If we assume typical low beam vehicle headlights a driver has an effectiveness of approximately 40–90 m in front of the vehicle (this varies as it depends on many factors) at speeds of above 60 km/h the stopping distances are greater than that the visibility of ones headlamps. Figure 17 - Car Headlight Model shows a calculated rendering of low beam car headlamps.

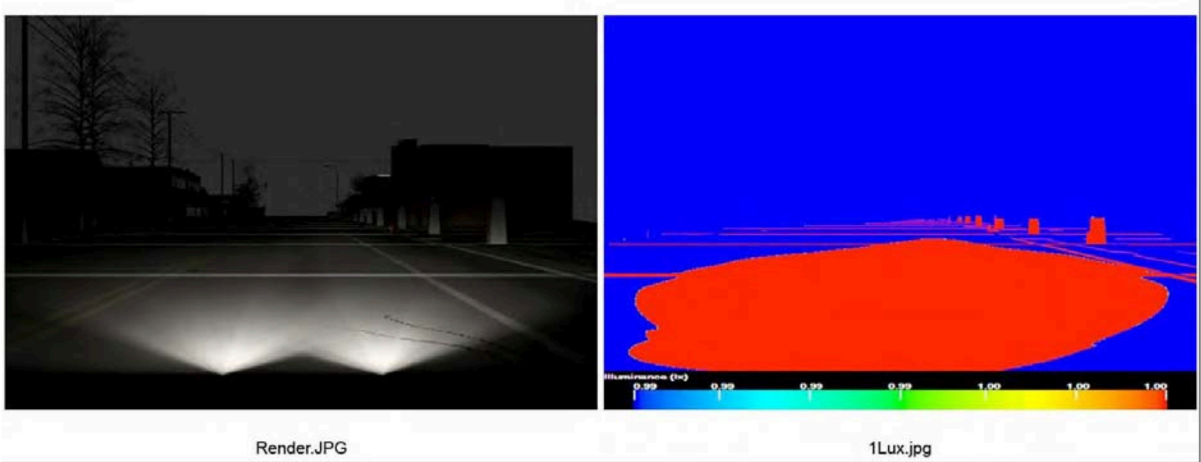


Figure 17 - Car Headlight Model

In order for a driver to detect a pedestrian or road hazard in time to stop at higher speeds (above 60 km/h) a roadway lighting system is of value in provide that necessary visibility.

For a driver to avert an accident, the pedestrian must be seen far ahead within the safe stopping distances. At night, the problems are exacerbated by the lack of roadway lighting at higher speeds, the limited power and aim of headlights, the conflict between positive and negative contrast, and by night myopia and glare.

Pedestrians can also contribute significantly to their own safety by using reflective clothing and avoiding risk-taking due to overconfidence in their conspicuity.

3.3.1 Conclusions

In order for a driver to detect a pedestrian or road hazard in time to stop at higher speeds (above 60 km/h), the roadway lighting system needs to be provided to enhance headlamp visibility. This further supports the need for lighting at intersections and mid block crosswalks where pedestrians are most likely to conflict with vehicles.

3.4 Security and Livability

Street lighting and pathway lighting provides guidance to pedestrians at night. The impact of lighting on crime is less clear. Crimes typically are either to a person such as assault or robbery; or property related such as vandalism or theft. Unlike driver or pedestrian safety for roadway lighting, which both have substantial research and data to prove a quantifiable benefit, crime reduction benefits of lighting are much harder to define and therefore much less clear.

The majority of the studies listed below indicate improved or increased lighting levels have no measurable impact on crime while a few studies show some level of crime reduction with improved lighting levels. No information is provided with respect to what illumination level and uniformity improvements defines “improved or increased lighting levels” thus it is hard to apply this information from a light level standpoint. In terms of security, some of the studies indicate that although lighting does not make one more secure, it does provide a feeling of security.

The following sampling of research studies reveal the complexity of this issue and characterize the range of findings:

- A study of a major lighting project in London[34] found no evidence to support the hypothesis that improved street lighting reduces reported crime. Although some areas and crime types did show reductions in night-time crime relative to the daylight control, the dominant overall pattern, from which this study draws its authority, was of no significant change. In addition, social surveys were conducted with a panel of residents in a re-lit area and an adjacent control area before and after re-lighting. The perceived safety of women walking alone after dark in the re-lit area was improved, but few other effects were statistically significant. No changes in un-reported crime, harassment or travel behavior could be detected. Nevertheless the reaction of residents to the re-lighting scheme was overwhelmingly favorable. It was concluded that although street lighting was welcomed by the public and provided reassurance to some people who were fearful in their use of public space, the area-wide introduction of new street lighting did not reduce crime.

- In a 2002 meta-analysis[35] , researchers looked in detail at UK and US studies of several different lighting projects. The researchers sought to determine the likely reason for the correlation in these successful studies – whether improved lighting led to increased desirable activity, surveillance, and deterrence of possible crime, or whether the lighting changes actually signaled community investments which foster community pride, and informal social control. Several of the studies showed a significant reduction in crime rates relative to control areas after the infrastructure improvements. (Another report {endnote Ramsay} pointed out flaws in many of these studies, calling into question the validity of the conclusions regarding crime reduction.) The meta-analysis notes that "these studies did not find that night-time crime decreased more than day-time crime." The researchers concluded that "a theory of street lighting … increasing community pride and informal social control may be more plausible than a theory focusing on increased surveillance and increased deterrence." Findings support the hypothesis that investment in communities can more than pay for themselves through crime reduction. It also supports lighting as a cost-effective component of such community investment. But the findings also seemed to suggest that the most effective lighting designs for crime reduction would be designed not for surveillance, but to encourage community pride and facilitate desirable activities.
- An Australian study[36] indicated that the presence of light tends to allay the fear of crime at night and it furthermore notes the balance of evidence, from relatively short-term field studies, that increased lighting is ineffective for preventing or deterring actual crime. The report also notes evidence indicating that darkness inhibits crime, and that crime is more encouraged than deterred by outdoor lighting. Additional quantitative evidence supports this hypothesis. The study notes excessive outdoor lighting appears to facilitate some of the social factors that lead to crime.
- In a report titled "The Chicago Alley Lighting Project[37]," a controlled analysis was undertaken to assess the benefits of lighting in alleyways. As the paper reports, "These findings indicate that, during the study period, there did not appear to be a suppression effect on crime as a result of increased alley lighting. In fact, it appears that with the increased lighting came an increase in the number of crimes reported." All categories of crime (violent, property, and non-index) were found to increase, to a greater40% in the experimental neighborhood versus 19% in the control. The report theorizes that the increase in reported crime in the evenings where lights were added, particularly the increase in non-index crime such as drug use, was due to improved visibility leading to increased detection.
- A paper titled "The Effect of Better Street Lighting on Crime and Fear" [38] states better lighting by itself has very little effect on crime. The findings state "lighting has positive impact on public perceptions of crime-reduction, but does little to reduce real crime rates."
- Many lighting projects seek the principal objectives of improving efficiency, lowering operational costs, or reducing environmental harm. Crime statistics analysis before and after these projects show no significant impact on crime. An example is Calgary's "EnviroSmart" program, which focused on light pollution reduction, energy savings, and waste elimination. According to the Calgary Police Department, analysis of crime trends in all affected neighborhoods, the program is not associated with any adverse impact on crime.
- At school and university campuses an effective approach to lighting improvement for crime reduction involves turning off and/or incorporating motion control on existing security lighting. Evidence from several programs demonstrates that both lighting costs and certain types of crimes can be reduced simultaneously. In San Antonio, Texas, for example,

vandalism damage at schools was reduced over 74% after exterior lights were turned off, saving the district almost $120,000 per year in repairs, plus substantial energy savings. Similarly, the Dark Campus policy at California's Cupertino Union School District is associated with a 29% reduction in vandalism costs. Three school districts in Washington State (Battle Ground, Spokane, and Riverside) as well as one in Eugene, Oregon, virtually eliminated extreme vandalism problems at key schools through programs which turned off exterior lights at 10:30 PM. At Edmonton's Montrose School, a serious pattern of vandalism was similarly halted when most of the building's exterior lights were turned off, and the remainder put on motion-sensor control.

The Illuminating Engineering Society of North America (IESNA) has produced a document entitled G-1-03 Guideline for Security Lighting for People, Property, and Public Spaces. In terms of the justification for lighting with respect to security, the document makes the following significant statements:

"Lighting can affect crime by two indirect mechanisms. The first is the obvious one of facilitating surveillance by the authorities and the community after dark. If the presence of surveillance is perceived by criminals as increasing the effort and risk while decreasing the reward for a criminal activity, then the level of crime is likely to be reduced. Where increased surveillance is perceived by the criminal as not to matter, then better lighting will not be effective. The second mechanism by which an investment in better lighting might affect the level of crime is by enhancing community confidence and hence increasing the degree of informal social control. This mechanism can be effective both day and night but is subject to many influences other than lighting".

The second mechanism, involving improved community pride, confidence, and engagement, is generally better supported by existing research. It should be noted that the two mechanisms can be mutually reinforcing, given lighting design and other environmental enhancements which match the needs and potential for a given community. For example, well designed lighting and other improvements can encourage more desirable traffic in an area (technically mechanism one) which creates more potential for detection of crime. If community improvements (lighting included) give residents a sense of ownership and pride in an area, the probability of a detected crime being reported and/or impeded can also increased. If law enforcement responds to a reported crime, improved lighting may enhance their ability to identify and apprehend a fleeing criminal. More significantly, the perceived likelihood of detection, reporting, and apprehension is likely to deter crime. Again, the research suggests that blanket lighting increases may not achieve desirable results, but well-designed lighting improvements have the ability to support both mechanisms for crime reduction.

Lighting of some areas such as alleyways and parks and can be a challenge and a concern as it provides a sense of comfort and security which may in fact be misleading. In a lighted alleyway or a remote park area, the criminal generally has the upper hand due to a lack of natural surveillance from the roadway and the number of concealed areas and shadows where a criminal can hide. Effective environmental design might include lighting and other features which would encourage pedestrians to use the sidewalk adjacent to the roadway, rather than side alleys or parks that typically have little natural surveillance. It might also include motion detectors on park and alley lighting, which would turn lights on and draw attention from neighbors to monitor those areas when either potential perpetrators or potential victims were present.

To improve security the city should work with the local police force and follow CPTED Principals noted below. Lighting design should consider pedestrian traffic as well as present ambient lighting. Sidewalk lighting levels can be provided through a spill from roadway lighting, but should not produce unwanted light trespass cast onto residential occupancies.

An accepted way to integrate security elements into lighting design is by adopting “Crime Prevention Through Environmental Design” (CPTED) strategies. CPTED is a proactive crime prevention strategy utilized by planners, architects, police services, security professionals, and everyday users of space. CPTED is based on the concept that the proper design and effective use of the built environment can lead to a reduction in the fear of crime and the incidence of crime, and to an improvement in the quality of life. As mentioned above, proper environmental design (including lighting design) can engage multiple, complementary crime reduction mechanisms to ultimately improve the sense of pride and engagement in a community, increase the opportunities for public detection of crime, enhance the chances of intervention and reporting, and increase deterrence to criminal behavior.

Effective implementation of CPTED principles leads to environments which provide adequate visibility, encourage a sense of ownership, and facilitate desirable activities and traffic. For example, an environmental design which gives a lone pedestrian visibility (clear sight lines, low-glare lighting) and options (open businesses, security devices, call boxes) provides a means of avoiding hazards they see ahead. (In CPTED terms, visibility allows the person to choose flight rather than fight.) When a crime is in progress, those same visibility features, plus a sense of ownership and pride among nearby motorists, business owners, residents, etc. lead to a greater chance of intervention and reporting. Designs which increase desirable traffic enhance both these effects and further serve to deter criminal activity, or even engage would-be criminals in more constructive behavior.

From an enhanced personal security standpoint, IESNA G-1-03 Guideline for Security Lighting for People, Property, and Public Spaces defines a minimum maintained average vertical illumination level of 5–8 lux, with average to minimum uniformity not exceeding 4:1 for facial recognition and enhancing surveillance and security. These lighting levels should be considered in areas such as the downtown where personnel security is an issue and enhanced surveillance is required.

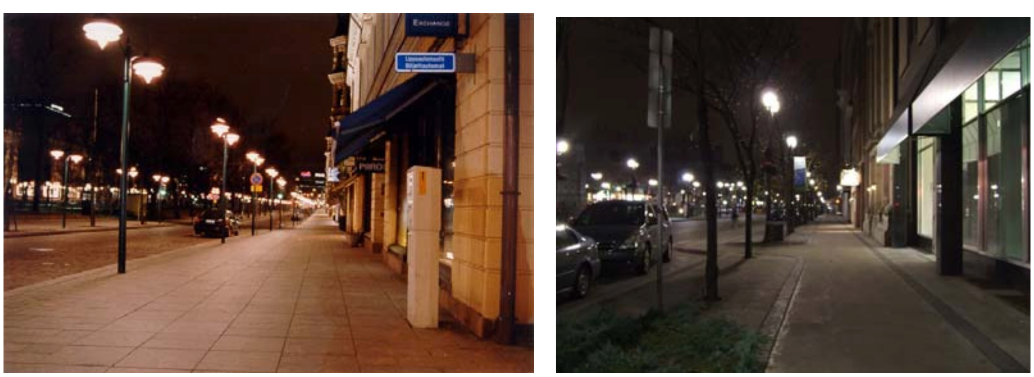


Figure 18 - Sidewalk Lighting

Sidewalk lighting levels can be misleading as the reflective properties of the sidewalks and buildings can impact the overall brightness and one's visibility. As shown in Figure 18 - Sidewalk Lighting, one's visibility can be improved by the very light building finishes which reflect light much better than dark finishes. Though the building finish is typically beyond the control of the lighting designer it is important to consider such factors when undertaking lighting design where security may be an issue.

From a pedestrian guidance standpoint and in the case of high pedestrian activity from both a guidance and security standpoint, the Transportation Association of Canada Guide for the Design of Roadway Lighting defines lighting requirements.

Visibility on the sidewalk can also be reduced by trees blocking the light. A July 2008 study entitled "Trees, Lighting and Safety in Context Sensitive Design" gave some examples of how a lighting system should be designed to allow for the presence of trees at all stages of maturity:

- To avoid light blockage locate luminaires on davit arms of suitable length to extend the luminaire outside of the full growth lines of the species of the tree.
- When a roadway or pedestrian lighting project includes new or existing trees in close proximity to the lighting, then an additional light loss factor should be included in the design for light loss due to shading. Insufficient research is available at this time to quantify the factor but an additional 10% to 20% appears reasonable. That would be an additional 10% to 20% on the light loss factor. This will not help with uniformity issues.

In addition, we would recommend the required pole spacing be tightened up by 20% - 30% to improve uniformity by compensating for any light blockage from the trees. In streetscape application it is recommended the roadway lighting and sidewalk lighting be provided by separate luminaires each designed to take into account tree canopy impacts. Refer to figure for exampled of such lighting.

A "Walkability Strategy" study has been prepared for City of Edmonton. Lighting is discussed in the study, however, it is very general and broad. Lighting is promoted as part of the recommendations. The information defined above provides further information in support of sidewalk lighting.

3.4.1 Conclusions

In terms of security, most studies show lighting does not reduce crime but it does provide a feeling of security. Lighting of some areas such as alleyways and parks and can be a challenge and a concern as it provides a sense of comfort and security which may in fact be misleading. When entering an alleyway or a remote park area, the criminal generally has the upper hand due to lack of natural surveillance from the roadway and the number of concealed areas where a criminal can hide. However, personal safety would typically be improved if pedestrians used the sidewalk adjacent to the roadway, rather than side alleys or parks that typically have little natural surveillance.

Lighting also aids in surveillance and enhances one's ability to detect crime. To improve security and safety related to crime reduction the city should work with the local police force and follow CPTED principals.

From a pedestrian guidance standpoint lighting sidewalks improves pedestrian visibility and provides guidance. Unlike motor vehicles, which have headlamps to improve visibility, pedestrians typically don't have such a feature unless they carry flashlights. Outdoor lighting is the only real practical aid to visibility and guidance to the pedestrian. Therefore, it is critical to prevent personal injuries that may result from tripping, and walking into others or objects. To improve the effect of lighting of sidewalks consider the reflectance of the surrounding area (sidewalks and building) and wherever possible consider reflective materials as part of the architectural design as they have a substantial effect on lighting and visibility as shown in the left image of Figure 18 - Sidewalk Lighting.

4 Potential Lighting Impacts and Mitigation

Though lighting can be used effectively to improve safety and promote a feeling of security in many applications, artificial lighting also has potential negative impacts. This section is aimed at providing research and information on impacts and where required mitigation methods are defined.

Though not discussed here in detail, it should be noted that all improvements in efficiency – whether through advanced lighting technology, reduced waste in sky glow, light trespass and glare, reduced lighting levels to match area needs, or adaptive lighting controls – will provide indirect benefits to public health and the environment. Edmonton derives the vast majority of its power from coal-fired plants. Reducing consumption from these plants will help control water and air pollution from these plants and the mining and transportation of their fuel. It will also help control greenhouse gas production, and may be of value to the City should a cap and trade system be established.

4.1 Health Issues

The effect of light on human performance and health is an ongoing point of discussion, research, and debate. Much of the research is focused on melatonin suppression and how outdoor lighting contributes. The hormone melatonin is the primary controller of circadian (day/night) biorhythms. Very bright light (the sun) suppresses the output of melatonin. After sunset, the pineal gland responds to the decreased light levels by greatly increasing its output of melatonin. After a few hours, blood melatonin levels reach a point where sleep is induced. Melatonin levels usually peak two to four hours after the onset of sleep and decrease gradually during the remaining sleep period.

The effect of exposure to light at night on human health is an area of ongoing research. Studies in the fields of biology and medicine have identified links, in both the laboratory and the field, between light exposure at night and a variety of human health risks. Maladies under investigation include sleep disorders, depression, seasonal affective disorder, and some forms of cancer. To date the largest body of evidence involves exposure to relatively high levels of light at night, such as one might receive in shift work. The World Health Organization now categorizes light exposure of this sort as a group 2A carcinogen (the same category as cigarette smoke). More recently researchers have investigated health effects from lower level light exposure, including levels which might be associated with light trespass into a sleeping area from outdoor lighting. At these lighting levels the research is still sparse and inconclusive, though some noteworthy evidence has been collected. Although there is still much to be learned on this subject, strong official statements in support of light pollution reduction have already come from several medical organizations, including:

- The Massachusetts Medical Society,
- The American Medical Association (AMA) Council of Science and Public Health, and
- The full AMA House of Delegates, which unanimously supported a resolution to encourage light pollution reduction.

A number of possible causal pathways have been identified in this research, and the search continues for others. The best researched pathway involves melatonin suppression. The hormone melatonin is the primary controller of circadian (day/night) biorhythms. Very bright light (the sun) suppresses the output of melatonin. After sunset, the pineal gland responds to the decreased light levels by greatly increasing its output of melatonin. After a few hours, blood melatonin levels reach a point where sleep is induced. Melatonin levels usually peak two to four hours after the onset of sleep and decrease gradually during the remaining sleep period.

Daylight inhibits the production of melatonin, and levels of melatonin usually reach a minimum sometime during the afternoon. Irregularities in melatonin production can cause sleep problems, lethargy, mood disorders, and has been linked to an increased risk to hormone dependant cancers such as breast and prostate cancer (Bartsch et al., 1985). This research also concluded "melatonin controls not only the growth of well differentiated cancers, but also possesses anti-carcinogenic properties." Figure 19 - Day Night Cycle shows the normal cycle of melatonin secretion based on the day night cycle. It was found very high level of artificial lighting at night could also suppress melatonin (using 2500 lux of white light for between 2–4 hours) (Lewy et al., 1980).

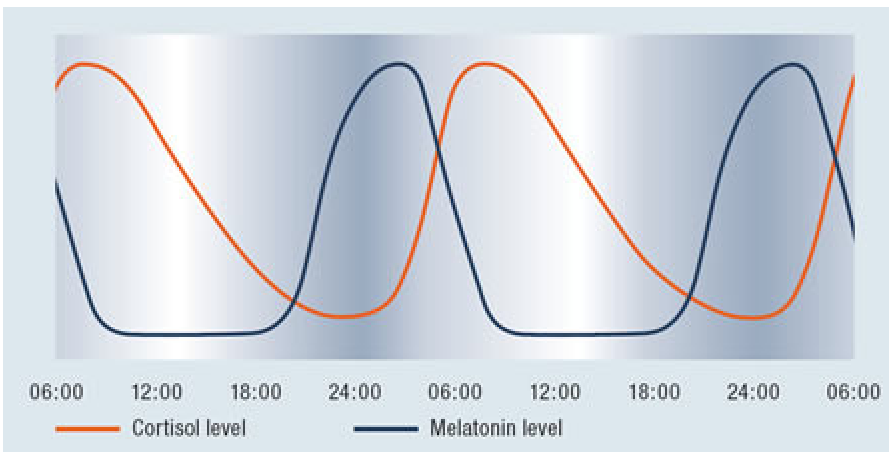


Figure 19 - Day Night Cycle

From an exterior lighting perspective, the question is whether levels and/or certain types of lighting can cause the suppression of melatonin levels at night through light pollution and trespass, negatively impacting the health of residents. The spectrum of the light can also have an influence, with shorter wavelength lighting having a greater impact.

The amount of light needed has to be at sufficient levels and also applied for a sufficient amount of time to have an effect on melatonin levels. Figure 20 - Predicted Human Melatonin Suppression by Lighting (Figueiro et al., 2006) shows this relationship.

Table 2: Predicted Human Nocturnal Melatonin Suppression from Incandescent and Daylight Illumination [46] of Varying Corneal Illuminances and Durations, Based on Rea et al. [37]

Incandescent			
Illuminance (lx)	Melatonin suppression after 30 minutes	Melatonin suppression after 60 minutes	Melatonin suppression after 90 minutes
0.1	0%	0%	0%
0.3	0%	0%	0%
1	0%	1%	1%
3	1%	2%	2%
10	3%	5%	5%
30	8%	11%	13%
100	19%	25%	27%
300	35%	42%	45%
1000	54%	59%	60%
3000	65%	68%	69%
Daylight			
Illuminance (lx)	Melatonin suppression after 30 minutes	Melatonin suppression after 60 minutes	Melatonin suppression after 90 minutes
0.1	0%	0%	0%
0.3	0%	0%	1%
1	1%	1%	1%
3	2%	3%	4%
10	6%	9%	10%
30	14%	19%	20%
100	29%	36%	39%
300	47%	53%	55%
1000	62%	65%	66%
3000	69%	71%	71%

Figure 20 - Predicted Human Melatonin Suppression by Lighting

Street lighting rarely exceeds 10 lux at the cornea outdoors. Indoors, behind closed curtains or blinds, the levels would likely to be much lower. Furthermore, the human eyelids transmit only about 1% to 3% in the short wavelength region of the visible spectrum.

Given the available published data on human melatonin suppression in response to light, light trespass through residential windows is an unlikely cause of melatonin suppression, simply because the light levels are so low, particularly with the eyes closed (Robinson et al., 1991). The typical levels of melatonin suppression associated with light exposure, and the attenuation of light expected from curtains and eyelids, suggest that people sleeping in a typical home in Edmonton would not be subject to substantial melatonin suppression from street lamps. Lighting that has poor optical control in very close proximity to windows may have some impact in individual cases (such as laneways or multi-level towers), if curtains were translucent or not fully closed. While streetlight trespass in bedrooms may not constitute a significant health hazard, city policies should seek to provide a margin of safety for all residents (not just those with high-quality curtains) against potentially cumulative, long-term health risks. In the case of outdoor lighting, a policy which emphasizes controls on light trespass and sky glow will help achieve this margin of safety.

A number of studies link light exposure at night to various forms of cancer. Most of these have involved higher levels of light exposure, and examined endochrine disruption (including melatonin suppression) as the most likely causal link. A few papers correlated light density from satellite imagery with regional incidence of breast cancer. These are deemed questionable given the number of potential confounding factors and the failure to precisely tie satellite imagery data to light exposure of individuals. Other more recent medical research utilizing data on light levels in bedrooms, suggest a possible causal link even at low levels. This is supported by some laboratory experiments with low-level lighting, though the amount of evidence is not sufficient to draw firm conclusions.

There is a growing interest in nighttime exposure to short-wavelength (blue) light for it is presence in some high colour temperature LED lighting. The interest in short-wavelength light is that it might reduce melatonin production at night or disrupt the internal body clock and, perhaps, increase incidence of disease.

Lighting can have impacts on animals. The same light pollution that impacts humans can an effect on resident and migrating wildlife, including mammals, birds, insects, insect predators, reptiles, amphibians, and others. Mating patterns, migration pathways, predation, growth, habits of movement, and feeding patterns can be affected. Almost all small rodents and carnivores, 80% of marsupials, and 20% of primates are nocturnal. Lighting in sensitive areas should minimize the duration, direct the light only where needed, and reduce intensity as much as possible.

An example of this is the impact on birds. An estimated 100 million to 1 billion birds die each year colliding with buildings at night in the U.S. alone. Migration patterns of birds are known to be shifted by urban lighting as well. Over the past 25 years, cities such as Toronto, Houston, Minneapolis, Indianapolis, Boston, and others are making efforts to reduce this effect. Chicago's "Building Lights Out" project, for example, is credited with saving an estimated 10,000 birds each year. This is, however, applicable to building lighting.

The effects of light pollution go far beyond birds. Through field and laboratory research, biologists have shown that excess lighting can interfere with the reproductive patterns of tree frogs and salamanders. Artificial lights have been shown to affect the emergence timing, and feeding behavior of species of bats. Sources of excess light also draw insect populations away from their normal habitat, introducing disproportionate impacts on feeding and success rates of different bat species.

Sky glow pollution has been shown to disturb the feeding patterns of zooplankton, which in turn allows excessive algae growth which can kill off other, important aquatic plants and ultimately killing off large numbers of lake-dwelling fish. Biologists have shown that exposure to artificial light, even for short periods, can cause some frogs to freeze in place even after the light is turned off – disrupting essential feeding and reproductive activity. Salamanders have also been shown unable to properly navigate at night, from one pond to another, in the presence of artificial lights. This leaves the creatures wandering, vulnerable to the elements and to predators.

Insects including many significant pollinators are especially hard hit by artificial light. Excess lighting interferes with the vision systems of moths and other insects, making it harder for them to find food. It also can disrupt their flight patterns, causing many insects to miss opportunities for feeding, mating, or laying eggs, which in turn can have a significant impact

on population. Artificial lights have even been shown to interfere with the production and release of pheromones, thereby interrupting or completely eliminating mating behaviors. The impact on insect populations may not seem important, until one considers their role in a food chain which supports amphibians, reptiles, birds, mammals, and all the higher-order animals which, in turn, prey upon them.

As light affects the pineal gland's production of melatonin in humans, so it also affects hormones regulating reproduction, growth, and circadian rhythms in many species of wildlife. Circadian patterns in many animals are affected by artificial light – shifting the daily and seasonal cycles of feeding, reproduction, nesting, and migration. When animals survive these disruptions, they may remain vulnerable to stunted or delayed growth, or interference with mating or reproduction, due to the effects of artificial light on hormone production.

Plants have evolved a wide range of photoreceptors that perceive and respond to light signals in the ultraviolet, blue, red, and near-infrared regions of the electromagnetic spectrum. While little research has been done to explore the specific effects of artificial lighting, there can be no doubt that there is an effect.

4.1.1 Conclusions

Medical and biological research shows evidence of links between exposure to light at night and health risks, including sleep disorders, depression, and some forms of cancer. A minority of these studies look at the effects of low light levels such as those from street lighting light trespass into sleeping areas. Research at these lower lighting levels is, to date, inconclusive. The American Medical Association and other professional organizations have taken a strong position supporting light pollution reduction with human health concerns in mind. Lighting design with proper avoidance of light trespass is an appropriate response which will provide a margin of safety around those potential health hazards still under investigation.

A more substantial body of evidence reveals significant harm from excessive outdoor lighting on local and migratory wildlife. Good lighting design with proper up-light and glare control can significantly diminish environmental harm while improving service to humans. The same is especially true for adaptive controls on lighting, which can substantially improve environmental impact.

Given the concerns raised over blue light (6000–7000 K), LED light sources should have a colour temperature of 5000K or less for outdoor lighting applications to reduce these impacts. A colour temperature of 4300K would closely replicate moonlight and has been favored by some such as the City of Las Angles for that reason. It is important to note that the higher colour temperature lamps such as 5000K produce higher light output than a source with 4300K so the 5000K source is more efficient power consumption wise. Some believe the softer colour produced by the 4300K lamp outweighs the energy efficiency gain. The city should, however, stive to use the lowest CCT ("warmest") practical.

4.2 Energy Consumption

Energy consumption associated with public outdoor lighting, could have some level of indirect impacts to water quality (e.g. heavy metal contamination from coal mining), air quality (particulates, etc.), greenhouse gas emissions and long-term climate impact, habitat destruction, etc. The exact impacts are unknown as the majority of power consumption is at night when demand is often at it lowest. Some energy producers have been known to burn-off (waste) energy in non-peak periods.

The Cities "The Way We Green" document has specific objectives for emissions control and energy efficiency. The use of LED technology and adaptive lighting systems now being applied by the city is a key way to meet these objectives.

Energy reduction is key in the stewardship of natural resources here. Energy we waste now through the use of less efficient lighting technologies uses resources that might otherwise be available for future generations.

4.3 Light Pollution

Light pollution can be annoying to residents. It can interfere with first nation's ceremonies and religious traditions. It can foil student science projects and university research. Like other forms of pollution (such as air, water, and noise pollution) light pollution can do harm to the environment and create human health risks.

Light pollution is a side effect that comes whenever artificial lighting is used. Its sources include building exterior and interior lighting, advertising, commercial properties, offices, factories, streetlights, and illuminated sporting venues. Though light pollution is unavoidable in a growing, industrialized world, it is possible to control. Since the early 1980s, a global movement has emerged, with concerned people working to reduce the amount of light pollution. For communities successful in reducing light pollution, the reward comes in the form of long-term savings and quality-of-life benefits.

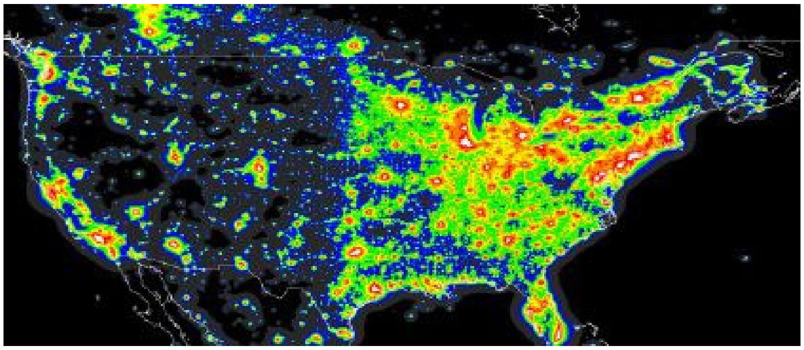


Figure 21 - Lighting Pollution Map of North America

Light pollution is defined by three major interrelated elements (Ref Figure 22 - Light Trespass (spill light), Glare and Sky-glow):

- Light Trespass (Spill light): Is the light that falls outside the area that was intended to be lit. It is typically measured in units of lux in a vertical plane with the light meter oriented towards the light source
- Glare: Is the light that is viewed at the light source (luminaire) and that reduces one's visibility (refer to Figure 24 - Example of Glarey Street Lighting). This is defined further in Section 2.3 Glare.
- Sky Glow: Consists of light which scatters or reflects off particles, clouds, or moisture in the air. This is the result of light from sources at or near ground level, which shines either directly above horizontal, or is reflected or refracted such that it reaches the reflecting or scattering area above ground. Sky glow can occur at altitudes from a few meters to kilometers above ground. Sky glow reduces one's ability to view stars in the night sky by casting a veil of unwanted light across the sky (refer to Figure 23 – Sky Glow Example). Sky glow limits the amount of research which can be done from the observatory atop the new Physics building at the University of Alberta. Similarly it limits the type of science projects Edmonton teachers can lead for our future engineers and scientists. Expansion of sky glow recently reached the point at which most people in the U.S. and Canada now cannot see the Milky Way and other celestial objects that were very familiar to almost all people 50 years ago. This aspect of light pollution impedes enjoyment and study of the cosmos. For many it also takes away the stars and planets which are natural reference points of cultural and religious traditions, native rituals, and the folklore of many mythologies.

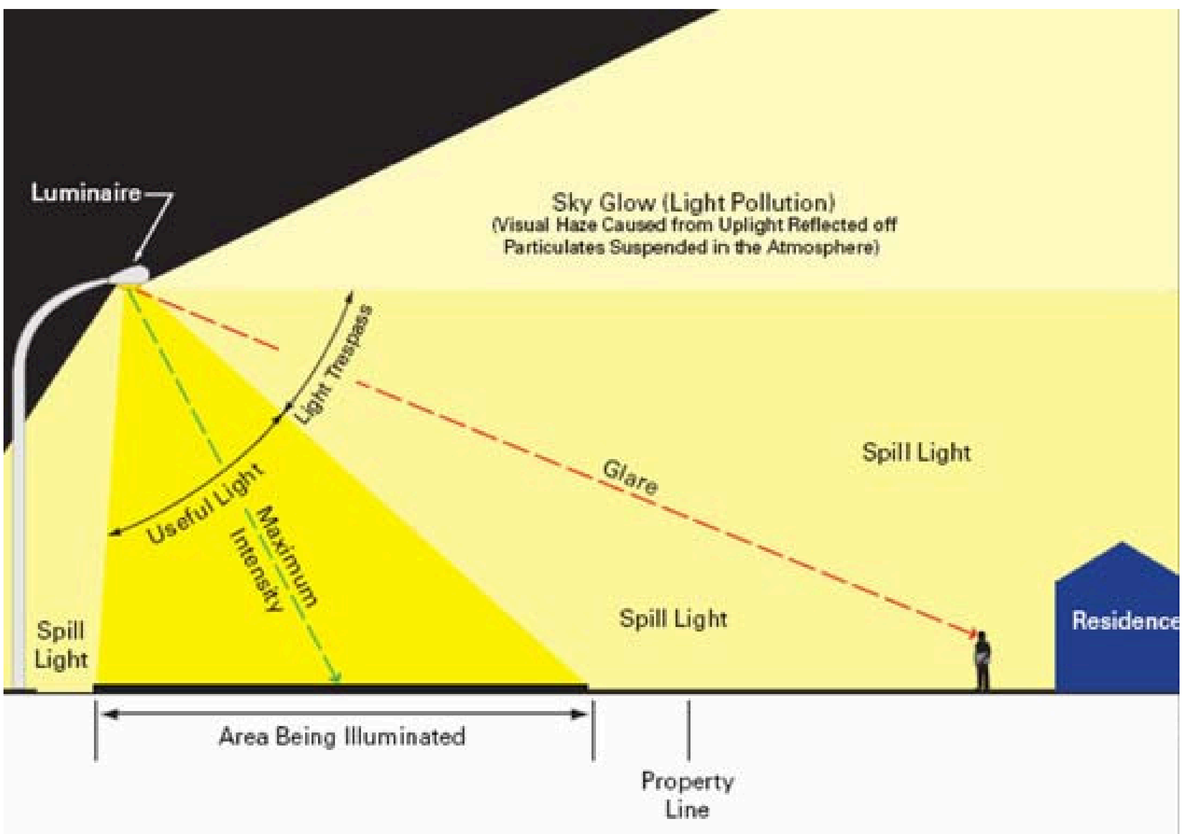


Figure 22 - Light Trespass (spill light), Glare and Sky-glow

Figure 23 – Sky Glow Example

The reduction of lighting pollution starts with the selection of luminaires with good optical systems to reduce unwanted back-light and up-light. Moreover, this will reduce veiling luminance (glare) from the luminaire on and off the roadway, thus improving overall visibility.

Figure 24 - Example of Glarey Street Lighting

Light trespass levels have been developed and are documented in IESNA TM-11 Lighting Trespass: Research, Results and Recommendations and IESNA RP-33 Lighting for Exterior Environments, and, are provided in Figure 25 - Light Trespass Levels. Designations (LZ1 to LZ4) define the light zone and are further defined in TM-11. In the case of the city, LZ3 levels should be applied for rural areas and LZ4 levels for urban areas.

Designation	Recommended Maximum Illuminance Level (Ee)	
	Pre-Curfew	Post-Curfew (Not Applicable to Roadway Lighting)
LZ 1	1.0 lux	0.0 lux
LZ 2	3.0 lux	1.0 lux
LZ 3	8.0 lux	3.0 lux
LZ 4	15.0 lux	6.0 lux

Figure 25 - Light Trespass Levels

These light trespass levels should not be exceeded wherever possible. However, they may be impractical to achieve in urban roadway lighting applications with tight right-of-ways where residences are very close to the street. It is important to note that the reduction or elimination of light trespass must never take precedence over proper roadway lighting as traffic safety is of paramount importance. The primary objective of lighting roadways and streets should be proper lighting of the roadway, street and sidewalk, with secondary consideration given toward the reduction of off-site impacts. Lighting the area adjacent to roadway travel lanes (typically within or adjacent to the road allowance) can also benefit a driver's peripheral vision. Some light trespass off the roadway improves overall roadway user safety by providing visibility of crossroads, driveways, and sidewalks. Fortunately, current LED technology provides more precise control of where light is cast, permitting designers to achieve good peripheral visibility without compromising on light trespass control.

To better aid in allowing designers to classify and better select products that reduce wasted light trespass and sky glow a new luminaire classification systems defined as the "BUG" have been developed. This replaces the past system for defining luminaire optics which was based on cutoff, semi-cut-off, and full cutoff designations which really only dealt with up-light cast into the atmosphere. The BUG is much broader than the past system in terms of defining optical performance.

BUG ratings are a classification system that establish back-light (B), up-light (U), and glare (G) ratings for luminaires based on lumen output limits for various regions. See the IESNA TM-15-07 (Revised) Luminaire Classification System for Outdoor Luminaires for complete details. The BUG rating considers luminaire output for specific regions that surround the luminaire as per Figure 26 - BUG System. The maximum lumen outputs must not exceeded the generalized B, U, or G rating. So, the BUG ratings are based on the highest zonal lumen value within the tables defined in Figure 27 - BUG Lumen Ratings for Various Zones. One should attempt to achieve the lowest BUG rating numbers as practical. The BUG ratings can be defined by the designer and the supplier will then be required to provide a product which meets the defined BUG. This is similar to defining a luminaire with full cut-off optics. Designers can use lighting software (e.g., AGI Photometric Toolbox) to determine a suitable BUG rating which will allow the luminaire to meet the required lighting criteria. The BUG ratings apply only to fixed position luminaries installed according to the photometric data. If the luminaire is aimable (e.g., such as with a floodlight or sports light), then it cannot have a BUG rating unless it is provided by the manufacturer for a specifically installed aiming angle.

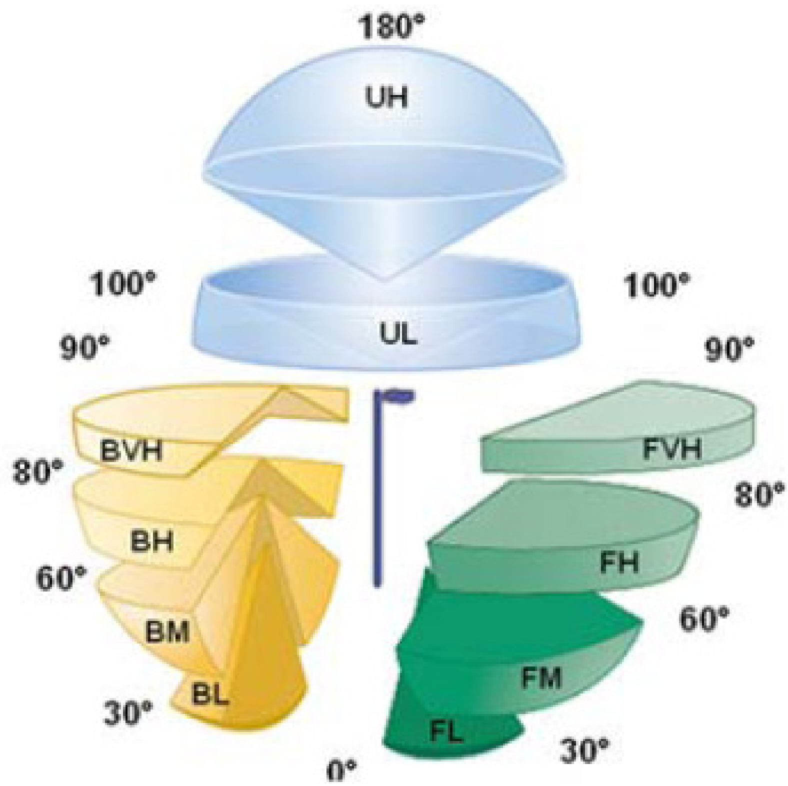


Figure 26 - BUG System

	Secondary Solid Angle	B0	B1	B2	B3	B4	B5
Backlight / Trespass	BH	110	500	1000	2500	5000	>5000
	BM	220	1000	2500	5000	8500	>8500
	BL	110	500	1000	2500	5000	>5000

Uplight Rating

	Secondary Solid Angle	U0	U1	U2	U3	U4	U5
Uplight / Skyglow	UH	0	10	100	500	1000	>1000
	UL	0	10	100	500	1000	>1000
	FVH	10	75	150	>150		
	BVH	10	75	150	>150		

Glare Rating for Asymmetrical Luminaire Types (Type I, Type II, Type III, Type IV)

	Secondary Solid Angle	G0	G1	G2	G3	G4	G5
Glare / Offensive Light	FVH	10	250	375	500	750	>750
	BVH	10	250	375	500	750	>750
	FH	660	1800	5000	7500	12000	>12000
	BH	110	500	1000	2500	5000	>5000

Glare Rating for Quadrilateral Symmetrical Luminaire Types (Type V, Type V Square)

	Secondary Solid Angle	G0	G1	G2	G3	G4	G5
Glare / Offensive Light	FVH	10	250	375	500	750	>750
	BVH	10	250	375	500	750	>750
	FH	660	1800	5000	7500	12000	>12000
	BH	660	1800	5000	7500	12000	>12000

Figure 27 - BUG Lumen Ratings for Various Zones

Often, light trespass is not the issue of greatest impact to local residents, as bright light sources set against a dark background may have little or no spill light. However, it can be very annoying to local residents. This is very significant for non-roadway lighting applications such as those that use high wattage sports lighting or floodlighting. In this case, source brightness (intensity) is an excellent method of evaluating and mitigating off-site impacts onto local residents.

In IESNA TM-11 Lighting Trespass: Research, Results and Recommendations it is defined that "source brightness had been generally identified as being the principal characteristic to which persons object. Spill light was seen as a less significant effect. It was decided, therefore, to design experimentation to identify quantitatively the relationship between source brightness and the degree to which the light source was found objectionable."

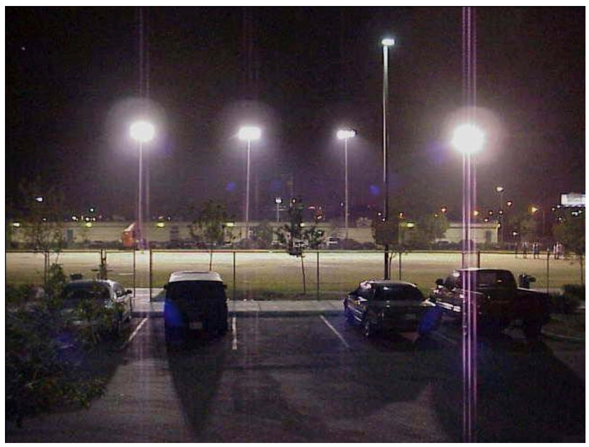
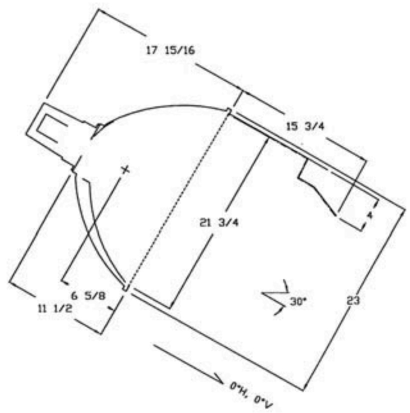


Figure 28 - Source Brightness Examples

Figure 28 - Source Brightness Examples shows how the third cluster of sports lights from the left is far less bright than the others despite being of the same wattage, voltage, beam spread, mounting height and aiming angle. The third cluster of lights has less source brightness than the others which is achieved by superior spill light control (external visor) and internal optics, which makes it less obtrusive than the others. This demonstrates how source brightness is an excellent way to define and reduce impacts. The cluster on the far right has poor optical control and therefore emits a much higher level of source brightness than the others.

To calculate the source intensity of a luminaire one must first obtain and review the lighting suppliers' photometric report, which can be obtained in PDF format from the sports lighting supplier. A sample photometric report is shown in Figure 29 - Candlepower Intensities for Sports Light below. The report below represents a sports lighting luminaire from a supplier. The test report should be produced by a third-party testing agency for the supplier. Luminaire suppliers normally can provide such reports. These reports are the basis of the digital IESNA photometric files used for computerized lighting calculations.

CANDLEPOWER



DEG	HORIZ.	DEG	VERT.
76.0	0.	76.0	0.
68.0	90.	68.0	0.
60.0	490.	60.0	0.
52.0	1220.	52.0	0.
44.0	3930.	44.0	0.
36.0	14040.	36.0	820.
28.0	41740.	28.0	4510.
20.0	84960.	20.0	22940.
12.0	137470.	12.0	72900.
4.0	186390.	4.0	170170.
0.0	190240.	0.0	190240.
-4.0	186390.	-4.0	190450.
-12.0	137470.	-12.0	161780.
-20.0	84960.	-20.0	117750.
-28.0	41740.	-28.0	76380.
-36.0	14040.	-36.0	42390.
-44.0	3930.	-44.0	26210.
-52.0	1220.	-52.0	19250.
-60.0	490.	-60.0	10650.
-68.0	90.	-68.0	3890.
-76.0	0.	-76.0	1840.

Figure 29 - Candlepower Intensities for Sports Light

The example photometric file above shows the various levels of intensity (candlepower) at various angles in both the vertical and horizontal planes. We have found intensities in the vertical plane to be the most significant and typically have the most impact on adjacent residences. From the photometric report one can see the most intense part of the vertical beam (190,240 cd) is at an angle of 0 degrees which is aimed to a defined location on the field. The most intense light is emitted at the (0, 0 angle) with the intensity decreasing as the angles increase, as shown. The positive vertical angles (DEG) define the upper part of the fixture beam and negative vertical angles (DEG) define the lower part of the fixture beam. The intensities at the upper (positive) vertical angles are typically the most visible when viewed from residences off site. As one can see, far less intensity is emitted from the upper angles than from the equivalent lower angles.

When undertaking lighting design, one must prepare lighting calculations to determine the off-field spill light levels. The designer selects a mounting height and aims the fixtures to various points on the field. The lighting design results should produce uniform illumination on the field. The luminaire aiming points along with the fixture photometric files are a key to assessing off-site intensity (candlepower).

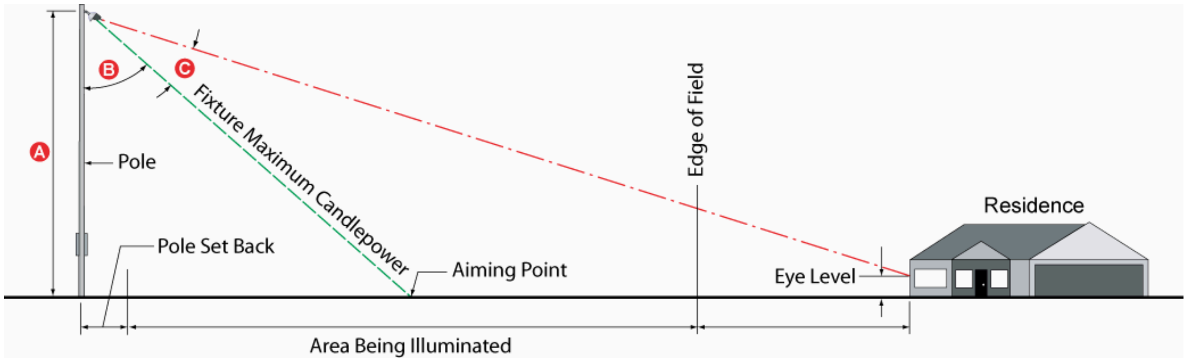


Figure 30 - Calculation Example

To determine the source intensity of a given luminaire when viewed from the point off site (as shown in Figure 30 - Calculation Example) one can undertake the following steps:

- Obtain fixture photometric report data files from supplier.
- Determine luminaire aiming angles from the computerized lighting calculations.
- The aiming angles (B) are based on the aiming point and fixture mounting height (A).
- The fixture aiming position will be the maximum candlepower at angle zero from the supplier's photometric report.
- Determine the vertical angle (C) between the aiming point and the point 5 ft above grade at the residential property line. This angle is typically 20 to 30 degrees. If this angle was found to be 28 degrees, then based on the photometric report above the source intensity would be 4510 cd.

The intensity (candlepower) will be quite similar for various beam types from one supplier to another, in the lower upper vertical angles range. Vast differences will be found from one supplier to another in 20 to 30 degree vertical ranges, which are the typical angles the luminaires will be seen from adjacent local residences.

As part of the fixture and mounting height and luminaire selection process, it is recommended that the lighting designer should review the supplier's candlepower curves and select the appropriate mounting height and optical system so that from any given fixture no greater candlepower than what is listed in Figure 31 - CIE Maximum Source Brightness Levels will be visible from the adjacent residential property lines. This method of using the fixture supplier's candlepower curves to access intensity (candlepower) is a common sense approach.

Light Technical Parameter	Application Conditions	Environmental Zones			
		E1	E2	E3	E4
Luminous intensity emitted by luminaires (I)	Pre-curfew:	2 500 cd	7 500 cd	10 000 cd	25 000 cd
	Post-curfew hours:	0 cd*	500 cd	1 000 cd	2 500 cd

*NOTE: If the luminaire is for public (road) lighting then this value may be up to 500 cd.

Figure 31 - CIE Maximum Source Brightness Levels

The International Commission of Illumination (CIE) 150:2003 Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations defines limitations for source brightness (intensity) for outdoor lighting applications. Figure 31 - CIE Maximum Source Brightness Levels below defines maximum source brightness (intensity) levels. In the case of the city, an E3 zone would be a rural application and an E4 zone would be an urban application. Curfew is an arbitrary time period set by an owner (typically, 11 P.M.) where lighting is to be reduced. It is typically not possible to achieve post-curfew levels that are very low.

Building façade or vanity lighting of City facilities can cast excessive sky-glow and light trespass. It should be limited to buildings with historical or cultural significance, and should be designed to avoid light trespass, up-light, or contribution to sky glow. They should also have controls to turn lights off when pedestrian activity is reduced.

4.3.1 Conclusions

About 20-30 years ago light pollution was not a very strong consideration in lighting design. Over the years, groups like the International Dark Sky Association (IDA) have become a strong industry watchdog in the reduction of light pollution. They have been effective in raising awareness and educating the public on light pollution. This has brought the subject more front and center.

New products and assessment methods have been developed to reduce the impacts. However, the mitigation of light pollution requires careful consideration. Reducing light pollution impacts while maintaining the required level of lighting for public safety is a true balancing act. Much information now exists to assess and reduce light pollution. These methods and techniques have been brought forward into the Policy Recommendation section of this document.

4.4 Current Costs

Cost is a significant factor when reviewing lighting impacts. The city currently has approximately 97,500 outdoor lights in operation throughout the city. Approximate city costs for these lights are:

- Power cost is $6.5M at an average rate of $0.10 per kilowatt hour;
- Maintenance cost is $5.9M;

The majority of the costs listed above are for roadway lighting.

Though roadway lighting has been shown to have a very high cost benefit as defined in section 3.1.1 Urban Roadways, its costs are significant to the city's operating budget. Over time, the cost of lighting is sure to increase as power and labour costs increase.

Many cities are typically being pressured to reduce operating costs, so, the dilemma is where to cut. Sourcing out more energy efficient light sources and even turning off or dimming streetlights in off-peak periods are under serious consideration by some cities.

4.4.1 Conclusion

Lighting has a high cost that is ongoing. Though research has shown the cost benefit of lighting to be high, the overall costs are significant. The city is justified in researching ways to reduce power and maintenance costs.

5 Existing Conditions (Benchmarking)

Benchmarking of existing levels and practices within the city and nationally were undertaken to define common and best practices. This is important to understand past practices and to define the general state of the lighting with the city. In the bigger picture we have also reviewed some lighting practices in other major cities throughout the country.

5.1 Within the City

For roadways the city has recently updated their Street and Walkway Lighting Design Manual to reflect the latest version of the TAC *Guide for the Design of Roadway Lighting*. Therefore, the city follows an up to date design practice. As requested by the city, DMD undertook an assessment of existing lighting in the Woodcroft area. The assessment included local, collector and arterial roads, parking lots, pathways, and a bus loop.

In terms of sports field lighting the city has outdoor lighting at John Fry Park, Goldstick Park, Rollie Miles Athletic, Coronation Park Kinsman#2 parks. This would include 11 lighted playing fields. The city also has two lighted stadium facilities, Commonwealth Stadium and Clarke Field. Commonwealth stadium was recently retrofitted with energy efficient Musco sports lighting. We can find no information with respect to standards for sports lighting used within the city. A more detailed review of sports lighting systems was not part of the scope of this project.

Lighting on buildings exists on various city buildings, however, no over lighting inventory exists as the lighting, controls, and power consumed is specific to each building.

The city has a number of parking lots, most of which have lighting. We are unaware of the inventory and total number of lights.

Figure 32 - Woodcroft Area

Road information, pole locations, heights, and wattages were obtained from the city's GIS database. The make of luminaire was established via consultation with the city and through contact with the supplier. From this, the photometric files to be used for the computer lighting calculations were obtained from the luminaire suppliers. Sidewalk and walkway lighting calculations were then performed.

Once the calculations were complete, they were compiled into a spreadsheet along with all relevant data for comparison with the recommended design criteria in this report. The end result being a pass or fail for both lighting levels and uniformity. The length of roadway calculations were undertaken for the worst case luminaire cycle and also over the entire length of the road. This was deemed to be sufficient to capture typical lighting levels that generally reflect the extent of the roadway's existing lighting installation.

To verify the calculations, sample light level readings were undertaken on roadways and sidewalks.

Once the calculations were complete and validated in the field, they were compiled into spreadsheets along with all other relevant data. They were compared to our recommended design criteria in this report with the end result being a “Pass” shaded in green or “Fail” shaded in red for both lighting levels and uniformity on the sidewalk and roadway.

The spreadsheet defines elements listed below required to determine lighting criteria and to undertake calculations:

- area
- road segment and its extents (from/to)
- road classification (i.e., local, arterial, collector)
- land usage (i.e., commercial, industrial, residential)
- segment length
- number of lanes
- median (yes or no)
- sidewalk (yes or no)
- lighting pattern (staggered, opposite, median, one sided)
- number of lights (over entire segment)
- setback (i.e., the amount the pole is set back form the edge of lane)
- pole height
- lamp wattage
- luminaire Type (i.e., cobra head, acorn, etc)
- pole type (i.e., davit, post top)
- pole spacing - Avg. - The average pole spacing is the product of the total poles on the road segment divided by the total length of the road segment and Max. - The maximum spacing is the worst case spacing (referred to a luminaire cycle).
- IES/TAC recommended illuminance levels (i.e., for roads and sidewalks)
- IES/TAC uniformity ratio (i.e., for roads and sidewalks)
- existing illuminance levels
- Road (Average) - Though this is not typically the basis of the lighting design but it gives an indication whether there is enough lighting on a per road segment basis.
- Road (Worst Case) - This is the basis of lighting and should be used as an indicator of the lighting level on a given roadway.
- Sidewalk (Average) - This is an average level on each sidewalk (typically two sidewalks exist on each roadway).
- existing uniformity ratio of road/sidewalk (i.e., uniformity ratio (average : minimum) on each road and worst of the two sidewalks)
- status - Road and Sidewalk (pass or fail) based on industry practice and standards recommended in this report.

Calculations were undertaken based on the worst-case luminaire cycle over the entire length of the road. This is referred to as the “worst case.” Calculations were also undertaken based the average luminaire pole spacing over the entire length of the road. This is referred to as the “average.” This was deemed as sufficient to capture typical lighting levels that generally reflect the extent of the roadway's existing lighting installation.

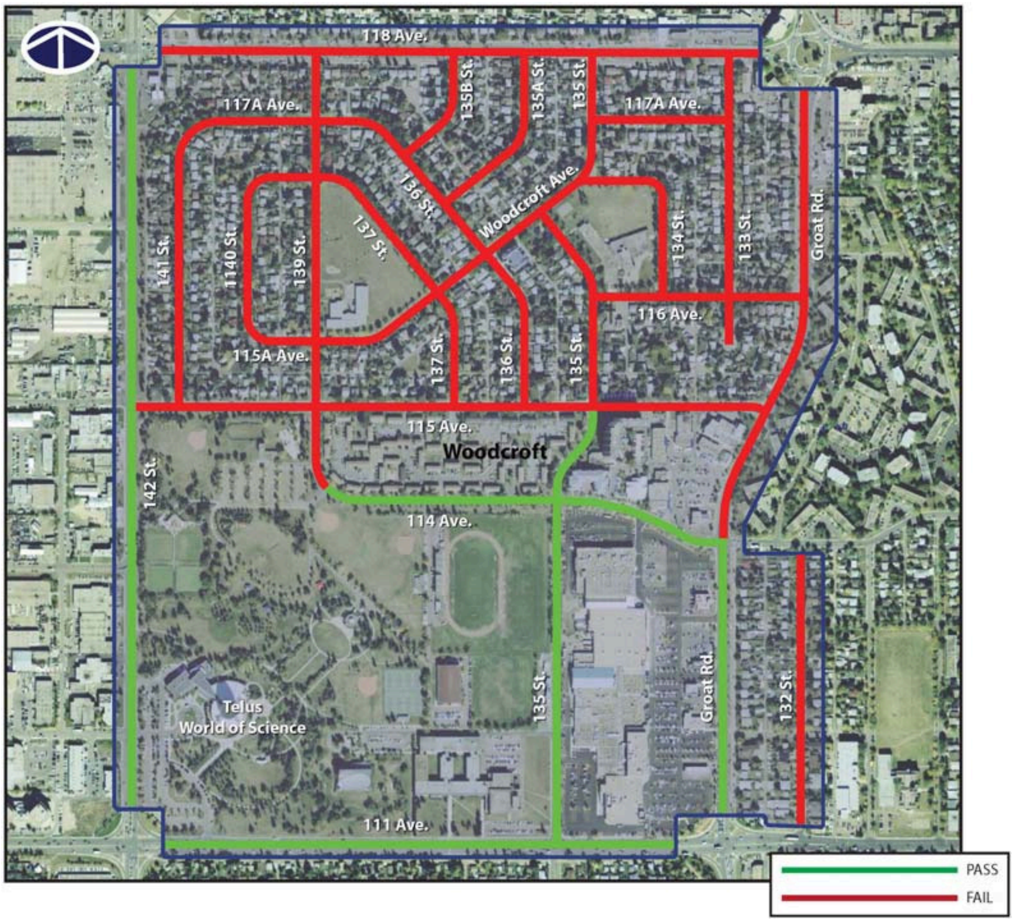


Figure 33 - Woodcroft Roadway Light Levels

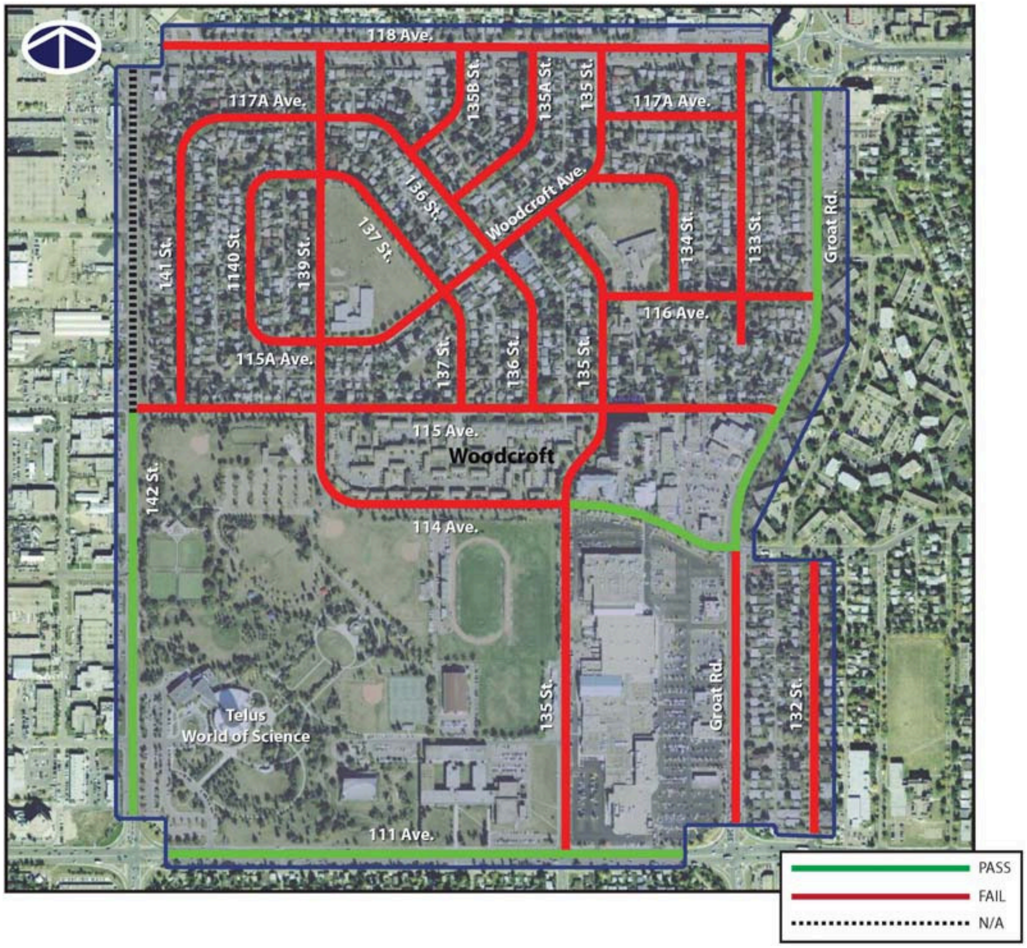


Figure 34 - Woodcroft Sidewalk Lighting Levels

The results calculated and field verified for the Woodcroft lighting is shown on Figure 33 - Woodcroft Roadway Light Levels and Figure 34 - Woodcroft Sidewalk Lighting Levels. The actual light level results are shown on

The results show the following:

- Residential lighting falls slightly below the required levels.
- Most arterial roads were well above the required levels. In some cases, over double the recommended levels. Over half of the sidewalks were below required levels.
- Most collector roads were properly lighted, however, most sidewalk lighting failed to meet the required levels.
- Most of the parking lot lighting criteria were not met.

Area	Road Segment	From	To	Road Classification	Land Usage	Segment Length (m)	Number of Lanes	Median	Sidewalk	Lighting Pattern	Number of Lights	Setback (m)	Pole Height (m)	Light Source	Lamp Wattage (W)	Luminaire Type	Pole Type	Pole Spacing (m) Avg.	Pole Spacing (m) Max.	IES Recommended Level (Lux) Road	IES Recommended Level (Lux) Sidewalk (Ver.)	IES Recommended Level (Lux) Sidewalk (Hor.)	IES Uniformity Ratio Road	IES Uniformity Ratio Sidewalk (Hor.)	IES Veiling Lum. Road	Exist. Illuminance Level (Lux) Road (Average)	Road (Worst-Case)	Sidewalk 1 (Hor. Avg)	Sidewalk 1 (Ver. Min)	Sidewalk 2 (Hor. Avg)	Sidewalk 2 (Ver. Min)	Exist. Uniformity Road	Exist. Uniformity Sidewalk (Hor.)	Exist. Veiling Lum. Road	Status (Pass
Woodcroft	118 Ave NW	142 St NW	Groat Rd NW	Arterial	Residential	963.0	4	No	Yes	Opposite	68	1.5	9.14	HPS	150	Cobrahead (DG)	Davit	34.4	74.6	9.0	0.8	3.0	3.0	6.0	0.3	23.0	10.6	1.8	0.9	1.8	0.9	1.9	1.5	0.4	Fail
Woodcroft	Groat Rd NW	118 Ave NW	114 Ave NW	Arterial	Residential	720.0	4	Yes	Yes	Opposite	39	2.0	9.75	HPS	150	Cobrahead (DG)	Davit	40.0	53.1	9.0	0.8	3.0	3.0	6.0	0.3	18.3	13.8	6.9	2.1			2.1	1.9	0.4	Fail
Woodcroft	Groat Rd NW	114 Ave NW	112 Ave NW	Arterial	Residential	244.4	4	Yes	Yes	Staggered	14	2.0	9.75	HPS	150	Cobrahead (DG)	Davit	18.8	31.1	9.0	0.8	3.0	3.0	6.0	0.3	19.3	11.8	1.6	0.8	7.4	1.7	1.7	1.2	0.2	Pass
Woodcroft	Groat Rd NW	112 Ave NW	111 Ave NW	Arterial	Residential	105.3	4	Yes	Yes	Staggered	7	2.0	9.75	HPS	150	Cobrahead (DG)	Davit	17.6	28.6	9.0	0.8	3.0	3.0	6.0	0.3	20.0	12.5	1.7	0.9	7.6	1.9	1.6	1.2	0.2	Pass
Woodcroft	132 St NW	114 Ave NW	111 Ave NW	Local	Residential	411.1	2	No	Yes	One-Sided	9	1.0	9.14	HPS	70	Cobrahead (DG)	Davit	51.4	57.1	4.0	0.8	3.0	6.0	6.0	0.4	3.4	3.1	1.2	0.1	2.4	0.1	4.9	3.0	0.4	Fail
Woodcroft	111 Ave NW	Groat Rd NW	142 St NW	Arterial	Residential	900.1	6	Yes	Yes	Opposite	45	1.5	9.75	HPS	150	Cobrahead (DG)	Davit	40.9	79.9	9.0	0.8	3.0	3.0	6.0	0.3	12.4	6.3	6.8	1.1	6.8	1.1	3.0	2.0	0.3	Pass
Woodcroft	142 St NW	111 Ave NW	114 Ave NW	Arterial	Residential	339.0	4	No	Yes	One-Sided	9	2.0	9.75	HPS	400	Cobrahead (DG)	Davit	42.4	44.3	9.0	0.8	3.0	3.0	6.0	0.3	23.4	22.4	6.4	3.0			2.8	1.1	0.3	Pass
Woodcroft	142 St NW	114 Ave NW	115 Ave NW	Arterial	Residential	122.0	4	No	Yes	One-Sided	4	0.5	9.75	HPS	400	Cobrahead (DG)	Davit	40.7	40.8	9.0	0.8	3.0	3.0	6.0	0.3	26.6	26.5	8.2	2.9			2.4	1.1	0.2	Pass
Woodcroft	142 St NW	115 Ave NW	118 Ave NW	Arterial	Residential	612.5	4	No	No	One-Sided	19	1.0	9.00	HPS	400	Cobrahead (DG)	Lease Light	34.0	49.0	9.0	0.8	3.0	3.0	6.0	0.3	32.4	22.2					2.8		0.3	Pass
Woodcroft	139 St NW	118 Ave NW	114 Ave NW	Collector	Residential	627.2	2	No	Yes	One-Sided	13	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	52.3	64.5	6.0	0.8	3.0	4.0	6.0	0.4	3.2	2.8	1.1	0.1	2.1	0.1	5.3	2.8	0.5	Fail
Woodcroft	114 Ave NW	139 St NW	135 St NW	Collector	Residential	348.7	2	No	Yes	One-Sided	9	0.5	9.75	HPS	150	Cobrahead (FG)	Davit	43.6	48.0	6.0	0.8	3.0	4.0	6.0	0.4	9.3	8.4	7.2	0.5			3.1	1.6	0.4	Pass
Woodcroft	114 Ave NW	135 St NW	Groat Rd NW	Collector	Intermediate	261.2	2	No	Yes	Opposite	16	2.0	9.14	HPS	150	Cobrahead (DG)	Davit	37.3	47.8	9.0	2.0	5.0	4.0	4.0	0.4	23.5	18.3	14.8	2.2	14.8	2.2	1.4	1.3	0.3	Pass
Woodcroft	135 St NW	115 Ave NW	114 Ave NW	Collector	Residential	107.6	2	No	Yes	Staggered	3	2.0	9.14	HPS	70	Cobrahead (DG)	Davit	53.8	55.9	6.0	0.8	3.0	4.0	6.0	0.4	6.4	6.2	2.0	0.1	2.0	0.1	2.2	1.8	0.3	Pass
Woodcroft	135 St NW	114 Ave NW	Bus Loop	Collector	Intermediate	135.9	2	No	Yes	One-Sided	4	0.5	9.14	HPS	150	Cobrahead (DG)	Davit	45.3	47.5	9.0	2.0	5.0	4.0	4.0	0.4	9.4	9.0	2.6	0.2			3.6	2.0	0.4	Pass
Woodcroft	135 St NW	Bus Loop	111 Ave NW	Collector	Intermediate	117.0	2	No	Yes	One-Sided	4	2.0	9.75	HPS	150	Cobrahead (DG)	Davit	39.0	41.2	9.0	2.0	5.0	4.0	4.0	0.4	10.7	10.2	6.4	0.5	7.2	1.7	2.5	1.8	0.3	Pass
Woodcroft	133 St NW	118 Ave NW	End	Local	Residential	392.7	2	No	Yes	One-Sided	7	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	65.5	97.4	4.0	0.8	3.0	6.0	6.0	0.4	2.6	1.7	2.5	0.1	0.8	0.0	13.0	8.0	0.6	Fail
Woodcroft	116 Ave NW	135 St NW	Groat Rd NW	Local	Residential	233.5	2	No	Yes	One-Sided	5	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	58.4	62.7	4.0	0.8	3.0	6.0	6.0	0.4	2.9	2.7	2.2	0.1	0.8	0.0	7.2	4.0	0.5	Fail
Woodcroft	117 Ave NW / 134 St NW	135 St NW	116 Ave NW	Local	Residential	192.3	2	No	Yes	One-Sided	5	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	48.1	62.1	4.0	0.8	3.0	6.0	6.0	0.4	3.5	2.7	0.9	0.1	2.6	0.2	4.4	2.3	0.4	Fail
Woodcroft	117A Ave NW	135 St NW	133 St NW	Local	Residential	117.8	2	No	Yes	One-Sided	3	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	58.9	59.4	4.0	0.8	3.0	6.0	6.0	0.4	2.9	2.8	0.8	0.0	2.2	0.1	9.7	8.0	0.5	Fail
Woodcroft	135 St NW	118 Ave NW	117 Ave NW	Local	Residential	145.8	2	No	Yes	One-Sided	4	2.0	9.14	HPS	70	Cobrahead (DG)	Davit	48.6	50.8	4.0	0.8	3.0	6.0	6.0	0.4	3.7	3.6	2.9	0.2	2.1	0.1	3.4	2.6	0.4	Fail
Woodcroft	Woodcroft Ave NW	117 Ave NW	137 St NW	Local	Residential	215.8	2	No	Yes	One-Sided	5	2.0	9.14	HPS	70	Cobrahead (DG)	Davit	54.0	59.7	4.0	0.8	3.0	6.0	6.0	0.4	3.4	3.0	2.6	0.1	1.9	0.1	4.2	3.8	0.4	Fail
Woodcroft	135 St NW	Woodcroft Ave NW	115 Ave NW	Local	Residential	228.4	2	No	Yes	One-Sided	5	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	57.1	61.9	4.0	0.8	3.0	6.0	6.0	0.4	3.0	2.7	2.2	0.1	0.8	0.1	7.5	4.0	0.5	Fail
Woodcroft	136 St NW	Woodcroft Ave NW	115 Ave NW	Local	Residential	160.1	2	No	Yes	One-Sided	4	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	53.4	60.8	4.0	0.8	3.0	6.0	6.0	0.4	3.2	2.8	2.3	0.1	1.0	0.1	6.4	3.3	0.5	Fail
Woodcroft	137 St NW	139 St NW	115 Ave NW	Local	Residential	353.6	2	No	Yes	One-Sided	8	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	50.5	55.6	4.0	0.8	3.0	6.0	6.0	0.4	3.4	3.0	2.5	0.1	1.1	0.1	4.9	2.8	0.4	Fail
Woodcroft	115A Ave NW	139 St NW	137 St NW	Local	Residential	105.7	2	No	Yes	One-Sided	3	2.0	9.14	HPS	70	Cobrahead (DG)	Davit	52.9	56.9	4.0	0.8	3.0	6.0	6.0	0.4	3.4	3.2	2.6	0.1	2.2	0.1	3.8	4.4	0.4	Fail
Woodcroft	135A St NW / 116B Ave NW	118 Ave NW	136 St NW	Local	Residential	209.2	2	No	Yes	One-Sided	5	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	52.3	56.7	4.0	0.8	3.0	6.0	6.0	0.4	3.2	3.0	2.4	0.1	1.0	0.1	6.3	3.3	0.5	Fail
Woodcroft	135B St NW / 117 Ave NW	118 Ave NW	136 St NW	Local	Residential	100.1	2	No	Yes	One-Sided	3	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	50.0	57.6	4.0	0.8	3.0	6.0	6.0	0.4	3.4	2.9	2.5	0.1	0.9	0.1	4.9	2.3	0.4	Fail
Woodcroft	117 Ave NW / 136 St NW	139 St NW	Woodcroft Ave NW	Local	Residential	291.4	2	No	Yes	One-Sided	7	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	48.6	51.8	4.0	0.8	3.0	6.0	6.0	0.4	3.5	3.3	2.6	0.2	1.1	0.1	4.4	2.8	0.4	Fail
Woodcroft	116 Ave NW / 140 St NW	139 St NW	139 St NW	Local	Residential	310.6	2	No	Yes	One-Sided	7	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	51.8	60.9	4.0	0.8	3.0	6.0	6.0	0.4	3.3	2.8	1.0	0.1	2.4	0.1	5.5	3.3	0.4	Fail
Woodcroft	117 Ave NW / 141 St NW	139 St NW	115 Ave NW	Local	Residential	582.3	2	No	Yes	One-Sided	12	0.5	9.14	HPS	70	Cobrahead (DG)	Davit	52.9	63.3	4.0	0.8	3.0	6.0	6.0	0.4	3.2	2.7	1.1	0.1	2.3	0.1	6.4	3.7	0.5	Fail
Woodcroft	115 Ave NW	142 St NW	Groat Rd NW	Collector	Residential	964.1	2	No	Yes	One-Sided	18	2.0	9.14	HPS	70	Cobrahead (DG)	Davit	56.7	101.7	6.0	0.8	3.0	4.0	6.0	0.4	3.0	1.7	1.8	0.1	2.5	0.1	3.8	6.0	0.5	Fail
Royal Gardens	Confederation Park	112 St	43 Ave	Parking Lot	Basic		N/A	No	No	Varies	4	Varies	9.00	HPS	150	Cobrahead (DG)	Double Davit			10.0			5.0			12.0						5.2			Fail
Rhatigan Ridge	School	Rhatigan Rd E	39 Avenue	Parking Lot	Basic		N/A	No	No	Varies	2	Varies	9.00	MH	175	Shoebox	Double Decorative			10.0			5.0			6.6						18.3			Fail
Woodcroft	Telus World of Science	142 St NW	111 Ave NW	Parking Lot	Basic		N/A	No	No	Varies	5	Varies	6.00	MH	175	Post Top	Post Top			10.0			5.0			1.8						2.5			Fail
Woodcroft	Telus World of Science	142 St NW	111 Ave NW	Pathway	Guidance		1	No	No																										
Woodcroft	135 St NW	114 Ave NW	111 Ave NW	Bus Loop		146.4	4	Yes	Yes	Varies	11	Varies	9.14	HPS	150	Cobrahead (DG)	Double Davit / Single Davit			50.0			3.0			17.8						6.6			Fail

Figure 35 - Light Level Assessments

5.2 Nationally

5.2.1 Roadway Lighting

In terms of how to light, the common practice across North America is to follow publications produced by the Illuminating Engineering Society of North America (IESNA), the American Association of State Highway and Transportation Officials (AASHTO), and the Transportation Association of Canada (TAC). All are very similar and are based on IESNA research and publications.

The International Commission on Illumination (CIE) defines a recommended design practice for Europe and many areas outside North America. CIE 115:2010 Lighting of Roads for Motor and Pedestrian Traffic is the CIE's defined standard for roadway lighting. Roadway levels in this are based on a series of ratings including speed, volume, and various geometric factors that define an M rating from M1 to M6. The M ratings define various lighting levels with the highest being a M1 rating (2.0 cd/m^2) and the lowest being M6 (0.3 cd/m^2). The levels defined in IESNA RP-8 are at a much lower range, from 1.2 cd/m^2 to 0.3 cd/m^2. The CIE roadway lighting levels are much higher than those in TAC or IESNA.

Though there is a consensus as to "how" to light across North America there is no consensus as to "where and when" to apply street lighting. However, most cities the size of Edmonton or larger typically light all roads in urban areas. Many factors, such as geometric, operational, environmental, and the number of collisions can define the need to light a roadway. The TAC *Guide for the Design of Roadway Lighting* has a warranting system based on these factors, however, it is commonly used by cities.

Figure 36 - Lighting Survey lists lighting practices employed by other cities across Canada. The key elements show common practice in the lighting of urban roads, intersections and standards. All have used some LEDs and have undertaken an adaptive lighting pilot project.

	Jurisdiction									
Item	Calgary	Ottawa	Winnipeg	Hamilton	Edmonton	Vancouver	Toronto	Ottawa	Montreal	Halifax
Light urban roads and subdivisons	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Light intersections where warranted	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Follow TAC or IESNA standards (see note 1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Use LED some lighting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Have undertaken adptive lighting pilot	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note 1 - City of Ottawa deviates in some areas from IESNA/TAC

Figure 36 - Lighting Survey

5.2.2 Other Lighting Applications

Typically outdoor lighting applications such as parking lots, buildings, and sports fields would be undertaken to Illuminating Engineering Society of North America (IESNA) standards. Some cities have specific buildings which meet LEED building standards. Where lighting is applied it is in accordance with local building code standards and requirements. There is no standard practice as to when and where to apply outdoor lighting, however, the how to light typically follows IESNA requirements.

On a national basis, the 2011 National Energy Code of Canada for Buildings (NECB) provides minimum requirements for the design and construction of energy-efficient buildings. They also cover the building envelope including outdoor lighting.

As of January 1, 2008, all new city-owned buildings and major renovations have been designed and constructed to meet LEED Silver Standard as a minimum and are LEED certified. This standard is above the NECB in terms of reducing energy consumption and environmental sustainability.

5.3 Conclusions

In terms of roadway lighting the city currently lights all urban roadways and intersections and rural intersections, as do other major cities in Canada. The existing City of Edmonton lighting analyzed in the Woodcroft area has indicated inconsistent lighting levels that could be improved via retrofit. As this is a very small sampling, it is not an indicator of whether the lighting in the city is typically under or over the required levels. A more detailed definition from a more extensive survey size would be required.

In terms of other lighting applications the city requires a LEED silver rating for buildings. This would include outdoor lighting on the building site. We are aware of no other specific city outdoor lighting requirements.

6 Energy Savings Concepts and Technologies

The purpose of this section is to define current energy saving concepts and technologies, and, to define their general benefits. Specific energy savings are listed in the Policy Recommendations section.

Calgary offers two examples of successful energy efficient street lighting programs. In the 1980's, hundreds of thousands of mercury vapour streetlights were replaced with high-pressure sodium units. More recently, the City of Calgary undertook their EnviroSmart™ street lighting program in which they installed lower wattage luminaires to reduce power use, operating costs, and light pollution. The existing drop glass refractor streetlights were replaced with new luminaires with full cutoff optics, reducing sky-glow and light trespass on local residents. Improved efficiency and waste reduction from EnviroSmart™ paid for the program and now provides an ongoing estimated surplus energy savings of $1.7 million per year. By moving to LED technology and adaptive controls, Edmonton can expect to achieve higher levels of efficiency than that previously achieved in Calgary.

In terms of other outdoor lighting applications LEED has defined specific energy reduction requirements and sustainable design elements.

6.1 Unit Power Density (UPD)

6.1.1 Roadways

Luminaire efficiency is best defined through the concept of unit power density (UPD). UPD is the ratio of the connected power (input watts) for a given area. It is an excellent way to set minimum standards for efficiency for either given luminaires or for various street lighting applications.

For assessing the efficiency of roadway luminaires, UPD is mathematically expressed as:

$$\frac{W}{m^2} = \frac{Rated\ Lamp\ Watts}{Roadway\ Width\ x\ Luminaire\ Spacing}$$

On a city-wide basis, roadway luminaires consume a significant amount of electricity. Reducing energy consumption by using the most energy efficient luminaires available can provide significant saving to owners and lighten the burden on taxpayers and utility ratepayers.

Though most luminaires may look alike, their efficiency can vary by supplier. The CAN/CSA-C653, Performance Standard for Roadway Lighting Luminaires (July, 2008) was developed to establish minimum performance requirements for commonly used cobra head roadway luminaires. CSA-C653 is based on defining common design criteria that will allow one to input various photometric files to computer lighting design software in order to compare product efficiency. CSA-C653 defines the maximum UPD values for various road classifications, pedestrian conflict, lane configuration, and luminaire cut-off classifications. When assessing UPD, lower is better.

CSA – C653 UPD requirements are required as part of the current City of Edmonton Road and Walkway Lighting standards documents. CSA-C653 is also being updated to include LEDs. At this time, the City of Edmonton LED specifications define a UPD not exceeding 0.25, which is based on the calculated performance of some of the better LED products.

6.1.2 Other Lighting Applications

The UPD can also be utilized for other lighting applications such as parking areas, walkways, plazas, stairways, and building facades. UPD levels for these lighting applications are defined in the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) ANSI/ASHRAE/IES standard 90.1[39].

6.1.2.1 Conclusions

The measure of UPD is an excellent means to save power by selecting energy efficient lighting and avoiding over lighting. Furthermore, the UPD can be easily regulated and assessed.

6.2 Reducing Light Levels

With rising demands, increased power costs, and the move toward conservation, reducing light levels has been under consideration by many. The current roadblock has been a lack of research and information in support of the reduction of lighting levels. This often brings up public safety and liability concerns. There is, however, significant research to show that following the IESNA/TAC lighting level has safety benefits in specific applications.

6.2.1 Roadway Lighting

According to information listed in IESNA DG-22 Residential Roadway Lighting – Draft, some municipal regulations allow streetlights for new subdivision developments to be spaced two to three times further apart than the distance required for achieving the minimum recommended uniformity ratios (this is often referred to as “half code” lighting). Another municipal streetlight practice that often creates a uniformity problem involves luminaires mounted intermittently on utility poles to reduce installation expense. Utility pole spacing is determined by wire distribution considerations, and often prevents in achieving the minimum recommended uniformity for street lighting.

IESNA DG-22 goes onto note that “reductions in uniformity or increases in the allowed glare may produce results that are more detrimental to visibility than an absence of lighting”. It is important to note concerns are more from a standpoint of reduced uniformity than a lower than required maintained level of illuminance or luminance on the roadway.

The City of Ottawa standards deviate from the IESNA/TAC levels for local roads with low pedestrian activity. IESNA/TAC defined a level of 0.3 cd/m^2 (4 lux) and the City of Ottawa has reduced that level in half. This was based on the use of the lower light levels over the last 35 years. Scott Edey of the city commented that most roads that end up being lighted to the full IESNA/TAC level as meeting the required 6:1 uniformity ratio do not allow them to use the lower level. He noted a very small percentage of their roads are actually lighted to half the IESNA/TAC levels. One major issue he noted was shadowing from trees that are common and impact on lighting levels and uniformity. Where street trees exist, roads seldom meet lighting or uniformity requirements.

A Finnish study [40] assessed a reduction in the road lighting levels from 1.5 cd/m^2 to 0.75 cd/m^2, to no lighting at all. The results showed that going from full lighting to no lighting increased the collision rate by 25%, and when the lighting levels were reduced by a half, the collision rate increased by 13%. This study was based on high volume and high-speed roadways. Other studies[41] of reduced illumination show that some effects may occur, and is indeed likely, if the route was well lighted (to IESNA/TAC) before the change. Conversely, partially or poorly lighted routes showed little to no effect.

6.2.2 Other Lighting Applications

Lighting levels for applications such as building exteriors, is aesthetic, whereas lighting for parking lots, sports fields and transit facilities is safety and security related. We know of no studies where reduced levels of lighting were reviewed. Building façade or vanity lighting of City facilities should be strictly limited to those with historical or cultural significance, and where used should be designed to avoid light trespass, up-light, or contribution to sky glow.

6.2.2.1 Conclusions

Most research and information shows safety may be reduced where reducing roadway lighting levels. There is no basis of science or research to support using lower levels of light on arterial, collector, freeway, or highway lighting applications. Local low volume roads in subdivisions and or industrial parks may be a different story as speeds and pedestrian activity in later hours of the evening are drastically reduced. That is not to say that lights can be dimmed during off-peak periods provided uniformity is maintained. This is discussed further in Section 6.4 Adaptive Roadway Lighting.

Lighting levels for aesthetic lighting applications such as building exteriors can be reduced in off peak periods. In applications involving safety and security, lighting may be dimmed when no activity is present and via motion sensors activated to full intensity when activity is present. Lighting levels for sports fields and transit facilities should not be reduced, however, they may be turned off when the facility is not in operation

6.3 Turning Lights Off

6.3.1 Roadway Lighting

It is clear from the research and studies summarized in this document that roadway lighting has high value in public safety. That value is, however, reduced in lower speed applications where vehicle and pedestrian activity is reduced at late night hours.

Several detailed studies involving lighting reductions or turnoffs (ref IES CP-31) illustrate how reductions in lighting resulted in an increase of collisions. It is important to note that these studies were based on high speed and high volume highways, freeways, collector, and arterial roadways, and not lower speed residential or industrial roadways or subdivisions. Recent projects in Great Britain involving lighting being shut off have had negative press and poor public perception.

Reductions in lighting for major roads during off peak hours needs further study. The Virginia Tech Traffic Institute (VTTI) is undertaking a significant project funded by the US Federal Highway Association (FHWA) which will define methodologies used to adapt a lighting system to the driving environment and what the factors should be that determine the lighting system characteristics. The focus of this project is highway and freeways applications. This project includes extensive crash analysis and the measurement of installed lighting systems. The measured characteristics of the lighting will be related to driver safety and algorithms for change will be implemented. This project also includes a complete legal review of the adaptation methodologies and a discussion of the legal impacts of the potential changes to a lighting system. Though not currently available, this information will be included in the TAC *Light Level Reduction and Energy Efficiency Guide*.

A recent municipal USA Today article indicated that there is a growing movement of cities that are or considering turning street lighting off during off peak periods. The article states that "The old-fashioned streetlight is the recession's latest victim. To save money, some cities and towns are turning off lights, often lots of them."

In July 2009, Santa Rosa, Calif., started a two-year effort to remove 1/3 of the city's 16,000 streetlights. An additional 1/3 will be placed on a timer that shuts lights off from midnight to 5:30 a.m. Savings to that city are estimated at $400,000 a year.

The City of Santa Rosa noted that those streetlights that will remain on throughout the night are as follows:

- Lighting at signalized and un-signalized intersections;
- Lighting directly adjacent to or incorporated with pedestrian activated flashing beacons or mid-block crosswalks;
- Lighting within high pedestrian zones, such as in downtown;
- One light will remain on at key traffic safety locations where there has been a documented history of traffic safety issues.

Discussions with the Rick Moshier, the city's Public Works Director, have resulted in the following additional information:

- Santa Rosa is 55 miles north of San Francisco; its population is 170,000.
- 1/3 of lights are turned off 100% of the time, 1/3 are shut off in the off-peak period, and 1/3 operate normally during hours of darkness.
- For every 100 lights turned off or shut off in the off-peak period, there are about 6 complaints that are dealt with on an individual basis; this takes a fair bit of time and effort.
- Much of this program has been well reviewed and discussed with local residents. The program is well publicized on Santa Rosa's city website at http://ci.santa-rosa.ca.us/departments/publicworks/streetlightreduction/Pages/default.aspx.
- To date (December, 2011), 3/4 of the program is complete; the work started 2.5 years ago
- To date, there is one pending litigation, which we were informed is not totally related to lighting being turned off.

Most cities use more light than they need, according to scientist John Bullough of the Light Research Center at Rensselaer Polytechnic Institute. Towns should be careful about removing lights, he says. "It's not something you want to do by throwing darts at the map." There's little evidence to support the belief that streetlights reduce crime. However, lighting does reduce traffic accidents, especially at intersections. To date the consensus amongst lighting designers and industry experts is that the turning off of existing lighting is not a good practice, as the public has an expectation that lighting should be operational in the places in which it exists. Turning streetlights off on major arterial or collector roads would pose significant liability risks, as the public has an expectation of lighting operating throughout the hours of darkness. As is the case in Santa Rosa, turning street lighting off in residential developments poses far less risk.

The biggest obstacle to overcome with the option to turn lights off would be public perception and reaction.

6.3.2 Other Lighting Applications

Lighting levels for applications such as building exteriors is aesthetic whereas lighting for parking lots, sports fields and transit facilities is safety or security related. Lighting on buildings can be turned off in off peak periods. Lighting for transit, sports and parking facilities can be turned-off when not in operation.

The City of Surrey, BC has an extensive parks network. They have found that turning their park lighting off after normal operating hours has actually reduced vandalism and crime.

6.3.3 Conclusions

Research has shown that turning lights off during off-peak periods on arterial, collector roads, or on highway and freeways results in an increase of collisions and reduces public safety. Such a practice is therefore not recommended.

Dimming or turning off lights could be considered on local low-speed roads in subdivisions during off-peak periods (this has been done in Santa Rosa). Dimming lights may be a better solution (as defined in 6.4 Adaptive Roadway Lighting), as even a very low level of lighting should continue to provide a feeling of security.

The city could select suitable subdivisions and undertake a few pilot projects to check the validity of this concept. New lighting technologies such as LEDs would allow lighting to be dimmed to a very low level of say 10–20% of full brightness during late night hours which would in essence be a lot less controversial than turning lights off, thus leaving residents in total darkness.

Listed below are scenarios where reducing lighting levels in off peak periods is not recommended:

- Intersections: These typically include those with marked pedestrian crossings. Pedestrian conflicts with vehicles are very likely at signalized intersections even during low pedestrian conflict periods.
- Mid-Block Crosswalks: The decision not to dim mid-block marked mid-block crosswalks follows the same logic as that stated for signalized intersections.
- Roundabouts: Due to the complex geometry in roundabouts and the ineffectiveness of fixed headlights within the tight roundabout circle, dimming should not be applied to these facilities.
- Rail Crossings: Lighting is provided for detection of the trains; therefore, reducing lighting during off-peak periods is not recommended

Dimming can be considered at marked pedestrian activated crosswalks by the use of motion detectors to increase lighting levels when pedestrians are present.

Lighting levels for applications such as building exteriors is aesthetic whereas lighting for parking lots, sports fields and transit facilities is safety security related. Lighting on buildings can be turned off during off peak periods. Lighting for transit, sports and parking facilities can be turned-off when not in operation. In park facilities turning lighting off after normal operational hours should be considered.

6.4 Adaptive Roadway Lighting

The need to reduce power consumption has brought on significant research and product development in the world of roadway lighting. The term "adaptive lighting" is now being used to define the concept of varying lighting levels to suit activity levels in off peak periods. Adaptive lighting is a lighting control method which allows lighting to be dimmed or turned off at predefined times. Simply put, by varying the levels of lighting during non-peak periods, significant power can be saved. Past projects have shown 20–30% energy savings while still maintaining the required lighting levels.

With the exception of a few adaptive lighting deployments installed or underway in BC, most adaptive lighting pilot projects and research have been undertaken in Europe. The fact that many street lighting standards, such as the International Commission on Illumination (CIE), the Transportation Association of Canada (TAC) Guide for the Design of Roadway Lighting (Canada), and the next upcoming edition of the Illuminating Engineering Society of North America (IESNA) RP-8 (North America), all outline adaptive lighting as an accepted practice and define how it can be applied. This practice being defined in national standards reduces one's liability when applying such a practice. The concept of adaptive lighting is sound. However, new products must be field-tested to prove performance.

The use of adaptive lighting technologies and practice is new and developing. Therefore, any deployments should first involve engineering research and guidelines or pilot installations and studies.

The US energy reduction bill (S3059), if accepted, will mandate adaptive controls by law for all new outdoor luminaires by 2013. It will require all outdoor luminaires be provided with adaptive lighting controls to allow 50% dimming capability. This is significant, as the law passed in the US mandating the use of LED traffic signals will render the incandescent traffic signal obsolete in favor of the energy-efficient LED signals. This will surely ramp up the development of adaptive lighting systems.

Roadway light levels are based on roadway classification and pedestrian activity, which is based on maximum pedestrian movement and conflicts. As those conditions only occur for limited times at night, in some cases lighting levels can be reduced outside these periods.

In British Columbia, BC Hydro is undertaking a program where adaptive lighting technologies are assessed, and they will provide cost sharing to retrofit such technologies throughout a jurisdiction.

6.4.1 Systems

As adaptive roadway lighting controls are relatively new and under development, there are various systems that range from basic to more advanced. The basic systems allows lights to be dimmed to a defined level for a defined duration or simply allow alternate luminaire driver currents to applied to compensate for reductions in light output over time.

More advanced systems allow lights to communicate with each other via Wi-Fi or line carrier technology.

Figure 37 - Example Adaptive Lighting System shows an advanced adaptive lighting system where dimming schedules can be adjusted and outages can be tracked remotely via one's desktop computer. Such systems typically require ongoing costs for data transmission and possible monitoring fees.

Figure 37 - Example Adaptive Lighting System

6.4.2 Applications

Three main applications exist to save power with an adaptive lighting technology. They are defined below:

Applications		Benefits
1	**Reduce Lighting Output to Maintained Levels**	**Energy Savings (ca. 5–10%) - Light Pollution Reduction**
2	**Dimming Areas Over Lighted to Meet Uniformity**	**Possible Energy Savings (ca. 5–30%) - Light Pollution Reduction**
3	**Match Light Output to Pedestrian Activity Levels**	**Significant Energy Savings (ca. 20–30%) - Light Pollution Reduction**

Figure 38 - Application Overview and Benefits

- Reduce Initial Light Output to Maintained Levels – Light output from street lighting depreciates over time. Because streetlights depreciate as they are in operation over their useful life, designers must provide an initial level of lighting higher than the minimum maintained level. One of the components of the light loss factor is lamp lumen depreciation that is defined based on the lamp suppliers' published curves at the anticipated end of lamp life. This factor is typically 10% to 30% depending on the light source. Applying an adaptive technology may allow the streetlights to operate at its maintained level for the entire maintenance cycle, thus reducing power input and saving energy. One would not apply lumen depreciation to a lighting design, as the adaptive system would adjust the lamp output to maintain constant illumination on the roadway.

- Dimming Areas Over Lighted to Meet Uniformity - Some roads are over lighted to meet uniformity criteria, which is often the main factor in the luminaire spacing. This may be the result of the lack of a lamp in the appropriate wattage (the design requires a 160 W lamp, which is not available, so a 200 W lamp is instead used), or because an owner has standardized a particular pole/luminaire combination for maintenance purposes. Many roads are in fact lighted to well above recommended levels. Examples are local, collector, or arterial roads where lighting levels are higher than required to meet uniformity requirements. A common scenario is a local road within a subdivision where the lighting is only required to be maintained to an average horizontal illuminance of 4 lux. Due to poles, luminaires, and wattages, a design must light to approximately 9 lux to achieve the required uniformity. In this case, an adaptive system could be used to reduce levels to those required.

- Match Light Output to Pedestrian Activity Levels - The amount of light provided by a street lighting installation is typically based on two significant engineering criteria: the classification of the roadway itself and the level of pedestrian conflict/activity. The pedestrian conflict/activity levels are established by estimating the number of pedestrians on the sidewalk in a single block (or 200 m segment) for a given one-hour nighttime sample period (typically between 18:00 and 19:00 hours). The sample period is typically the hour of highest nighttime pedestrian conflict. If 100 or more pedestrians are anticipated, the pedestrian activity level is high; if 11 to 99 pedestrians are anticipated, the pedestrian activity level is medium; and if 10 or fewer pedestrians are anticipated, the pedestrian activity level is low.

It is well known that pedestrian conflict/activity levels do not remain constant throughout the hours of darkness for a given portion of roadway, and in most instances the numbers of pedestrians present in a given area will be dramatically reduced in the late night and early morning hours when businesses are closed.

Lighting designers typically have little data with respect to pedestrian activity levels for lighted roadways. The actual energy savings potential may increase under this scenario as pedestrian patterns are better analyzed and understood. In downtown core areas or stadium districts with complex patterns of pedestrian activity tied to holiday and event schedules, the opportunities for dimming may be more or less significant than in areas with predictable volumes of pedestrians at regular hours once pedestrian behavior is better understood.

The reduction of lighting levels on local, collector, and major roads can go from a high conflict to medium to low, depending on the predicted pedestrian activity during the course of the evening. In some cases where conflict has been designed for the medium level then only a single reduction to a low conflict/activity can be achieved.

Figure 39 - City Roadway Lighting Levels (Based on TAC) shows required lighting levels based pedestrian activity. As one can see the reduction in light levels going from high to low are reduced by half.

Road Area and Pedestrian Activity: Road Type	Road Area and Pedestrian Activity: Pedestrian Activity	Average Luminance cd/m²	Average-to-Minimum Uniformity Ratio	Maximum-to-Minimum Uniformity Ratio	Maximum-to-Average Veiling Luminance Ratio
Freeway	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Partial Lighting of Interchange On-Ramps/ Off-Ramps	--	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Expressway-Highway	High	≧ 1.0	≦ 3.0	≦ 5.0	≦ 0.3
	Medium	≧ 0.8	≦ 3.0	≦ 5.0	≦ 0.3
	Low	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Arterial	High	≧ 1.2	≦ 3.0	≦ 5.0	≦ 0.3
	Medium	≧ 0.9	≦ 3.0	≦ 5.0	≦ 0.3
	Low	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.3
Collector	High	≧ 0.8	≦ 3.0	≦ 5.0	≦ 0.4
	Medium	≧ 0.6	≦ 3.5	≦ 6.0	≦ 0.4
	Low	≧ 0.4	≦ 4.0	≦ 8.0	≦ 0.4
Local/Alleyway	High	≧ 0.6	≦ 6.0	≦ 10.0	≦ 0.4
	Medium	≧ 0.5	≦ 6.0	≦ 10.0	≦ 0.4
	Low	≧ 0.3	≦ 6.0	≦ 10.0	≦ 0.4

Figure 39 - City Roadway Lighting Levels (Based on TAC)

6.4.3 Conclusions

The development of adaptive control system should accelerate with the increased demand and usage of LED luminaires as the controls are much easier to integrate into LEDs than conventional high intensity discharge sources such as high-pressure sodium.

Approximately 22 cities across the country have recently participated in NRCan demonstration projects featuring adaptive lighting controls retrofitted into existing high-pressure sodium luminaires. The City of Edmonton was one of those cities. As the author of the report we can confirm the results and feedback were favorable, however, the report has not been approved or made public by NRCan so additional information can't be provided.

The use of adaptive controls requires careful planning, study, and testing as the technology is new and all systems are not equal. Adaptive lighting has the potential to reduce energy consumption by 20–30% regardless of the efficiency of the light source. Recommendations for adaptive lighting are defined further in Section 7 Policy Recommendations.

The varying of lighting levels via adaptive lighting controls is not recommended in all outdoor lighting scenarios. Listed below are scenarios where reducing lighting levels during off-peak periods is not recommended:

- Intersections: These typically include pedestrian crossings. Pedestrian conflicts with vehicles are very likely at signalized intersections even during low pedestrian conflict periods.
- Mid-Block Crosswalks: The decision not to dim mid-block crosswalks follows the same logic as stated for signalized intersections.
- Roundabouts: Due to the complex geometry in roundabouts and the ineffectiveness of fixed headlights within the tight roundabout circle, it was determined that dimming should not be applied to these facilities. Roundabouts are a replacement for signalized intersections, and may also contain pedestrian crossings.
- Rail Crossings: Lighting is provided for detection of the trains; therefore, reducing lighting during off-peak periods is not recommended.

For a city realizing the power cost savings for adaptive lighting, one potential barrier can be the local power providers who bill the city on a flat basis based on set wattages. These flat rates are set in the utility provider street lighting power rate tariffs. Applying adaptive lighting does not fit this model. Input wattage can be used and a simple formula based on the defined dimming schedule can be developed to define actual energy usage. This has been developed and accepted by other utilities such as BC Hydro as part of their PowerSmart™ program. The other, more expensive option would be to meter each street lighting service so actual power consumption is measured and billed for. Before any adaptive lighting system is considered the utility provider must be consulted and a basic agreement put in place to define rates and billing for the system. We would recommend the BC Hydro model be considered.

The use of adaptive lighting technologies and practice is new and developing. Therefore, any deployments should first involve engineering research and guidelines or pilot installations and studies.

6.5 Light Sources

New light sources offer energy efficiency benefits over those used in past practice. This section defines, discusses, and recommends new energy efficient light sources.

6.5.1 LEDs

Light emitting diodes (LEDs) are currently the buzz of the lighting world, and are getting the majority of the attention. Nearly every major lighting manufacturer is promoting LEDs as the wave of the future. To date, LEDs have been primarily used for decorative applications where colour changing is required. However, they are now becoming more common for outdoor roadway lighting and similar applications. They have become the industry standard for other applications such as traffic signal displays and building emergency exit signage.

LEDs are solid-state semiconductor devices that convert electrical energy into visible light. When certain elements are combined in specific configurations and electrical current is passed through them, photons (light) and heat are produced. At the heart of an LED (often called a "die" or "chip") is the combination of two semiconductor layers: an n-type layer that provides electrons and a p-type layer that provides holes for the electrons to fall into. The actual junction of the layers (called the p-n junction) is where electrons and holes are injected into an active region. When the electrons and holes recombine, photons (light) are created. The photons are emitted in a narrow spectrum around the energy band gap of the semiconductor material, corresponding to visible and near ultraviolet wavelengths.

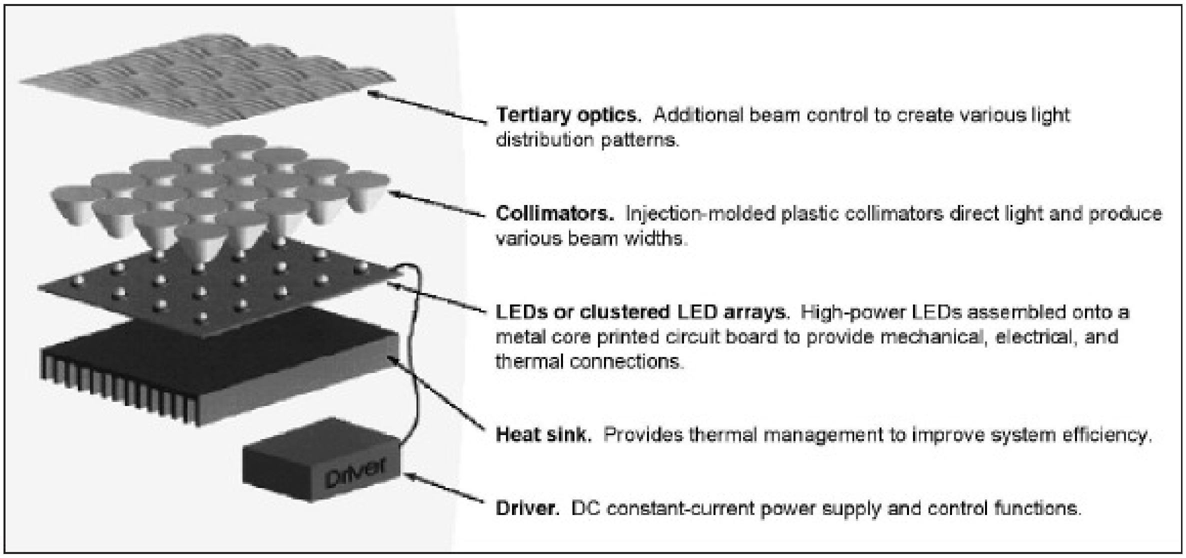


Figure 40 - LED Luminaire Components

Figure 40 - LED Luminaire Components defined the optics and driver for a typical LED luminaire. The design of the actual optical systems varies widely for many of the suppliers.

LED streetlights are very new and as such are still evolving. A few years ago, such luminaires were not close efficiency-wise to proven sources such as high-pressure sodium. Lighting manufactures are investing extensive capital and research into developing new LED products. The transition from suppliers producing high intensity discharge type sources to LEDs has been very rapid.

Little is known about their long-term performance. Product design and quality varies from supplier to supplier as each has their own idea of to how to utilize the technology. In street light applications, LEDs themselves continue to evolve and are now well outperforming traditional high-pressure sodium cobra head luminaires.

The City of Edmonton has been very diligent with respect to LED street lighting. They have tested and evaluated numerous products in pilot installations. They have developed good specifications to set product performance requirements and have retrofitted approximately 8,000 existing high-pressure sodium streetlights with new more energy efficient LED streetlights.

At this stage, a significant number of pilot projects have taken place. In one recent project in the autumn of 2009, LED Roadway Lighting Limited (LRL), the Province of Nova Scotia, ecoNova Scotia, and Conserve Nova Scotia partnered on a pilot project to retrofit existing high-pressure sodium streetlights with new LED streetlights in at least 10 municipalities throughout Nova Scotia. About 1,100 existing high-pressure sodium cobra head streetlights were converted to LRL's LED Satellite series streetlights. The installation involved street lighting on various municipal roads, and Halifax's Stanfield International Airport roads, a parking lot, and provincial highways. The results showed a 55% energy savings while maintaining or exceeding existing lighting levels. Public feedback was very positive.

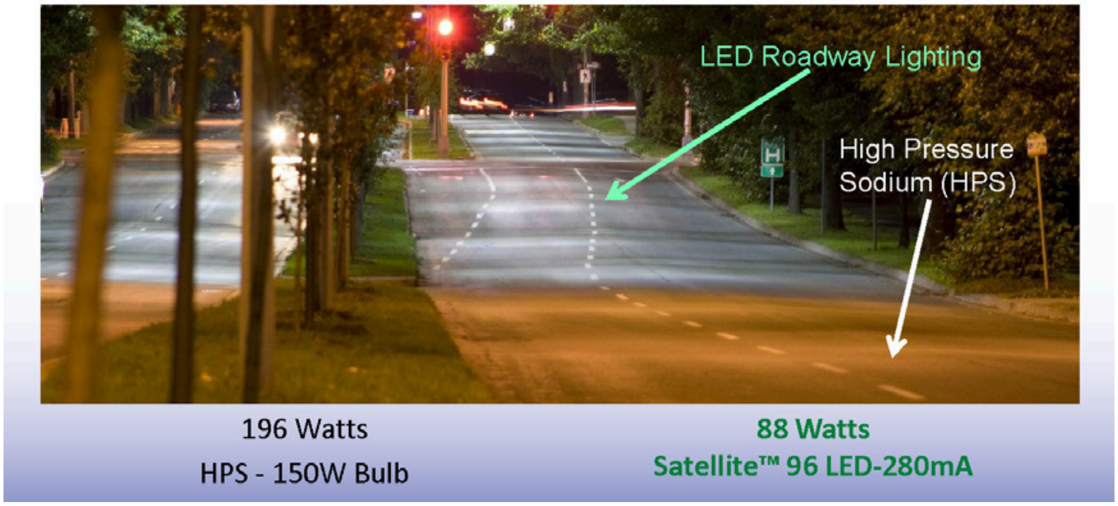


Figure 41 - City of Halifax LED Pilot Project

On February 16th, 2009, former President Bill Clinton and the Los Angeles Mayor announced a major public works project to retrofit 140,000 of L.A.'s more than 209,000 street light fixtures with energy-efficient LED fixtures. The program—a collaboration of the Los Angeles Bureau of Street Lighting, the Los Angeles Mayor's Office, the Los Angeles Department of Water & Power, and the Clinton Climate Initiative—is the largest LED lighting retrofit ever undertaken. The $57 million retrofit will be executed using city labour over 5 years beginning in July 2009. It is expected to enhance the quality and equity of municipal lighting, reduce light pollution, and, upon full implementation, return US$10 million per year in energy and maintenance savings while avoiding 40,500 tons of CO_2 emissions.

The City of Los Angeles owns the second-largest municipal street lighting system in the United States. It's over 209,000 streetlights includes more than 400 distinct fixture styles. Each year these streetlights consume approximately 197,000,000 kilowatts of electricity. Annually the Bureau of Street Lighting's electricity bill totals approximately US $15 million, or 29% of the Bureau's US$52 million operating budget. Funding for the Bureau is provided primarily by the Street Lighting Maintenance Assessment Fund (SLMAF), a yearly assessment paid by city residents for the operation and maintenance of Los Angeles' street lighting system; the SLMAF generates $42 million per year for the Bureau of Street Lighting.

To date (December, 2011) approximately 54,000 LED streetlights have been installed replacing mostly high-pressure type luminaires. Most of the retrofits have been on local residential roads resulting in an energy savings of 5,517 kilowatts of power. To date the city has not only been able to save energy in the 50–60% range but have also improved lighting, particularly with respect to uniformity. Figure 42 - Example LED on Arterial / Collector Road and Figure 43 - Example Retrofit on Local Roads show before and after results of how lighting is improved where LEDs are installed. The white LED light source has also been preferred by local police and thought to improve visibility thus benefiting police surveillance. Public acceptance has also been high as most prefer the improved colour rendition.

In terms of the LED driver currents, the City of Los Angeles defines those as 350 mA or 525 mA however the luminaires are equipped with the ability to switch (inside the luminaire) from 350 mA to 525 mA to 725 mA driver currents. They feel this will allow flexibility for making adjustments over time to increase light output or increase life.

In terms of maintenance LED failures have been few to date and maintenance costs have been dramatically reduced. In fact, over a two (2) year period the City of Los Angeles tracked luminaire failures and found a 10% failure rate for high-pressure sodium luminaires (mostly failed lamps) and a 0.2% failure rate for LEDs. The city still plans on cleaning the LED luminaires at 4-year intervals as dirt accumulation on the lens is a factor that will reduce light output. Cleaning every 4 to 5 years is an important consideration.

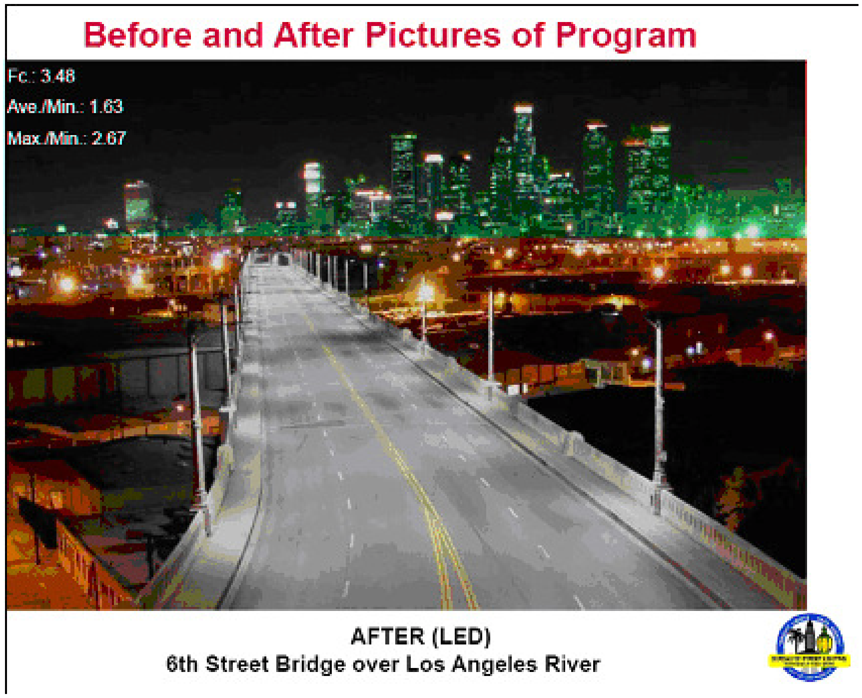


Figure 42 - Example LED on Arterial / Collector Road

Figure 43 - Example Retrofit on Local Roads

LED lighting is changing the face of roadway lighting. In the past, lighting design was pretty simple and only required a basic level of knowledge and understanding. Easy-to-use computer lighting design software allows for easy lighting design by those with little or no lighting background. LED lighting is, however, far more complex. Calculating factors (such as the light loss factor) coupled with a very broad range of optical choices requires a much higher knowledge base than in the past.

One ongoing challenge to designers is the determination of the light loss factor applied to the design. As light levels are based on the end of lamp life, in the past a standard light loss factor was applied based on a given re-lamping cycle. Like all light sources, the output of LEDs will gradually depreciate over time which will eventually result in lower than required light levels. Unlike other lighting technologies, LEDs typically do not fail catastrophically during use. LEDs can last up to and over 100,000 hours and beyond. Therefore, a designer must define the useful lifetime of the LED as part of the life loss factor that is applied to the design. The useful life of an LED is defined by $L\rho$, where ρ is the end of useful life percentage of the light output required. If one required 70% output at end of life, then L70 would be used. The ambient temperature is also a consideration. Typically anything under 10°C would be recommended for Edmonton, as the average night-time temperature is 2.6°C. However, most photometric files provided by supplies are based an ambient temperature on 25°C or less.

Establishing the useful life requires balancing between the maximum light output and the overall life before replacement. It is important to note that selecting a useful life of, for example, L100 (could be 25 years) may dramatically increase the light loss factor. This would require additional lighting or higher wattages, whereas, going with a lower useful life of L50 (could be 12 years) may increase light output (this may require much earlier replacement though). It is also important that when considering useful life, other components such as the LED driver may fail beyond the useful LED life. Also, the technology will be refined and improved in the upcoming years. Therefore, it is reasonable to consider a 15 to 20 year useful life (L70 or L80) when designing with LEDs

The calculation of the light loss factor is not a simple one. It will vary for lights from different suppliers. The calculation of the light loss factor is a very important consideration in lighting design to ensure maximum efficiency and that light levels are achieved at the end of useful life. The calculation is well defined in IESNA TM-21 Project Long Term Lumen Maintenance of LED Packages. The calculation of the lumen maintenance, which is a key part of the light loss factor that is applied to a design, is far more complicated then it was in the past. There is no longer a "one a one size fits all" method.

To add further to the choices in selecting an LED luminaire, numerous driver currents are available that will all impact the performance of the luminaire. Driver currents are typically 280mA, 350mA, 450mA, 525mA, 600mA. Lower driver currents offer increased life, but less output than higher driver currents, whereas the opposite applies for higher driver currents. Therefore, the driver current is applied to meet useable life and light output requirements.

With LEDs, manufactures are much better able to control the light distribution and as such offer a very broad choice in optical systems. One issue that persists is the achievement of the required levels of sidewalk illumination and uniformity. Many products are now designed to cut-off the behind of the luminaire, making it difficult to properly light the sidewalk. This is borne from the demand to reduce light trespass.

6.5.1.1 Conclusions

For roadway lighting the use of LEDs provides a very effective means to save power, however, many of the well-engineered products still have a much higher capital cost than traditional cobra head luminaires. A number of past projects have shown a >50% reduction in power use after converting existing installations to LEDs. LEDs can also save costs in maintenance. As the market increases, the costs of the LED luminaires should decrease with increased demand. Some suppliers are considering offering LED retrofit kits for existing decorative luminaires. This would allow for the simple retrofit of the optical system of an existing decorative luminaire with a more efficient LED optical system.

For other applications LED's also offer high energy savings and for building lighting application colour changing can be provided.

6.5.2 Induction (E-Lamps)

E-lamps, also referred to as Induction™ or Icetron™ lamps, use an induction coil to create a magnetic field inside a gas technically called an "electron/ion plasma." The mercury vapour generates ultraviolet (UV) light, which excites a phosphor coating on the inside surface of the glass globe. The phosphor glows with visible light.

Figure 44 - Induction Lighting

As there are no electrodes or filaments to wear out, lamp life is 60,000–100,000 hours. Electrode and filament deterioration is one of the main reasons for failures of typical high intensity discharge sources.

The induction system comprises three components: the generator, the power coupler, and the lamp. Lumen maintenance for E-lamps is 75% of lumen output at 60,000 hours.

Due to their long life, E-lamps are effective at reducing maintenance costs when located in hard to access areas. They are limited to luminaires with larger optical cavities due to the size of the lamp.

Advantages include: instant start (hot or cold), excellent colour rendition, and long life. Disadvantages include: very high cost, large lamp size, limited retrofit options, a limited number of available wattages and voltages, low lumen output for many applications, and the requirement for special disposal since these lamps contain mercury vapour.

6.5.2.1 Conclusions

To date, induction has not been a cost effective alternative to conventional high-pressure sodium street lighting. Suppliers are investing far more in LED product development thereby making LEDs a better choice.

6.5.3 Cosmo Lamps

The Philips Cosmopolis lamp is an alternative to traditional high-pressure and metal halide roadway light sources. The product uses an electronic ballast to drive the lamp. It offers high light output, great colour rendition, and is dimmable. However, the product is available only in limited wattages and luminaire styles, and, the lamps are very expensive.

6.5.3.1 Conclusions

To date, the Cosmo technology has not been a cost-effective alternative to conventional high-pressure sodium street lighting. Suppliers are investing far more on LED product development, making LEDs a better choice.

6.6 Alternate Power Supplies

Alternate power supplies exist and though they are not cost effective at this time, they will evolve over time and become more viable. Two alternate power supply systems are described below.

6.6.1 Solar (Photovoltaic)

Solar powered street lighting is available. Typically, solar-powered systems utilize LED, compact fluorescent, or low-pressure sodium light sources to reduce the power consumption and to minimize the size of the solar panels, the size and/or number of batteries, and the overall cost. Due to these restrictions, light output is very limited.

Figure 45 - Example of Solar Street Lighting

Solar-powered systems are generally self-contained systems requiring no external power supply. The solar panels charge the system's batteries during daylight hours. The luminaire is powered

from the battery when lighting is needed. A photo-control may be used to turn the lights on during darkness and off during daylight. Solar-powered lighting can be considered where no power is available or if it would be cost prohibitive to install a power line.

Advantages include: no power cost resulting in maximum energy efficiency. Disadvantages include: very high capital costs, battery cost and replacement over time, and limited battery storage and solar panel sizes that limit luminaire wattages.

6.6.1.1 Conclusions

Given the city's relatively high northern latitude and lack of daylight in the winter, larger solar collectors and batteries would be required compared with a location such as Arizona. This would increase costs. At this time, this option is not cost effective.

6.6.2 Wind Power

Some suppliers have considered street lighting powered from small wind turbines. One such system was installed at Vancouver International Airport where a single luminaire was fed via a small wind turbine installed above the streetlight. The installation was more for demonstration purposes and the overall cost, while not verified, is believed to be over $20K for one pole.

6.6.2.1 Conclusions

At this time this option is not cost effective. Few products exist.

7 Policy Recommendations

Information listed below is intended as back-up and supporting material for the city's Outdoor Lighting and Roadway Lighting Policies and Procedures documents provided.

7.1 Roadway Lighting

7.1.1 Value of Lighting

Lighting is recommended for urban roadways and urban and rural intersections as it has proven public safety benefits. Unless specifically warranted for safety or a high pedestrian activity is anticipated, it is recommended that the city avoid lighting rural roads and alleyways except where specifically requested by local police force or there are collision issues which would be reduced with lighting. With respect to security lighting, practices should follow principals of Crime Prevention Through Environmental Design (CPTED) as discussed in section 3 Purpose and Justification for Lighting

7.1.2 Light Pollution Reduction

The control of light pollution outdoors is a consideration that cannot be neglected. To reduce light pollution, we recommend the following:

- Avoid over lighting. Light only to the required levels and do not exceed by more than 15%.

- Reduce spill light to the greatest extent practical. Vertical spill light levels should not exceed 8 lux in rural and 15 lux in urban residential areas (at residences). The 15 lux level would mainly apply in areas of dense residential or commercial with no front yards where the building is tight to property line or sidewalk;
- Where applicable use the lowest BUG rating practical for outdoor luminaires. Use no worse than B2-U1-G2 (or G1, if possible) for urban areas and B2-U0-G1 for rural areas. The BUG does not apply to sports lights and flood lights;
- Reduce Unwanted Light –
  1. Reduce up-light, spill light (light trespass) to greatest extent practical
  2. Avoid lighting in natural areas

7.1.3 Urban Streetscape Design

For wider roads, or roads with numerous street trees, street lighting should be mounted on 9 m to 11 m tall poles. The street lighting shall be mounted over the roadway beyond any tree canopy (to whichever extent practical) as shown below.

Sidewalk lighting requires separate pedestrian scale lighting mounted on poles at 4.5 m to 6 m above the sidewalk. Pedestrian luminaires can be mounted on the backside of the main poles. However, additional pedestrian level poles will be required to provide high levels of uniformity. Where street trees are proposed or existing, the sidewalk and street lighting systems shall be calculated separately with no contribution from each other to ensure good lighting uniformity and that pedestrian precincts are properly lighted.

Pedestrian scale lighting must be in scale with the pedestrian as shown in figure below. Poles typically use luminaires mounted 4.5 m to 6 m above the sidewalk. This lighting will light the street and sidewalk provided no trees are present and the road doesn't exceed 2 lanes in width. Poles should be arranged on both sides of the road in a staggered or alternate pattern.

Well designed pedestrian scale lighting contributes to the quality of urban design in the city, both during daytime and nighttime. Well designed luminaires and poles that fit their context and nearby street furnishings, contribute to the ambiance of the city.

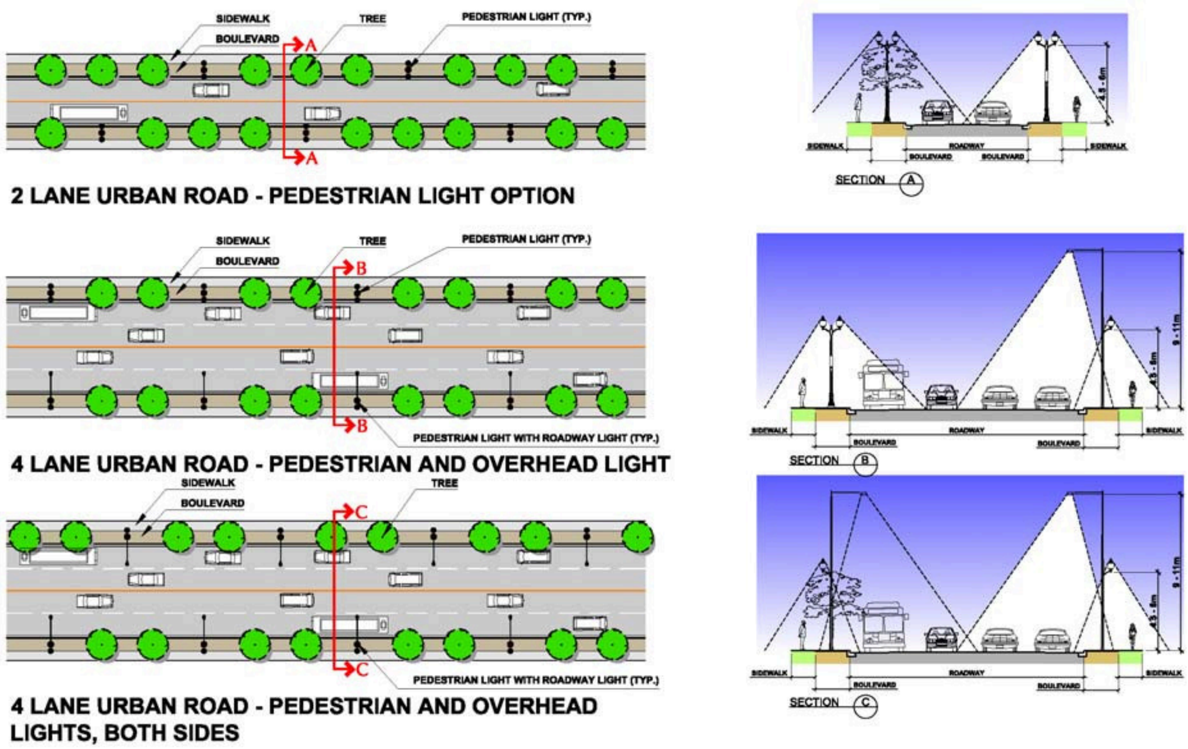


Figure 46 - Overhead and Pedestrian Scale Lighting Options

7.1.4 Energy Savings

7.1.4.1 General

The city should continue to use LED lighting as it has proven energy saving of 40-60%. To ensure maximum efficiency, a maintained luminaire should have the lowest UPD (as per CSA C653) possible and ideally should be 0.1 or less and never above 0.3.

7.1.4.2 Adaptive Lighting Controls

Adaptive lighting controls (dimming in off peak periods) should also be considered as it can have 20-30% energy saving above and beyond that for LED lighting. The application of an adaptive technology will require extensive review. An adaptive technology is not for all roads and should be reviewed on per road or per area basis. Prior to installing an adaptive technology, it is recommended a feasibility study be undertaken for each road or area. This study should include:

- A review and estimate of pedestrian activity levels
- Computer lighting calculations to confirm existing lighting levels
- A definition of dimming schedules

- Development of a cost benefit analysis
- An assessment of technology options
- Verification and testing
- An agreement between owner and utility companies
- Public education and communications

7.1.4.3 Energy Savings Local Roads (Subdivisions)

The city currently has approximately 32,840 streetlights in operation on local residential and local industrial roads. This represents approximately 33% of the total number of 97,505 streetlights in the city. The lights vary in wattage from dominantly 70 W and 100 W lights all the way to a few 400 W luminaires. They consume approximately 6,300 kW and given that they operate approximately 4400 hours per year, the total annual kilowatt consumption would be approximately 27,720,000 kW/h.

We estimate based on past projects that retrofitting to LEDs would cut energy usage by around 30–50%, which would be significant. Uniformity may actually improve given the great beam control for LEDs. If we consider a 40% savings then the annual kW/h used would be reduced to approximately 16,320,000 kW/h. The city's current practice to review and retrofit existing street lighting with LEDs is a very sound one. To date, the city has evaluated LED products in the field and has also undertaken the retrofit of approximately 8,000 existing streetlights. Based on this, the city is one of the leaders in Canada in this area. The retrofitting to LEDs should be continued. The energy savings listed includes the 8,000 luminiares already retrofitted.

Another option would be to consider turning lights off or dimming them from about midnight to 5 A.M. as has been done in other jurisdictions such as Santa Rosa, California. The option for an adaptive lighting system that would meet full TAC levels may not be practical as the majority of these roads are lit to the lowest level as defined in TAC (i.e., local roads with low pedestrian activity). Dimming the lights to 20% of their full brightness may be less controversial to local residents than turning the lights off. This would be less impacting on residential subdivisions with speeds of 50 km/h or less during off-peak periods when little or no pedestrian activity exists. Visibility would be mainly via car headlamps only. If we then consider turning off two-thirds of the LED lights from about midnight to 5 A.M., this would reduce the annual kilowatt consumption to approximately 12,000,000 kW/h. As opposed to turning the lighting off, if LEDs were dimmed to 20% of full output then the annual kilowatt consumption would be around 13,000,000 kW/h. The lighting would not meet TAC lighting levels but uniformity and veiling luminance ratios would be met. Turning off or dimming LEDs should be done with an adaptive lighting system so that lighting can be adjusted remotely if required.

We would recommend that lighting not be turned off or dimmed in the following applications:

- Lighting at signalized and un-signalized marked intersections;
- Lighting directly adjacent to or incorporated with pedestrian activated flashing beacons or mid-block crosswalks;
- Lighting at key traffic safety locations where there has been a documented history of traffic safety issues.

The city should continue with the retrofit of LEDs on residential roads. Turning off lights or dimming below recommended levels in the middle of the night poses some level of risk. Thus, prior to undertaking this practice en masse we recommend that pilot projects be undertaken. Prior to undertaking any pilots a directive for public education in lighting design and light pollution control should be undertaken. To date, some cities have been successful with their practice of turning lighting off during off-peak periods. However, the level of acceptance of this practice is not know in the City of Edmonton, as lighting does create a feeling of security to its local residents. While the power savings benefits are significant, public acceptance could be major roadblock which is why pilot installations must be undertaken.

The city should continue to light all urban residential roads including rural and urban intersections. Lighting on rural roads, though having some value, would be far less valuable than on urban roads and is therefore is not recommended.

7.1.4.4 Energy Savings on Collector and Arterial Roads

The city currently has approximately 31,565 streetlights in operation on collector and arterial roads. This represents approx 41% of the total number of 97,505 streetlights in the city. They vary in wattage from 70–1,000 W, with the majority of lights in the 150–400 W range. They consume approximately 8,327 kW. Given that they operate approximately 4,400 hours per year, the total annual kilowatt consumption would be approximately 36,638,800 kW/h. Based on past projects, we estimate that retrofitting to LEDs would cut energy usage by around 30–50%, which is a significant reduction. Uniformity may actually improve given the great beam control with LEDs. If we use 40% as average energy savings then annual kW would be reduced to approx 22,000,000 kW/h.

Based the results averaged from past studies, one can assume an energy savings of approximately 25% if adaptive lighting is applied. Annual power would be reduced to approximately 16,500,000 kW/h with an adaptive lighting system. This would be based on dimming at around 11 P.M. If a second level of dimming can be applied (high to medium to low pedestrian levels) then that would occur at around 1 A.M., where lights would later be back to full brightness at 5 A.M. for the morning rush hour. We do not recommend turning lights off on arterial and collectors for safety reasons.

We recommend that the city continue to light all urban collector and arterial roads including rural and urban intersections. Lighting on rural roads, though having some value, would be far less beneficial and are therefore not recommended. Where lights exist they should remain in operation.

7.1.4.5 Energy Savings for Alleyways

The city currently lights their alleyways. Alley lights are installed as part of a local improvement process, requested by residents or business owners adjacent to the alleyway. The majority of the lighting is low wattage (70 W). There are currently more than 14,000 alleyway luminaires. The lights consume approximately 622,600 kW/h per year. Lighting of alleyways can be a challenge and a concern as it provides a sense of comfort and security that may, in fact, be misleading. It has been noted by police that when entering an alleyway, the criminal generally has the upper hand due to lack of natural surveillance from the roadway and the number of concealed areas within an alleyway for which a criminal can hide. Many commercial alleyways have low night-time traffic with little natural surveillance from the city's street or windows. Pedestrians may

walk into a well-lit alleyway thinking they are safe when, in fact, there may be hidden areas that pose risk. In a situation where the alleyway is a main route, it should be well lighted throughout. However, personal safety would typically be improved if pedestrians used the sidewalk adjacent to the roadway, rather than side alleys that typically have little natural surveillance.

Motion sensor activated lighting is a consideration over lights that are on continuously at night. If alleyways are lighted, then all alcoves and hidden areas must also be lighted to reduce surprise attacks. Where property security is required, the city should encourage private property owners to maintain and/or, where required, upgrade existing lights on their own buildings. The police prefer motion sensitive lights, so that activity can be noticed by neighbors or from adjoining streets, as the lights turning on will indicate activity. Recommendations for building owner lighting should include luminaires with full cut-off optics using energy efficient fluorescent or LED sources. Incandescent light sources should not be allowed.

If the city wishes to maintain alley lighting then it is recommended that lighting be retrofitted to low wattage (22W) LED's and motion sensors be considered. It is also recommended that business owners be encouraged to install their own security lighting on motion sensors. It is not possible to accurately estimate annual power usage savings by retrofitting to LED lighting with motion sensors. However, the power usage would be a small fraction of what is currently being used. We recommend pilots projects be undertaken and overall operation and benefits be studied.

7.1.4.6 Energy Reduction on Freeways and Highways

There is high safety benefit in lighting high-speed urban freeways with high traffic volumes such as Whitemud. There is far less value in lighting rural highways and freeways. At this time, LEDs are not available in high enough wattages to properly light major freeways and highways. However, that may change in the future. Adaptive lighting is typically not applicable as only one lighting level is required for freeways, which is not based on pedestrian activity. Therefore, adaptive controls will not meet light level requirements.

7.1.4.7 Public Education and Communications Program

Public education and communications are important in establishing and maintaining acceptance of a lighting policy. We have found that on past projects, most of the public takes lighting for granted and there is often not a lot of public interest until lights are removed. An example of a project which was well run and promoted was the City of Calgary's "Envirosmart" Street Lighting Program which ran from 2002–2005. Though the work was not ground breaking technology-wise, it served as an example of how a well-promoted program can be viewed very positively by the public and within the lighting community. The project was promoted via a designated website, numerous awards were submitted and many were obtained, project brochures were developed and distributed to the public, and to local and national media outlets, and groups like the International Dark Sky also promoted the program and its results.

The City of Calgary also did a great job in branding the project "Envirosmart". This branding was a great way to get the message out to the public. It is unfortunate that few create such buzz as did the City of Calgary. Many undertake energy efficiency projects with little to no information to the public. Thus, the public is often kept in the dark. The City of Santa Rosa and the City of Los Angeles both have done excellent work in promoting their streetlight energy reduction programs and their benefits via media and project websites.

As noted above, many members of the public take lighting for granted. They find lighting gives them a feeling of security. When considering turning or dimming lights during off-peak periods, the public must be consulted. This consulting should include brochures defining what is proposed, the reasoning, and the objectives with some of the key support information in this document. Open house meetings and forums should also be considered with local communities such that feedback could be obtained.

The city should also develop a “Public Safety” campaign to promote the use of retro-reflective clothing to improve pedestrian and cyclist safety at night. This significantly improves the visibility of pedestrians/cyclists at night, maybe more so than lighting alone. This is significant if lights are to be dimmed to below TAC levels in residential subdivisions and rural roads without lighting.

A well-defined media campaign should include some technical information and public consultation. We would recommend that a media specialist be retained to develop the program and lead the effort.

Recommendations in this report should be developed into city policy and be included in applicable city lighting standards and bylaw documents. The policies should be simple statements that reference this document. Changes in standards and bylaws will require updating and re-issuing current city bylaw documents.

7.1.4.8 Compliance and Enforcement

As with any policy and regulations created, enforcement is critical. City engineering staff currently review designs that are typically undertaken by the utility provider EPCOR or by consultants. The city currently has very qualified staff to undertake such reviews. Reviews in the past often focused on achieving the required lighting criteria and they now focus on not exceeding it.

The city has also recently completely rewritten their Street and Walkway Lighting Design and Construction Standards, which define all the required lighting criteria. These would need to be updated to include these policies.

7.2 Outdoor Lighting

7.2.1 Value of Lighting

Lighting is recommended for specific areas listed and where there are proven public safety benefits. With respect to security lighting practices, lighting should follow principals of Crime Prevention Through Environmental Design (CPTED) as discussed in section 3 Purpose and Justification for Lighting

7.2.2 Light Pollution Reduction

The control of light pollution outdoors is a consideration that should not be neglected. To reduce light pollution, we recommend the following:

- Avoid over lighting. Light only to the required levels and do not exceed by more than 15%.
- Reduce spill light to the greatest extent practical. Vertical spill light levels should not exceed 8 lux in rural and 15 lux in urban residential areas (at residences). The 15 lux level would apply mainly in areas of dense residential or commercial with no front yards where the building is tight to property line or sidewalk;
- Where applicable use the lowest BUG rating practical for outdoor luminaires. Use no worse than B2-U1-G2 (or G1, if possible) for urban areas and B2-U0-G1 for rural areas. The BUG does not apply to sports lights and flood lights;
- Limit Source Brightness to the greatest extent possible. For high wattage applications such as recreational and sports lighting including ski slopes (1000 W and greater), define source brightness limits of 10,000 cd when viewed from any residence;
- Use lighting controls to turn lighting off when not required. Control options range from simple astronomical time clocks to full adaptive lighting control systems.
- Reduce Unwanted Light –
  1. Reduce up-light, spill light (light trespass) to greatest extent practical
  2. Avoid lighting in natural areas

7.2.3 Energy Reduction

7.2.3.1 General

Light efficiency can be measured in two ways: the luminaire itself or the actual watts used over the area being lit. The most effective way to measure is to regulate power usage is by assessing the wattage used over a given area. Unit Power Density ("UPD" measured in watts/m2) standards such as ANSI/ASHRAE/IES Standard 90.1-2010 Energy Standard is an effective way to regulate power usage for given applications over a given area. UPD is used and regulated throughout North America.

For other outdoor applications - UPD Table includes UPD levels extracted from ASHRAE 90.1 (with the exception of sports fields). Lighting zones defined have been modified to suit city zones (i.e., zone 2 –residential, zone 3 – suburban/industrial and zone 4 commercial). We recommend that the UPD requirements listed be applied to outdoor lighting designs in the city.

Item	Residential	Suburban / Industrial	Downtown
Uncovered Parking Lots	0.65 W/m^2	1.1 W/m^2	1.4 W/m^2
Walkways and plazas	1.5 W/m^2	1.7 W/m^2	2.2 W/m^2
Stairways	10.8 W/m^2	10.8 W/m^2	10.8 W/m^2

Landscaping	0.54 W/m^2	0.54 W/m^2	0.54 W/m^2
Building Facades	1.1 W/ m^2 or 8.6 W/Linear m of wall surface	1.6 W/m^2 or 12.3 W/Linear m of wall surface	2.2 W/m^2 or 16.4 W/Linear m of wall surface
Sports Fields (soccer, football, baseball, etc.)	8 W/m^2	8 W/m^2	8 W/m^2
Additional requirements: • Lighting shall be controlled by device which automatically turns lights off when daylight • Building façade lighting should turn off at midnight or when business closes (whichever is later) and 6 AM or business opening (whichever comes first) • Sports field levels based on “class 3” level play defined in IESNA RP-6. UPD not based on ASHRAE 90.1.			

Figure 47 - UPD Recommendations

To effectively enforce and maintain these UPD levels they must be tied into the permitting process, as is common practice in other jurisdictions. The onus would be on the lighting designers and/or suppliers to provide UPD calculations and certify UPD values are not exceeded. This information should be signed and sealed by a professional engineer and submitted to the city as part of the approval process.

7.2.3.2 Walkways and Multi-use Trails

Walkways and multi-use trails are separated from roadways and should not be confused with sidewalks that are part of the roadway system. The city currently has approximately 3,100 walkway and pathway lights in use. The wattages are mostly 70 W and 100 W with some at 150 W however they are being replaced with 35W LED luminaires with a BUG rating of B1-U0-G1. The total annual kilowatt usage is approximately 1,636,800 kW/h, which would be reduced dramatically with LED lighting.

These lights have value from a guidance perspective for cyclists and pedestrians. Walkway and multi-use trails should only be lighted if the following conditions are met:

- Urban areas;
- High night time usage;
- Paved surface.

Retrofitting to LED lighting would also have significant benefits in that lighting levels could be reduced by approximately 16% per the mesopic adjustment factor. LEDs can also be set up with dimmers and motion sensors to reduce levels in the later hours of the night (and they could still be activated if motion is present). This would reduce power consumption to a very low level.

The UPD levels listed should also be adhered to.

7.2.3.3 Buildings

The city currently has a Façade Improvement Program that encourages building owners to invest in façade renovations, which may include lighting. Though this document covers city-owned building and not privately owned commercial buildings, the city should set an example by ensuring they meet the UPD requirements on their own buildings. For all new construction the city currently follows LEED silver requirements which are aimed at reducing energy and off-site light pollution impacts. It is recommended the applicable City departments develop guidelines on lighting requirements and lighting levels.

Building façade or vanity lighting of City facilities can cast excessive sky-glow and light trespass. It should be limited to buildings with historical or cultural significance, and where used should be designed to avoid light trespass, up-light or contribution to sky glow and should have controls to turn lights off when pedestrian activity is reduced. Where façade lighting is required it shall be designed to minimize light pollution to the greatest extent possible.

Lighting building exteriors is mainly an aesthetic choice and has no real safety or security benefits. This lighting is therefore much different than say roadway lighting. The IESNA Lighting Handbook makes some recommendations for architectural lighting however they vary depending on the lighting effect. When lighting building exteriors, the unit power density levels listed should be adhered to and should also be a part of building permit process. Lighting for purely commercial purposes should be avoided.

It is unknown how much lighting exists and how much power is consumed on the exterior lighting of city buildings. We recommend, as an example, that the city lighting either be turned off in peak periods and/or refitted with more energy efficient LED lighting which will also reduce power bills and maintenance costs. Lighting controls should also be mandated to turn off lighting in non-peak periods.

7.2.3.4 Parking Lots

Parking lots may be covered (e.g., parkades) or be an open type. This policy covers only open type parking lots. Lighting of parking lots should provide both safety and security. The safety benefit comes from improving visibility for both motor vehicles and pedestrians. Although parking lots are low speed, drivers are often backing up with reduced visibility and their motor vehicle's headlamps provide little benefit for this task. As parking lots are large open areas, lighting has significant security benefits, as it allows the users to see activities of concern, and also allows those outside the parking area to view possible criminal activities within and take action accordingly. It is recommended the applicable City departments develop guidelines on lighting requirements and lighting levels.

Parking lots in urban areas should be lighted in accordance with the TAC *Guide for the Design of Roadway Lighting*. A "basic" lighting level should be used with the exception of where security is an issue, in which case "enhanced" levels should be applied. A consideration for parking lots could involve the use of dimming and motion sensors to reduce power when lighting is not needed. The UPD levels listed should also be adhered to.

7.2.3.5 Sports Fields

The lighting of outdoor playfield’s has become an integral part of new synthetic turf field projects as the sports lights allows for extended hours of play thus adding to the overall cost benefit. Many fields are also being constructed in close proximity to residences where light trespass can be a concern. Mitigating light trespass impacts while providing a sufficient level of lighting for safe play is a challenge for the lighting designers and equipment suppliers alike.

Sports fields can have a high level of impact on local residents. Tall poles with high wattage sports lighting are placed around the field to deliver the required illumination on the field. Different sports and levels of play will require different levels of lighting and uniformity as defined in the IESNA RP-6 Recommended Practice for Sports and Area Lighting.

When lighting sports fields, the UPD levels should adhered to and should be a part of the permit process. Lighting controls should also be used which are tied into the field scheduling software. Spill light source intensity levels listed above must be adhered to in order to limit impacts on local residents.

7.2.3.6 Parks and Open Spaces

Parks and open spaces should only be lighted where there is a heavy night-time public usage. Lighting a park at night will not make the park safer or reduce vandalism. Rather, the opposite may be the case. It is recommended based on the City categorization of POS, Parks and Sustainable Development Departments to develop guidelines on lighting requirements and lighting levels for those categories.

There are no specific standards for park and open space lighting. However, the IESNA Lighting Handbook defines similar lighting application which can be used.

Lights in parks (including playgrounds and open spaces) shall be turned-off via controls when children are not likely to be present.

Tree and landscape lighting serves no safety benefits. Therefore, it shall only be considered in areas of aesthetic significance and where installed shall be turned-off via controls in non-peak periods. For light level recommendations and lighting effects refer to the IESNA Lighting Handbook.

The UPD levels listed should also be adhered to.

7.2.3.7 Special Places

Special places such as Telus World of Science can attract high volumes of pedestrians at night, thus lighting is required for guidance, safety, and security. Typically the outdoor parts of these facilities consist of a parking lot and a walkway from the parking lot to a plaza, usually just outside the entrance. It is recommended that the applicable City departments develop guidelines on lighting requirements and lighting levels.

Typically, the lighting around these facilities is designed by the architect (as part of the building design). The aesthetics and appearance of the lighting is more the focus than the actual level and quality of the lighting from a safety and visibility perspective.

In the case of the Telus building, only low wattage bollard lighting exists, as the ambient lighting from the building windows and the street provide a reasonable level of lighting.

All lighting in special places must have a specific application, such as pedestrian safety and guidance to be required. Where required it shall have controls (ie; motion sensors) to turn off lighting when not required.

For light level recommendations refer to the IESNA Lighting Handbook.

The UPD levels listed should also be adhered to.

7.2.3.8 Transit Facilities

Lighting should be designed to provide an adequate and safe visual environment on site while reducing lighting impacts on local residents off site. This could be accomplished by not over lighting, as well as through the selection of energy efficient luminaires with suitable optics mounted at appropriate heights. It is recommended the applicable City departments develop guidelines on lighting requirements and lighting levels.

Lighting shall be designed for the hours of darkness and typically controlled via lighting contactor(s) and photocells. However, in areas where a facility has no activity during later hours of the evening, the majority of the lighting may be shut off or dimmed via suitable controls.

Specific lighting criteria for transit facilities do not exist in TAC or IES documents, so criteria based on similar applications have been defined in the table below.

Lighting levels for specific elements of Transit Passenger-Pick-Up and Drop-Off Facilities, Transit Exchanges, and Transit Park and Rides shall be as follows:

Area	Maintained Average Horizontal Illuminance	Uniformity Ratio (Average : Minimum)	Maintained Average Vertical Illuminance	Reference
Bus Loading/ Unloading Berths and Roads	17 lux	3:1	n/a	Levels based on those for an arterial roadway with high pedestrian activity. Reference *TAC Guide for the Design of Roadway Lighting* Appendix A
Bus Layover Areas	9 lux	3:1	n/a	Levels based on those for an arterial roadway with low pedestrian activity. Reference *TAC Guide for the Design of Roadway Lighting* Appendix A
Platforms	30 lux	3:1	n/a	Level based on IESNA Lighting Handbook Table 4.1 Recommended Illuminance Targets, Category I, 25-65.
Crosswalks	17 lux	3:1	40 lux	Levels based on a high pedestrian activity. Reference *TAC Guide for the Design of Roadway Lighting* Chapter 12 Mid- Block Crosswalks
Parking Areas	10 lux	5:1	n/a	Levels based on a “Basic Parking Lot Illumination Level”. Reference *TAC Guide for the Design of Roadway Lighting* Chapter 16 Off-Roadway Facilities – Table 16-4. Where public security is a concern, or CCTV cameras are required or present then consider “Enhanced” levels.
Crew Room (Indoor)	100 lux	3:1	30 lux	Level based on IESNA Lighting Handbook Table 22, Support Spaces - Break Room/Lunch Room, 25-65.
Bus Shelters (within the Shelter footprint)	10-20 lux	3:1	n/a	Level based on IESNA Lighting Handbook Table 4.1 Recommended Illuminance Targets, Categories F,G & H, 25–65. Where no power is available solar power can be considered.

Figure 48 - Transit Lighting

7.2.3.9 Digital Signs

The location, size, lighting, and design of signs on private property are regulated in City Bylaw 12800. Digital signs are not covered in detail elsewhere in this report, as a recent amendment bylaw 15892 covers digital signs. This bylaw is fairly well defined with the exception of limiting the intensity (brightness) of digital signs. In October 2011 an amendment to Bylaw 15892 was presented by the Light Efficient Communities Coalition. The recommended "Revision 1 Brightness Limits", which is defined in subsection 5, adds the following after subsection a. "Brightness level of the Sign shall not exceed 400 nits when measured from the sign face at its maximum brightness, between sunset and sunrise, at those times determined by the Sunrise/Sunset calculator from the national research Council of Canada."

Limiting the source brightness of the sign is very important, as over-bright signs can reduce driver safety and impact local residents. The 400 nit level is reasonable and should be attainable by most suppliers. Some have considered lower brightness levels. The Pattern Outdoor Lighting Code (POLC) proposed in the Maricopa Association of Government (Phoenix, Arizona) Resource Guide and Report recommends a maximum brightness of 100 nits for digital (multi-colour LED) billboards. The standard in some Arizona jurisdictions is 300 nits, a limit supported by the sign industry. Achieving the 100 nit standard may be nearly impossible. Overall, Bylaw 15892 and the proposed amendment make sense and constitute a good step forward.

7.2.3.10 Public Education and Communications Program

Public education and communications are important in establishing and maintaining acceptance of a lighting policy. We have found that on past projects, most of the public takes lighting for granted and there is often not a lot of public interest until lights are removed. They find lighting gives them a feeling of security. When considering turning or dimming lights during off-peak periods, the public must be consulted. This consulting should include brochures defining what is proposed, the reasoning, and the objectives with some of the key support information in this document. Open house meetings and forums should also be considered with local communities such that feedback could be obtained.

The city should also develop a "Public Safety" campaign to promote the use of retro-reflective clothing to improve pedestrian and cyclist safety at night. This significantly improves the visibility of pedestrians/cyclists at night, maybe more so than lighting alone.

A well-defined media campaign should include some technical information and public consultation. We would recommend that a media specialist be retained to develop the program and lead the effort.

Recommendations in this report should be developed into city policy and be included in applicable city lighting standards and bylaw documents. The policies should be simple statements that reference this document. Changes in standards and bylaws will require updating and re-issuing current city bylaw documents.

7.2.3.11 Compliance and Enforcement

As with any policy and regulations created, enforcement is critical. City engineering staff currently reviews designs. In terms of enforcement, outdoor lighting is not well addressed in the current city standards. In terms of energy efficiency and unit power density levels, they should be included in city bylaws and reviewed for compliance as part the city review and permitting process.

Lighting controls are somewhat more difficult to enforce as their operation can be changed or turned off over time by those who control them. Lighting controls for city outdoor lighting should, therefore, be under full control of the city senior staff. Senior staff, not those operating the system, must approve changes to controls.

Much information and many recommendations have been provided throughout this document. Some are provided for general information and to aid in good design practice while other are aimed purely at saving power. It is critical to define a future direction in order for information to be implemented and new policies established and followed.

7.3 Return On Investment

The information listed in policies is a snapshot of potential energy savings based on the information in this report. It is important to note that saving power has a capital cost and over time this cost can be recouped in energy savings.
Based on the information in this report and policies it recommended, the city develop a long-term plan and budget with defined goals. As this is based on budgets and financing the city must define such a plan.

The benefits of using more energy efficient lighting such as LED's and adaptive lighting can be assessed through a Return of Investment (ROI) analysis. Though the costs and assumptions are very rough this will give a general overview of the city's ROI when investing in more energy efficient lighting and controls.

Simple ROI = Gain from investment – cost of investment / cost of investment x 100

For say an LED retrofit of 97,500 street lights we would assume the following to define the ROI.

- Gain for Investment
  1. Assume the luminaire life will be 20 years therefore
  2. Assume a reduction of 50% in power consumption - $3.25M x 20 years = $32.5M
  3. Assume maintenance costs will be reduced by 60% as the majority of these costs are for re-lamping - $3.54M x 20 years = $35.5M
  4. Total gain $32.5M + $35.5M = $68M plus a factor of say 1.2 to include power cost rise and increase labour costs = $81.6M

- Cost of Investment
  1. Assume luminaire cost of $500.00
  2. Assume installation of $60.00
  3. Total cost $560.00 x 97,500 = $54.6M

The simple ROI from an LED retrofit would be approximately 50%. These costs and ROI is very approximate and would require extensive study and evaluation to define further. The ROI should be considered an order of magnitude at best and will need to be verified by the city.

The ROI would improve by using an adaptive lighting technology, however, the amount would depend on how aggressively lights were dimmed in subdivisions. Without more extensive analysis the increase in ROI can not be confirmed.

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[3] MOVE (Mesopic Optimization of Visual Efficiency) was carried out during 2002-2004 by a consortium of European Institutions. The project consortium brought together multi-disciplinary expertise in the areas of lighting engineering, vision science, metrology, human behavior and image processing. The outcome of the project is a mesopic model based on visual task performance.

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