



2017 Best Practices Effective Lighting
is a companion book to

BIRD-FRIENDLY
DEVELOPMENT GUIDELINES



Best Practices
for Effective **Lighting**



Photo Credit: © Canadian Space Agency



Photo Credit: www.chrishadfield.ca

Our Earth is a beautiful, ancient place.

From high above, in orbit, our astronauts can see the entirety of it – the scars of prehistoric natural events, the traces of civilisations that have risen and fallen, and the many thriving centres of humanity today.

But when the Space Station races behind the planet, into the blackness, the impact of humanity really stands out. Our primordial fear of the dark has led us to light the night, worldwide. Without thinking, our outdoor lights not only shine where we want them on our streets and buildings, but also up, into the sky. Big cities like Toronto glow intensely, visible testaments to incomplete planning and wasted energy.

The impact is far-reaching. Nocturnal animals, wildlife mating instincts and migrating birds have their natural patterns disrupted. Fossil fuels are burned for no purpose. Glare exceeds the ability of the eye to properly use the created light. The Northern Lights are rendered invisible. City children get a stunted intrinsic understanding of the night sky and the universe.

Fortunately, the problem is largely solvable. Improved technology and public awareness can lead to policy changes that benefit everyone. Through incremental replacement and new construction we can efficiently shine the light, and the resources behind it, where we truly need it.

And that's better, for everyone.

Chris Hadfield
Colonel, Astronaut (ret'd), Torontonian



Photo Credit: © Canadian Space Agency

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Front cover features Toronto skyline at night. Right-hand side shows the actual view, left-hand side shows how the skyline would look without light pollution.

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1 Introduction

Rationale

Lighting is an important component of urban life. Properly designed lighting provides safety and security so the city may be navigated and used at night.

Well designed lighting both uses energy efficiently and minimizes the negative effects on human and nocturnal animal life. Effective lighting improves the quality of urban life for everyone.

Need for Policy and Action

Although artificial lighting has had a positive impact on city life, it has resulted in negative effects where it has been poorly designed or improperly installed. Most types of lighting are beneficial, but glare, light trespass, overlighting and sky glow can actually worsen visibility for city inhabitants.

Light pollution is growing faster than the rate of increase of population. Controlling this wasted light results in energy savings and reduced greenhouse gas emissions. Lighting improvements can pay for themselves in energy savings, sometimes in a matter of months.

Negative Health Effects:

Certain animals such as **Migratory Birds** are negatively affected by light at night. For humans, there is growing evidence that light at night may be affecting many facets of mental and physical health.



City of Toronto at Night | Features of the night sky, such as the **Milky Way** are no longer visible from an urban location.

Scope of the Document

In this document, we show what residents, architects, urban designers and planners can do to provide well designed, energy efficient lighting that is cost-effective and has a low impact on the environment. Many of these measures - such as shielding outdoor lamps - can be done as retrofits or incorporated into new design.

The document begins with a description of the design principles and shows how they may be applied in practice. The appendices contain technical information and a list of additional sources of information.

The document highlights the importance of well designed lighting. It also provides a framework for discussing lighting in the city.

Policy Context

This document provides guidance for the 'light pollution' section of the Toronto Green Standard, a 'made in Toronto' set of performance measures intended to improve the overall quality of life in Toronto. The Toronto Green Standard encourages sustainable site development to a standard that will reduce greenhouse gas emissions, increase energy efficiency, improve air and water quality, protect urban forest and wildlife habitat, reduce waste, and minimize the impact of lighting in the night sky. A new or existing building that meets the 'Best Practices for Effective Lighting' would contribute to Toronto's overall sustainability and resiliency.

The Good News:

Relative to other issues of the environment, Light Pollution: Over lighting, Sky Glow, Glare and Trespass are easy to prevent in the first place or correct after the fact. These Best Practices point the way.

Current Official Plan Policies

In May 2016, the Province of Ontario approved Official Plan Amendment 262 with respect to the Environmental Policies and Designation of Environmentally Significant Areas, which were adopted by Toronto City Council in November 2015. The new environmental policies included the following additions with regard to light pollution:

3.4.1. To support strong communities, a competitive economy and a high quality of life, public and private city-building activities and changes to the built environment, including public works, will be environmentally friendly, based on:

v) mitigating the unacceptable effects of noise **and light**;

New Sidebar, Section 3.4

Light Pollution

Light pollution in the form of glare, light trespass, over lighting and sky glow can reduce visibility for pedestrians and vehicles and have a negative impact on the health of humans, birds and the natural environment. Light pollution has also drastically limited our view of the stars in the night sky. Properly designed lighting is efficient and effective, providing light exactly where it needs to be for safety and security and results in energy savings and reduced greenhouse gas emissions. Controlling light spillage can also result in darker environments for sleeping, less light at night that may attract migratory birds and less disturbance for fauna natural areas. Effective lighting improves the quality of urban life for everyone.

Examples of Uses and Misuses of Artificial Light

Lighting is effective when it is directed precisely where needed, provides the right amount of light and is used only when necessary.



Withrow Park Rink | Illuminated while unused

TTC Subway Car Yards | Over-illuminated



Photo Credit: Gabriel Guillen

Riverdale Park Lighting | Office windows illuminated unnecessarily (after hours)

2 Light Pollution

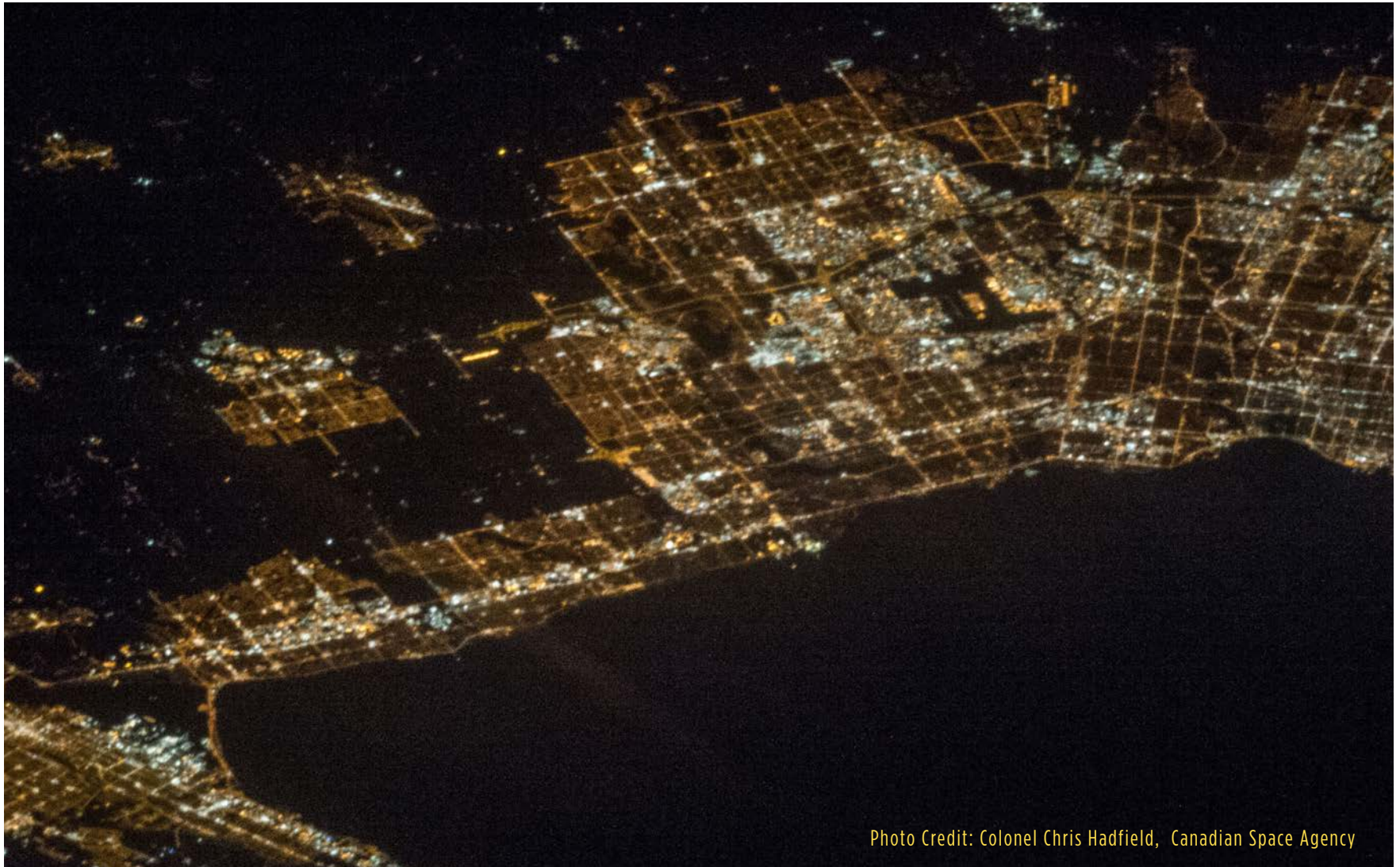


Photo Credit: Colonel Chris Hadfield, Canadian Space Agency

GTHA at Night, 2013

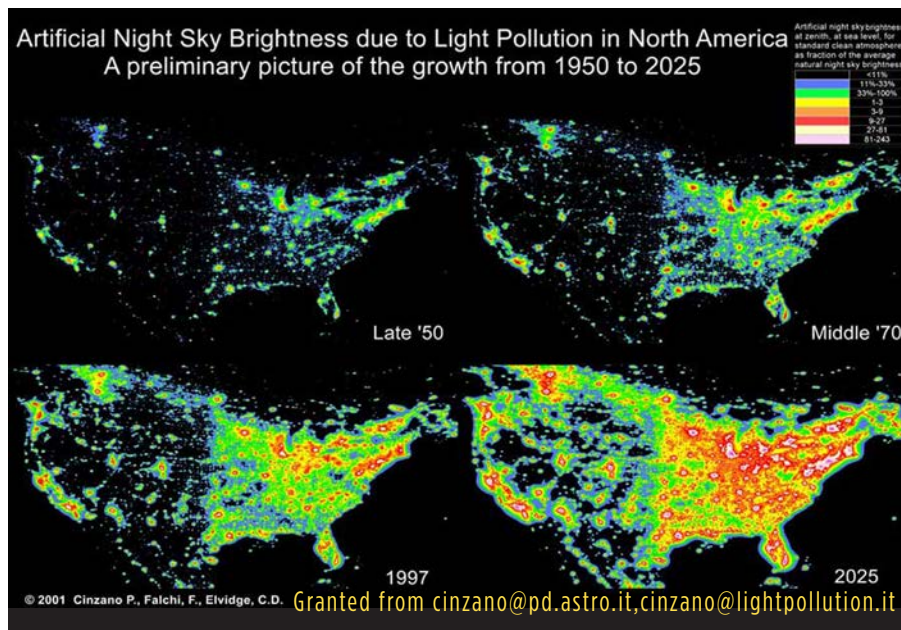
Light Pollution is a general term used to describe misused light. Light pollution may be caused by glare, light trespass, over lighting, and sky glow.

Glare is light that overloads the human visual system, typically by direct vision of a light source.

Light Trespass is the intrusion of light from a nearby source, typically through a window or onto a property.

Overlighting is illumination in excess of what is required for a person to see properly.

Sky Glow refers to the illumination of the sky over urban areas, caused by stray light from thousands of fixtures in a city or town.



Artificial Night Sky Brightness, 1950 to 2025

Interactive world map for light pollution can be accessed at www.Lightpollutionmap.info

Eastern Seaboard of USA from space
Toronto is visible at upper right

Glare prevents the human eye from discerning a range of brightness levels, hiding part of the scene from view. Even momentary exposure to glare removes dark adaptation for 30 seconds and causes discomfort or night blindness - the inability to view properly into darker areas of the same scene. This increases the difficulty of tasks like walking over uneven ground, riding a bicycle, or driving at night.

The images below provide an example of the impacts of glare. In the left image, the illumination is poorly designed and causes glare, indicated by the flare in the photograph. In the right image, the light is shielded to eliminate glare and greater detail is visible.



Photo Credit: Gabriel Guillen



Photo Credit: Gabriel Guillen

Glare is the result of misdirected light. Traditional style 'wall packs' which are mounted on buildings and beam light horizontally are common sources of glare.

In order to prevent glare, lighting fixtures must be shielded and directed so that the light illuminates only the surface to be observed. This can be achieved with a combination of directed light (using lenses), shields in the light fixtures and careful placement and aiming of the light source. In cases where the glare from the light source cannot be controlled (such as a sports field), light barriers such as bushes, trees or berms may be strategically placed to help mitigate the impact of the lighting while ensuring good visibility and access to and from the area being illuminated.

A standard for Glare is given in Appendix I, page 76.

Horizontally directed light causes glare

**Withrow Park
North Area**

Covering the obtrusive light reduces glare and improves seeing into dark areas

Light Trespass is the intrusion of light from a nearby source, typically through a window or onto a property. The light source illuminates not only the intended area, but unintended surroundings.

Light trespass can often be addressed by shielding the light source. If the source area is over-lit, it may be necessary to reduce the overall light level in that area, provided that the lighting still meets levels required for safety.

For example, a residential property next to a soccer field has two possible sources of light trespass. Light trespass may result directly from the field lights, as well as from a general brightening of the area due to reflected illumination from the soccer field itself. In this case light trespass could be reduced by shielding the fixture and/or by dimming or turning off the lights when the field is not in use.

See [Municipal Property Standards Chapter 629-17](#) for buffering and reducing nuisances related to lighting.

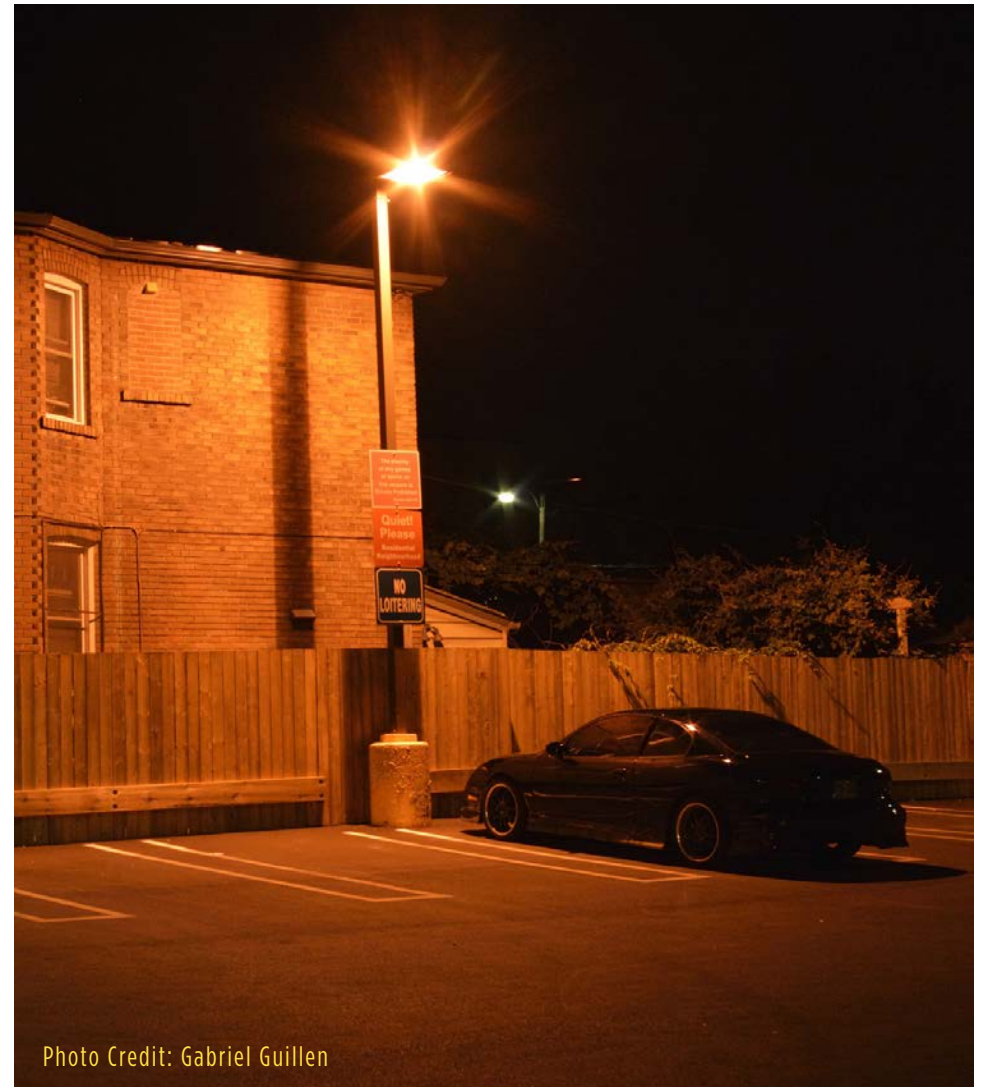


Photo Credit: Gabriel Guillen

Unshielded path lighting shines strongly into nearby residence windows

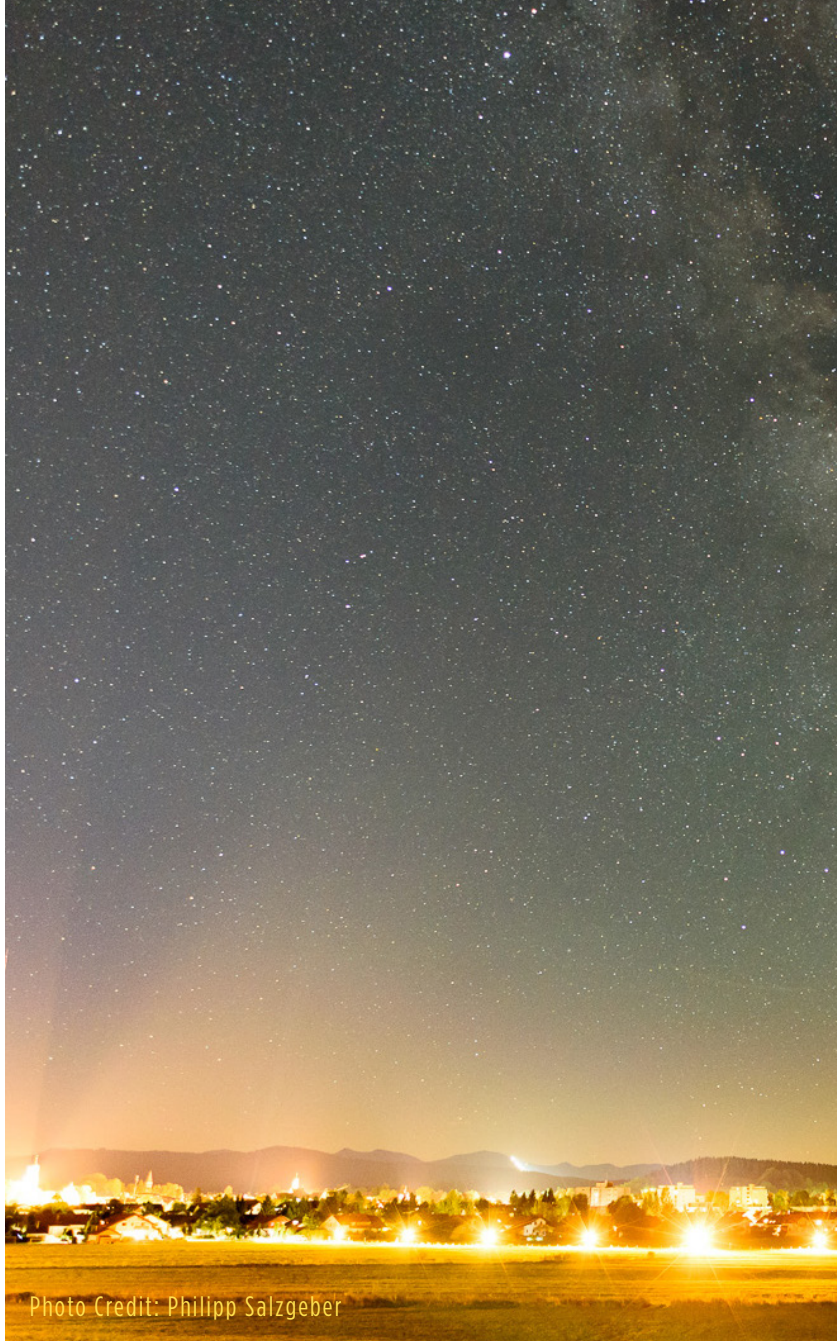


Photo Credit: Philipp Salzgeber

Overlighting is illumination in excess of what is required for good visibility. Depending on the situation, an illuminance level of 10 lux is enough, yet the illuminance level is often higher.

The marketing of a business, such as a gas station or car lot, can lead to a competition in light levels. As each business uses brighter lights, its neighbours feel compelled to match or exceed that light level.

This competition can lead to light levels that are far in excess of requirements for seeing properly. The excess light impacts the surrounding area and represents unnecessary lighting equipment costs and increased energy consumption.



Photo Credit: Gabriel Guillen

Milky Way above light pollution

This car lot is lit to 800 lux at the property line, when a level of 10 lux would be adequate. Some car lots are visible from the International Space Station.

Many car lots are overlit

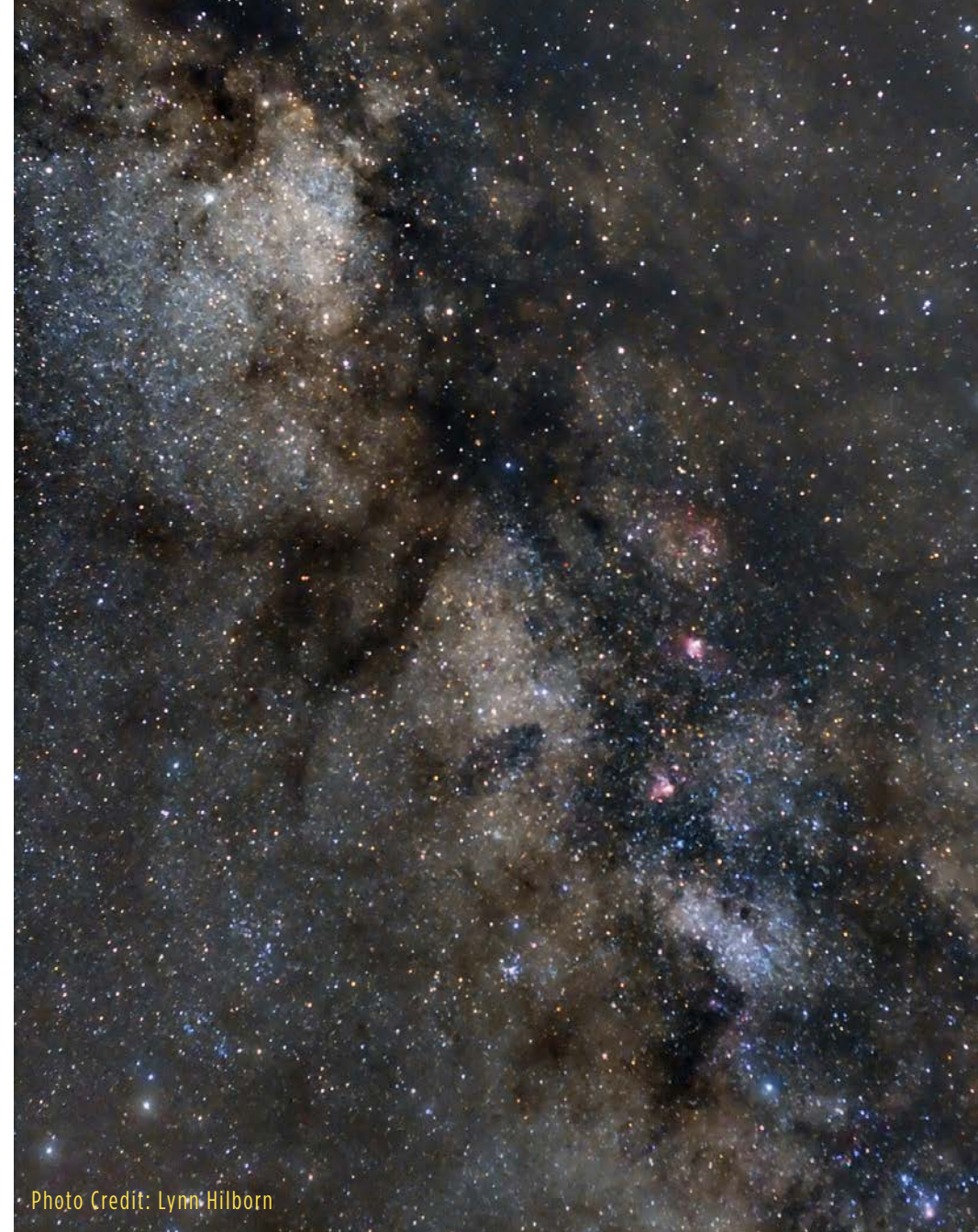
Sky Glow refers to the illumination of the sky over urban areas, caused by stray light from thousands of fixtures in a city or town.

Sky glow represents increased energy consumption, interferes with the ability of birds and animals to navigate, inhibits the recovery of the atmosphere from air pollution, and prevents city residents from seeing the wonders of the night sky such as the Milky Way.

Sky glow can be reduced by minimizing overlighting and using fixtures designed so that light is directed where it is needed, rather than beamed at an angle into the sky.



Toronto Sky Glow from Richmond Hill



Milky Way

3 Lighting for Safety and Security

Safety and Security lighting is designed to protect people and property. The goal of security lighting is to discourage criminal activity by creating an environment where such activity may be readily and accurately observed. Poorly designed security lighting actually has the opposite effect: the glare of an unshielded lamp blinds an observer and affects dark adaptation, making it difficult to see into shadows. Security lighting is a major source of glare and overlighting.

It is not evident that increased lighting decreases crime. Studies have shown that criminal activity and vandalism actually increase with increased lighting. Most burglaries occur during daylight hours.

Our city becomes safer when more people use public spaces at night. Well-designed public lighting creates an inviting environment for the use of public spaces. To create an attractive streetscape, priority should be given to uniformity of lighting that is used in conjunction with security cameras.

Where security lighting is required, motion sensor activated lighting saves energy and reduces light pollution.

The central concepts of CPTED (Crime Prevention Through Environmental Design) include the following:

- When creating lighting design, avoid poorly placed lights that create blind-spots for potential observers and miss critical areas.
- Avoid overly bright security lighting.
- Use shielded or cut-off luminaires to control glare.
- Place lighting along pathways and other pedestrian-use areas at proper heights.
- Only light areas where needed.

Refer to Appendix H for further information on pg 76.



Photo Credit: Gabriel Guillen

Distillery District

Property Standards Requirements for Lighting

Current property standards for lighting are given in the Toronto Municipal Code, Section 629-36 Sections C and D relevant to outdoor lighting include:

Section C

For parking lots, walkways, stairs, porches, verandas, loading docks, ramps or other similar areas, a minimum level of illumination of 10 lux (0.90 foot-candle) at ground or tread level and at angles and intersections at changes of level where there are stairs or ramps.

The best practice for reducing light pollution is to specify average light levels with a typical uniformity ratio of 3:1, where the maximum light level can be 3 times the brightness of the minimum level.



Photo Credit: Toronto Archives, Fonds 1268, Series 1317, Item 828.

University Avenue 1934

Toronto Municipal Code, Section 629-36,
www.toronto.ca/legdocs/municode/1184_629.pdf

Section D

Interior and exterior lighting fixtures and lamps shall be installed and maintained so that the work, operations or activities normally carried out in or about any part of the property can be undertaken in safety and without undue eye strain.

The mentioned eye strain is caused by glare.

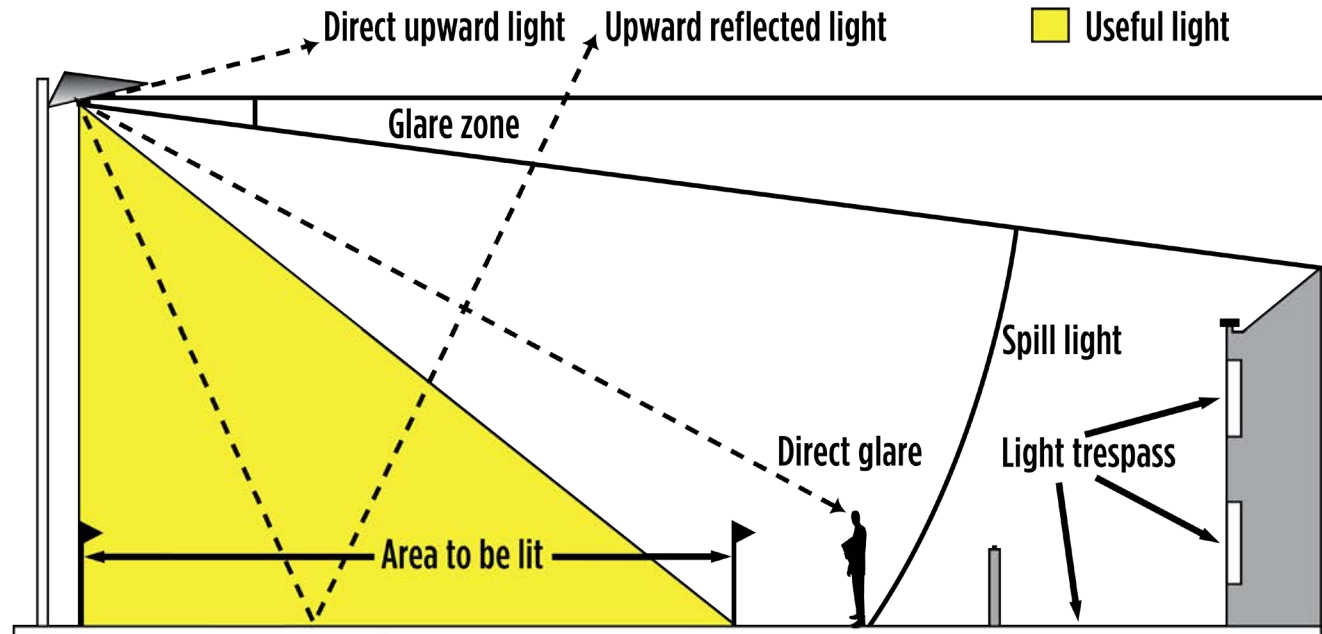


Photo Credit: Gabriel Guillen

University Avenue 2012

4 External Lighting Fixtures

Ineffective external lighting contributes to glare, light trespass, overlighting and sky glow. These effects can be minimized through careful lighting and architectural design.



Light pollution is often caused by the way light is emitted from lighting equipment. Choosing proper equipment and carefully mounting and aiming it can make a significant difference.

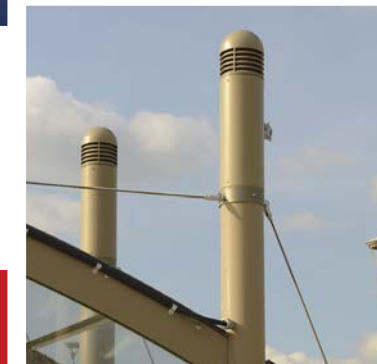
Adapted From Institution Of Lighting Engineers
National Lighting Product Information

Best Practices for external lighting:

- Minimize glare
Shield the light emitting surfaces from direct view.
- Eliminate direct upward light
Direct upward light is projected directly upward by inefficient lighting fixtures.
- Reduce spill light
Spill light reaches beyond areas that need to be lit for safety and security reasons.
- Optimize useful light
Useful light is used to illuminate areas for navigation and safety.
- Enhance Urban design
Architectural form should be complemented by using light wisely for place-making and to design a more welcoming pedestrian environment that will be monitored over time.
- Use appropriate Colour temperature
Use an appropriate colour temperature to the context of its application
(i.e. maximum 3000K in residential areas including mixed-use areas with residences, maximum 4000K along high traffic arterial roads)
- Use Dark Sky compliant fixtures
Select fixtures that have the [Dark Sky Fixture Seal of Approval](#)

Effective Lighting Fixtures

Lighting used to illuminate the pathways and surrounding site of a building should be efficient while providing enough illumination to make the site safe and secure at night.

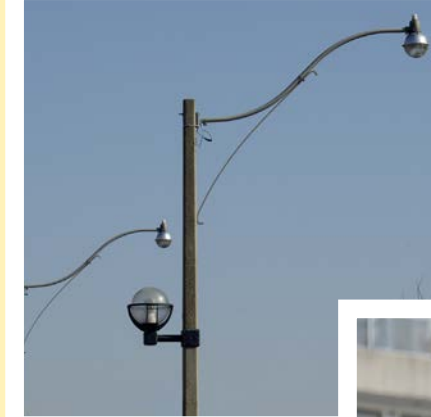


Examples of effective fixtures are shown in this collage. Preferred fixtures direct light downward to the surface where it is needed. They minimize uplight which causes skyglow and glare to an observer. For locations of examples, see Appendix G, pg 75.

Photos Credit: Gabriel Guillen

Ineffective Lighting Fixtures

Ineffective lighting fixtures create skyglow, light trespass and/or glare.



Locations of these fixtures can be found in Appendix G, pg 75.



Photos Credit: Gabriel Guillen

5 Approaches to Effective Lighting



Photo Credit: Gabriel Guillen

See “Best Practices for Bird-Friendly Glass” City of Toronto |



Searchlights can be appropriate for special events, but should be avoided as a permanent architectural feature. They contribute to sky glow and trap birds, especially during bird migration periods: April-May, September-October.

The Toronto Green Standard (TGS) is a tiered set of performance measures that facilitates more sustainable and resilient new development in Toronto. The TGS implements the environmental policies of the City of Toronto Official Plan and the requirements of multiple City divisions through the community planning and development approvals process.

The TGS was first introduced as a voluntary standard for new development in 2006 and then became a two-tier set of performance standards with Tier 1 mandatory and Tier 2 voluntary stretch targets in 2010. The TGS is revised and updated every four years. TGS version 2 came into effect in 2014 and version 3 is in effect for all new planning applications beginning May 1, 2018.

Low-Rise Residential

- Applies to detached, semi-detached and town homes, in projects containing a minimum of 5 dwellings / units up to three storeys in height.
- Use the minimum amount of light that will allow proper vision.
- Operate security lighting from a motion detector with sensors which are accurately adjusted to avoid random switching.
- Ensure that all lighting is shielded and pointed so that it shines downward onto the ground rather than into a person's eyes.
- Minimize the trespass of your lighting onto another property.
- When adding exterior lighting, look for fixtures that are Dark Sky certified to prevent light trespass and glare.





ECOLOGY



Development
Feature

Light Pollution

Reduce nighttime glare and light trespass to support ecosystem and human health

TIER 1

EC 5.1 Exterior Lighting

All exterior fixtures must be Dark Sky compliant.

Mid to High Rise and all Non-residential Buildings

- Applies to all residential apartment buildings and non-residential buildings.
- Minimize office lighting after-hours by using timers, area control switches and occupancy sensors.
- Where offices must be lit, use blinds, electronic shutters and task lighting to minimize light spill.
- Where external lighting of the building is necessary, use downlight to highlight architectural features.
- All lighting should be facing downward on building facades.
- Shield street facing lighting so that establishments and the sidewalks can be seen by passers-by.
- Observe the Toronto City Sign Bylaw: turn off signage after hours and observe limits on sign brightness and light trespass.



Photo Credit: Gabriel Guillen

Bright Building
on Simcoe Street



Photo Credit: Gabriel Guillen

Queen Street West
Sign Bylaw | www.toronto.ca/signbylawunit



Dark Sky Compliant fixture must have the Dark Sky Fixture Seal of Approval which provides objective, third-party certification for lighting that minimizes glare, reduces light trespass and doesn't pollute the night sky. If a Dark Sky Fixture Seal of Approval is not available fixtures must be full-cutoff and with a with a colour temperature rating of 3000K or less



ECOLOGY



Development Feature

Light Pollution

Reduce nighttime glare and light trespass to support ecosystem and human health

TIER 1

EC 5.1 Exterior Lighting

All exterior fixtures must be Dark Sky compliant.

TIER 2

EC 5.2 Lighting

Any rooftop and facade architectural illumination must be directed downward and turned off between the hours of 11 p.m. and 6 a.m.

EC 5.3 Lighting Controls (Core)

Non-residential: Install an automatic device that reduces the outward spillage of internal light by:

- a) Reducing the input power to lighting fixtures by at least 50% between the hours of 11 p.m. and 6 a.m. year-round; OR
- b) Shielding all openings in the envelope with a direct line of sight to any non-emergency light fixtures between the hours of 11 p.m. and 6 a.m. year-round.

Parks

Toronto has more than 1,500 parks with numerous open spaces, covering 11.62 per cent of the city's surface. These parks are actively used in the daytime and during evenings. To facilitate evening use, pathways and sports areas are illuminated. The lighting fixtures in use vary in effectiveness. Many existing wall pack fixtures shine horizontally and are a major source of glare. Wall pack fixtures should be full cutoff.

Notice how distant fixtures are less bright, indicating proper shielding.



Photo Credit: Gabriel Guillen



Photo Credit: Gabriel Guillen

Newer fixtures improve on the management and direction of light.

- Use fixtures that are full cutoff so that they light a pathway or sitting area without causing glare.
- Use only full cutoff wall pack fixtures on park buildings, that are mounted at an appropriate height.
- Manage sports lighting installations for minimum impact on the lighting of the surrounding park.

This pathway is illuminated by solar energy that is collected during the day. During the evening, LEDs and a special material release the luminous energy, causing the pathway to glow with a green-blue hue. This is one of many possible lighting innovations that can improve the lighting environment for parks and roadways.



Photo Credit: Studio Roosegaarde

Unshielded Park Lighting Fixtures

Shielded Park Path Fixtures

Glowing Bike Path Solar-powered LED lights

www.npr.org/sections/parallels/2014/11/17/364136732/in-a-dutch-town-a-glowing-bike-path-inspired-by-van-gogh

Natural Heritage Areas

Natural Heritage Areas consist of a mosaic of natural habitats that support a variety of species found in the city. Toronto's natural heritage system includes the Don River Valley. The wildlife in natural heritage areas respond in a variety of ways to artificial light in their environment.

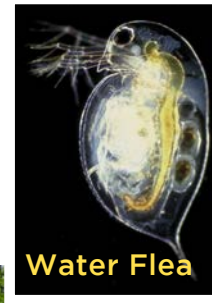
The direct effects of light at night on some species is well known, for example: moths gathering around street lamps or the harvesting of fish with spotlights. It is the long term impacts of light and changes to the ecosystem that are not well understood. Studies suggest that: frogs and fireflies may be deterred from mating, bats may change their habitat, and water fleas may be deterred from fish feeding areas. Ultimately, these changes can have a dramatic effect on humans by impacting ecosystems we rely on for natural resources, for example: the negative impact of light at night on salmon fisheries. Consequently, it is important to use the absolute minimum of lighting in natural heritage areas.

Best Practice: pathways can be illuminated by passive fluorescent pads (which absorb light during the day and re-radiate it at night), parking lots should rely on automobile headlights for lighting, and signage and buildings should be illuminated only when absolutely necessary. The intrusion of light from nearby streets, businesses and residences should be strictly controlled.

For a map of natural heritage areas, see the Toronto Official Plan:
www.toronto.ca/planning



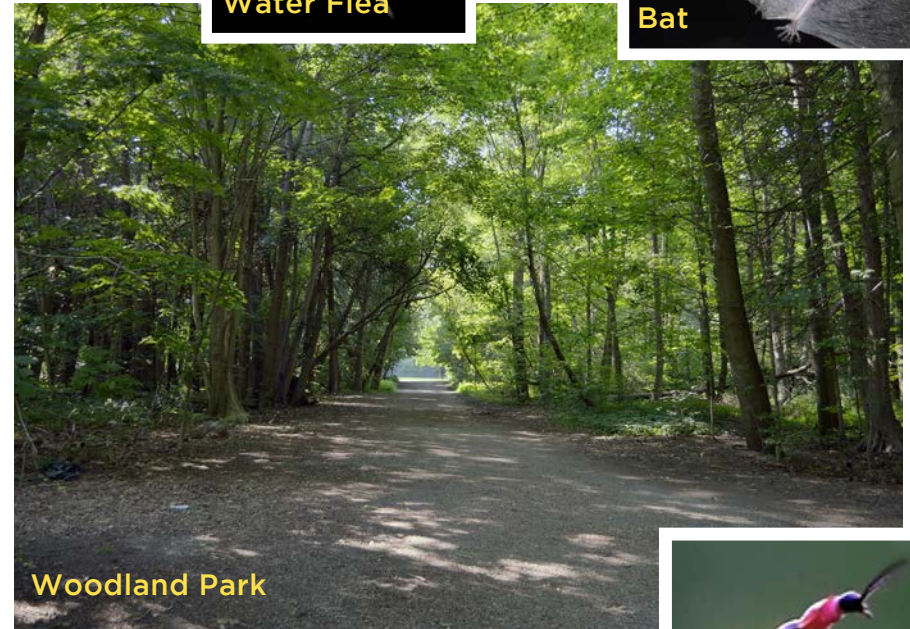
Bullfrog



Water Flea



Bat



Woodland Park



Firefly

Photo Credits : Bullfrog - Carl D. Howe, source: Wikipedia
Bat - Gabrielle Graeter/NCWRC, www.fws.gov/whitenosesyndrome
Water Flea (Daphnia pulex) - Paul Hebert, source: Wikipedia
Firefly - Roger Schlueter article, www.bnd.com/living/liv-columns-blogs/answer-man/article89921367.html



Photo Credit: Colonel Chris Hadfield

Taken from International Space Station | Toronto at Night, 2013

Street Lighting

Street lighting is a critical component in city infrastructure. It affects the safety and security of streets, and can enhance the urban night-time environment.

Street lighting is a significant contributor to light pollution and is a major contributor to sky glow (30%) [1].

The glare of poorly-designed street lamps can interfere with seeing, especially among older people.

Light trespass is an issue where street lighting is close to residences. Street lighting should be reviewed to ensure that it accomplishes a useful purpose.

Adaptive lighting controls should be used to dim street lighting in off-hours to reduce energy consumption and minimize light pollution. This is especially important in residential neighbourhoods where light at night may impact human health.

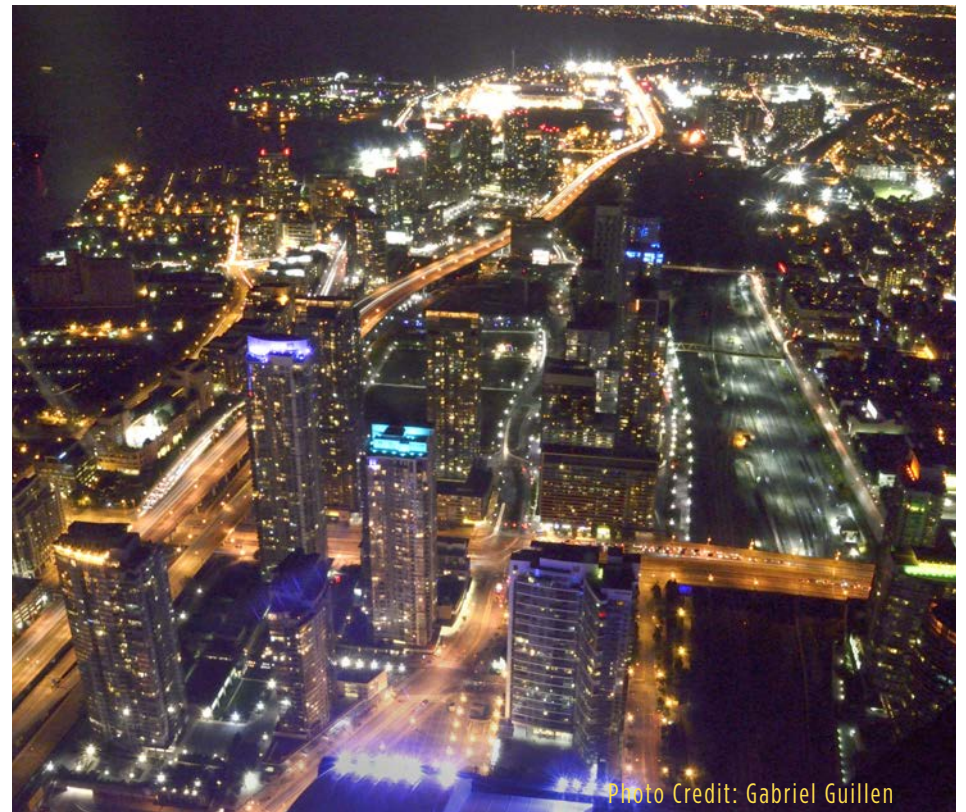


Photo Credit: Gabriel Guillen

[1] The Contribution of Street Lighting to Light Pollution
Peter D. Hiscocks, Sverrir Guomundsson
Journal of the Royal Astronomical Society of Canada
October 2010, pp 190-193

CN Tower Looking West | City at night, showing street lighting

Full Cutoff in Street Lighting

Awareness of problems with street lighting are growing, and there are a number of excellent examples of street lighting in the City of Toronto.

Full cutoff street lighting is designed to direct the light where it is needed – to the roadway and sidewalk surfaces. This minimizes the waste light that causes sky glow and lessens glare by shielding the viewer from a direct view of the light source. Full cutoff fixtures also minimize light on nearby properties.

Full cutoff or shielded lighting fixtures accomplish both objectives.



Photo Credit: Gabriel Guillen

**St Clair Avenue
and Yonge Street**

Showing shielded and
unshielded light fixtures

HID Lamps

Street lighting in Toronto uses high intensity discharge (HID) lamps in which an electrical current passes through a light-emitting gas. A high intensity discharge (HID) lamp has a much higher luminous efficiency and lasts much longer than the incandescent lamp commonly used in households. HID lamps require special circuitry (the ballast) to start and run the lamp. They are physically large, which complicates the design of the lens and reflector to control the direction of the output light. In general, HID lamps can be dimmed, but the dimmer circuitry is complicated and expensive.

The output colour of a metal-halide lamp is bluish-white, which renders colours reasonably well.

Two types of HID lamps are used for street lighting in Toronto: Metal-Halide Lamps and High-Pressure-Sodium Lamps

The light output of high-pressure-sodium is a yellow-orange colour. High pressure sodium lamps have higher efficiency and last longer than metal halide lamps.

Both Metal-Halide and High-Pressure-Sodium lamps contain mercury, so they have to be disposed of properly.

The induction lamp is a new version of the fluorescent technology. Rather than pass an electrical current through the discharge gas, this lamp energizes the internal gas by magnetic fields. Although the induction lamp is capable of producing significant light output, LED technology has surpassed induction lighting in terms of efficacy and performance.



Photo Credit: Gabriel Guillen

**Bloor Street
Spadina Avenue** | Metal Halide
(Mercury-Vapour) Lamps

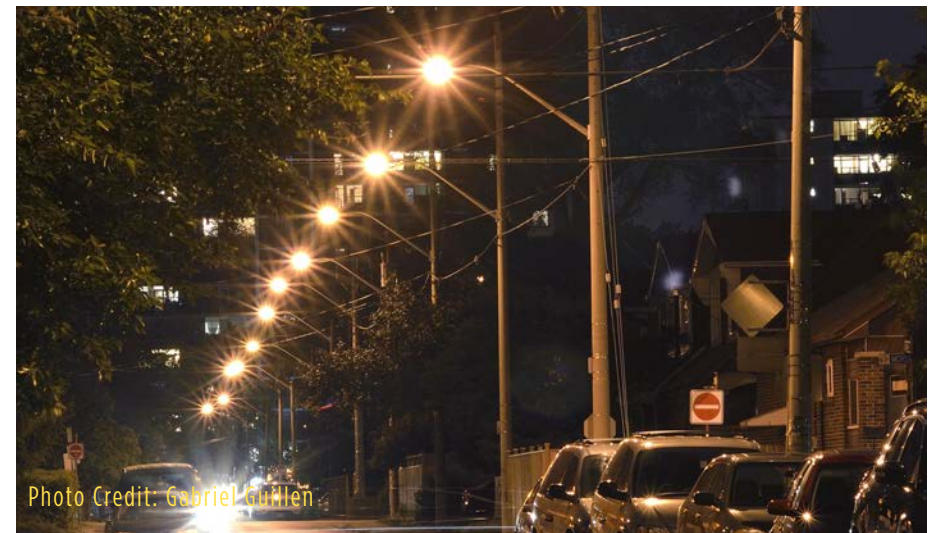


Photo Credit: Gabriel Guillen

**Carlaw Avenue
Mortimer Avenue** | High-Pressure-Sodium Lamps

Light Emitting Diode Lamps

The light emitting diode (LED) uses semiconductor technology to generate light. LEDs can inherently produce red, green, amber, yellow and blue coloured light. White LEDs use the same technique as fluorescent lamps (a coating to convert the internal colour of the LED into white light).

LEDs have a significantly higher efficiency to HID lamps in converting electricity to light. They have a long lifetime and their small size allows innovative design that can provide better control over stray light, potentially reducing sky glow and light trespass. LEDs can be dimmed, thereby forming the basis of a system of intelligent lighting. Then energy savings can be achieved by dimming them when they are not needed.

The small size and high efficiency of LED lighting could lead to dramatic and wide range changes in the way we light our urban environment. Creative innovations are enabled by this new lighting technology.

See appendix E page 66

Refer to *Color Temperature and Outdoor Lighting: Examining the Limits of CCT* Ian Ashdown

The small size of an LED means that an individual LED is extremely bright, which makes it a potential source of glare, due to the multi-directionality of the lights. Higher colour temperatures contain a strong blue component, which is scattered more in the atmosphere and contributes to sky glow. The dark-adapted human eye is particularly sensitive to blue wavelengths; and evidence is starting to show that blue light in sleeping areas, can have an impact on human health. As with all lighting, careful consideration should be given to visibility and health issues around colour temperature in the application of this technology.



Photo Credit: Gabriel Guillen

**Brickworks
Parking Lot**

LED lamp in foreground,
sodium vapor lamps in
background

Historical Comparison

Bay Street and Wellington Street West.
Many changes, but still the same street lighting fixture.

Our collective understanding about light pollution and best practices has changed over time. Much of Toronto's current lighting was installed at a different time in history. In contrast, what is available with today's technology and in line with current environmental awareness - newer installations and eventual retrofits and replacements - should all be achieving current/future best practice. However, it will take time to implement incremental improvements. Comprehensive change relies on significant investment.

1966



2012



6 Design for Effective Lighting



Image Credit: DIALux

Ottawa | Computer-generated rendering of street light levels

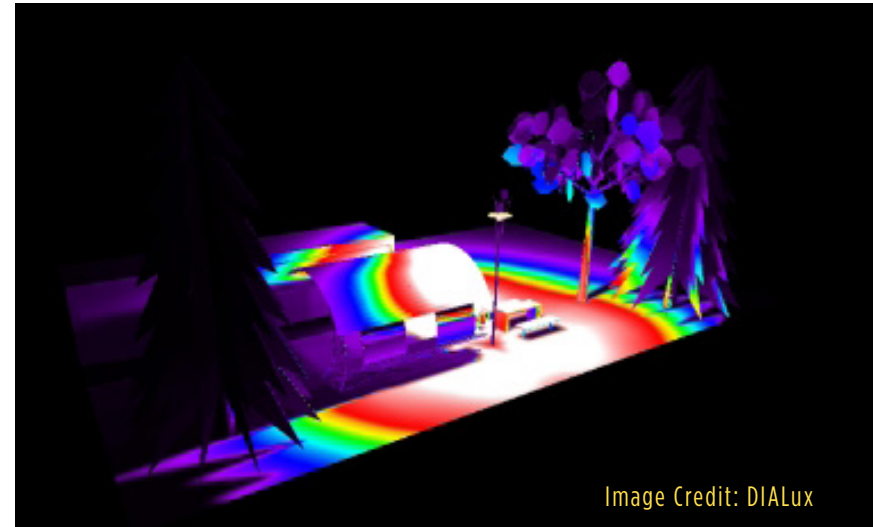


Image Credit: DIALux

Falsch Farben | Computer-generated rendering of street light levels

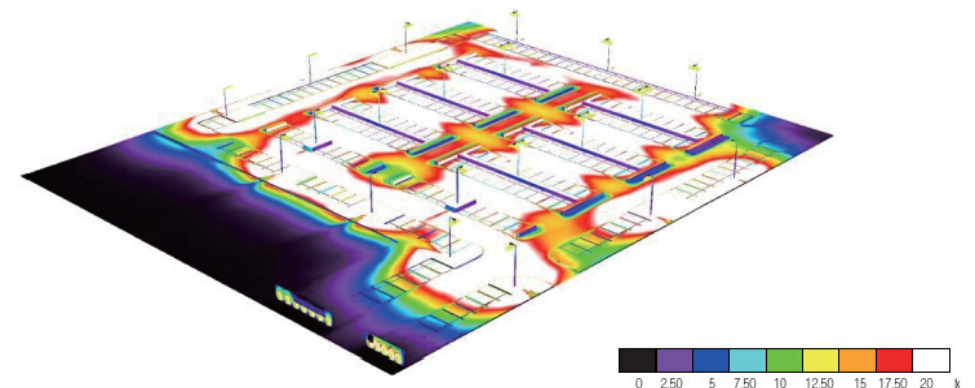
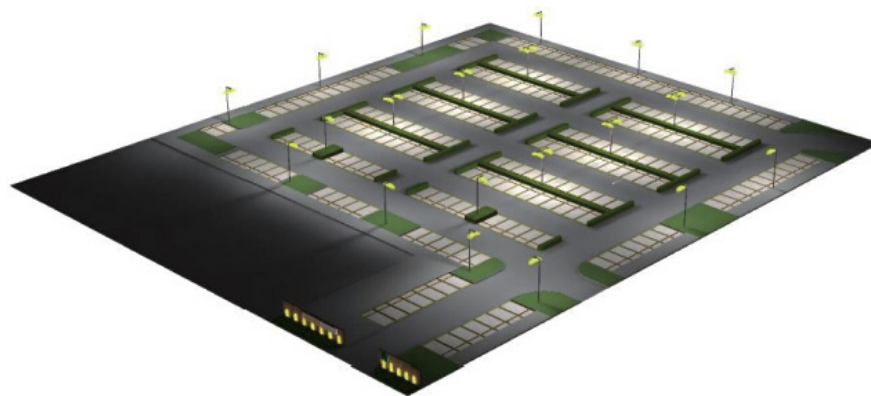
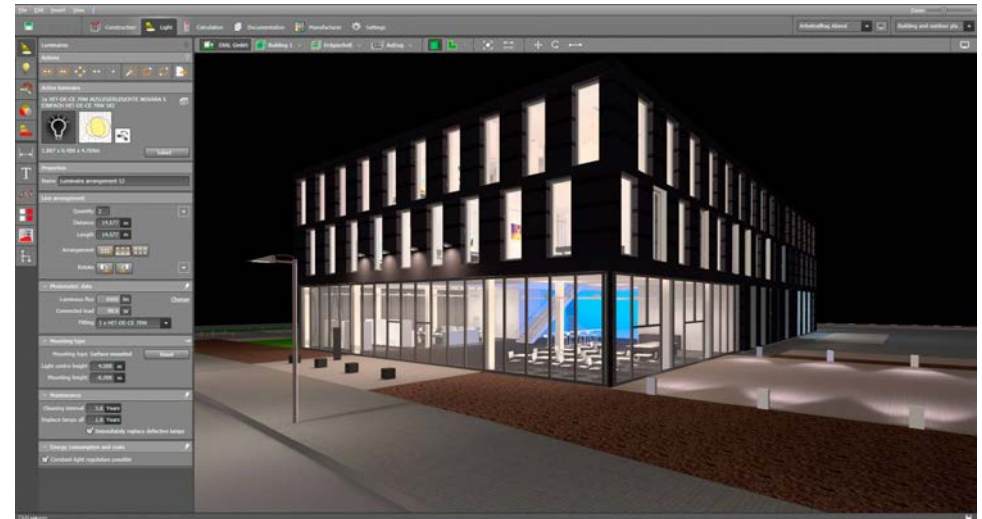
Planning Tools

Light Level and Distribution

Sophisticated computer-aided lighting design tools are available to demonstrate the results of an exterior lighting design. The figure to the side shows an example of a computer-generated rendering of street light levels.

For effective lighting design, all new developments and major upgrades to existing designs can be accompanied by a lighting plan.

This plan will show light level in lux measured horizontally and vertically as a contour map overlaid on the site plan and brightness of light sources in candela per square metre as viewed from the property line.



DIALux I Computer-generated rendering of street light levels

Image Credits: DIALux evo

Measurement Techniques

Horizontal and Vertical Illuminance

Illuminance is the measure of light falling on a surface. It is measured in units of lux (metric) or foot-candles (Imperial) with a lux meter (illuminance metre). One foot candle is equal to 10.7 lux. One lux is equal to one lumen of light falling on each square metre of surface. A lux meter is a relatively inexpensive and readily available measuring instrument.

Illuminance is often used to ensure sufficient light in a working environment, such as an office or store. For controlling light pollution, illuminance is also used to measure light trespass. It is important to measure both the horizontal and vertical component of illuminance.

For a concentrated source of light, the illuminance decreases by a factor of four with each doubling of distance from the source.



Vertical measurement



Horizontal measurement

Luminance and Brightness

Luminance is a measure of the brightness of a light source, measured in units of candela per m². Technically, one candela is the brightness of a light source emitting one lumen of radiation through a solid angle equal to one steradian. Luminance is then this light energy per unit area of the source.

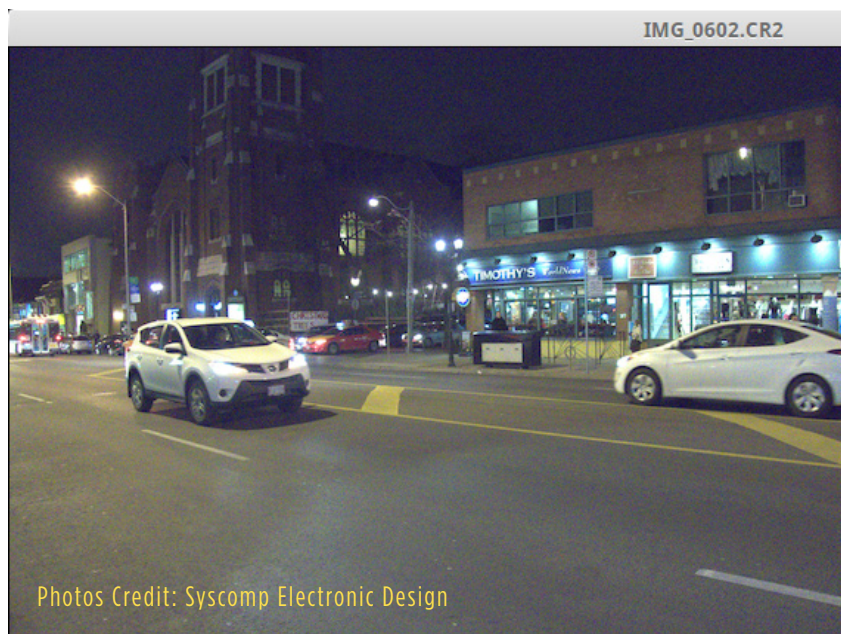
Luminance can be measured by a photographic spot meter, a special luminance meter, or a calibrated digital camera.

A luminance measurement takes a small area sample of the emitting area of the source. Provided the measurement area is within the source, the luminance is not affected by distance. Luminance can be used to quantify glare, where the maximum comfortable brightness of a source is about 1500 candela per mm².

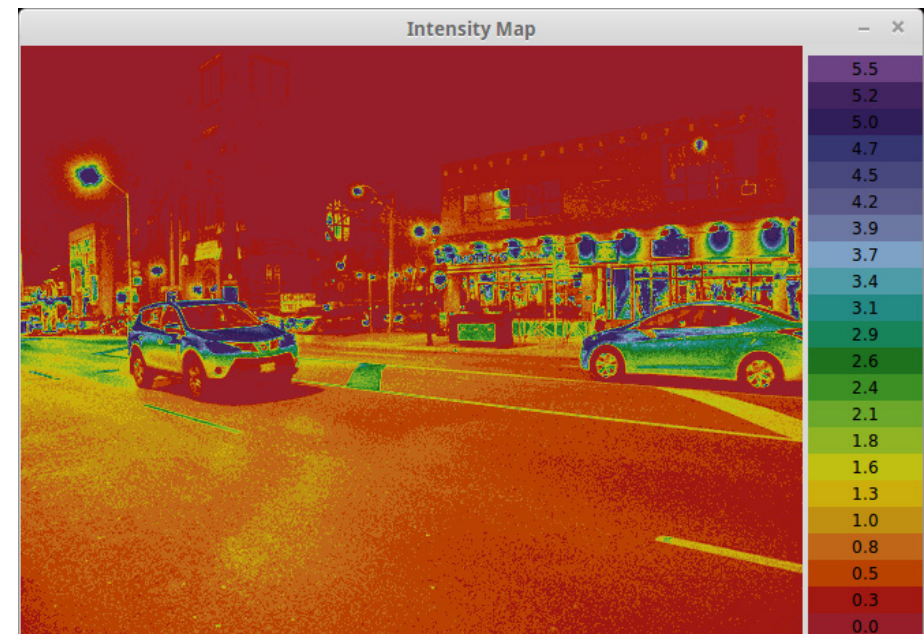
Luminance Meter



Photo Credit: Peter Hiscock



Photos Credit: Syscomp Electronic Design



Original Digital Image

Luminance Calibrated Digital Image

Typical Illuminance and Luminance (Brightness) Levels

Light Source	Illuminance, Lux	Light Source	Illuminance, Lux
Direct Sunlight	32,000 to 130,000	Sun	1.6×10^9
DayLight	10,000 to 25,000	Arc Lamp	1.5×10^8
Operating room	18,000	LED Streetlamp	1000000
Sports field	200 to 3,000	LED Domestic Lamp	50000
TV Studio	1,000	Maximum Visual Tolerance	30000
Retail store	500	Frosted Incandescent Lamp	20000
Office	320	Compact Fluorescent Lamp	12000
Overcast day	100 to 3,500	Mercury Vapour Streetlamp	8000
Washroom	80	High-Pressure Sodium Streetlamp	4000
Family living room	50	Clear Sky	3000
Roadway lighting	3 to 16	Threshold of Discomfort	1500
Civil Twilight	3.4	Cloud	1400
Sidewalk	2 to 10	Surface of the Moon	600
Candle at one metre	1.0	Candle	50
Full Moon	0.1	Night Sky (City)	0.007
Quarter Moon	0.01	Urban Sky Park	0.001
Total starlight	0.0002	Night Sky (Wilderness)	0.00017
		Threshold of Vision	0.000001

These values can be obtained by direct measurement using appropriate equipment.

Classification of Luminaires

The traditional method of classifying lamp fixtures is by 'cutoff' designation, as shown in the chart.

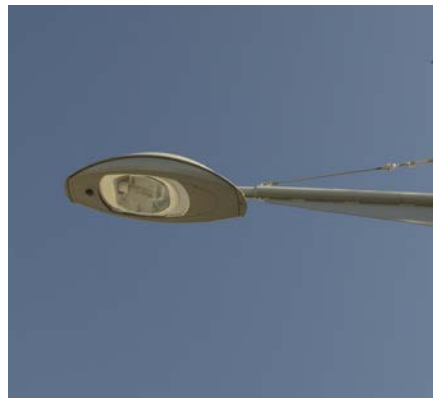
Fixture Designation	Radiation Above Horizontal	Radiation 10 Degrees Horizontal
Full Cutoff	Zero	Less than 10% of rated output
Cutoff	Less than 2.5% of rated output	Less than 10% of rated output
Semi-Cutoff	Less than 5% of rated output	Less than 10% of rated output
Non-Cutoff	Any	Any

The main designations are 'Full Cutoff' (also commonly referred to as 'fully shielded') and 'Non-Cutoff (unshielded)'. In general, full cutoff fixtures should be used to minimize light trespass, glare and sky glow. Full cutoff fixtures are characterized by a flat lens surface with a recessed lamp. Non-cutoff fixtures have a 'sag lens' which protrudes from the bottom of the fixture, and contains the lamp.



Photos Credit: Gabriel Guillen

Non Cutoff
(Unshielded) Fixture



Full Cutoff
(Shielded) Fixture



Non-Cutoff
(Unshielded) Fixture



Full Cutoff
Lamp



Photo Credit: NASA

Applying Effective Lighting

The glow of light over cities has enormous reach, decreasing gradually with distance. Particles in the atmosphere (aerosols) reflect the light horizontally. As a consequence, outside the urban areas the major contributor to sky glow is not direct uplight or light reflection from surfaces, but light that is emitted at a low angle above the horizontal. Consequently, 'semi-cutoff' lamps are not effective in reducing sky glow.

Excess light increases energy use, negatively impacts the environment and is a source of light pollution. Light levels should be chosen to provide sufficient light to meet recommended light levels, and no more.

This is particularly important in commercial areas, where establishments try to exceed the light levels of their neighbours, and a light-level competition develops. In fact, studies show that reasonable light levels and the absence of glare are more attractive to visitors.

Sign Brightness (see Toronto City Sign Bylaw)
www.toronto.ca/signbylawunit

A night-time view of the eastern USA,
with Toronto and the Golden Horseshoe

Source: An Evaluation of Three Types of Gas Station Canopy Lighting
P.R. Boyce, C. M. Hunter, and S. L. Vasquez Lighting Research Center
Rensselaer Polytechnic Institute Troy, NY 12180
www.lrc.rpi.edu/programs/transportation/pdf/lightPollution/canopy.pdf

Light from all sources on a property should not raise the illuminance level at the property line by more than 1 lux. The light measurement is the larger of the horizontal and vertical measurements.

Light sources should be properly shielded so that the light source itself or a mirror-like reflection of the light source is not visible from outside the property. Light sources should not have a visible luminance exceeding 1500 candela per m². Lamps should be full cutoff and emit all light well below the horizontal.

Holiday lighting would not necessarily engage the same concerns provided that they are used for short durations.

Recommended Light Levels

For detailed minimum lighting requirements please consult Municipal Code Chapter 629-36

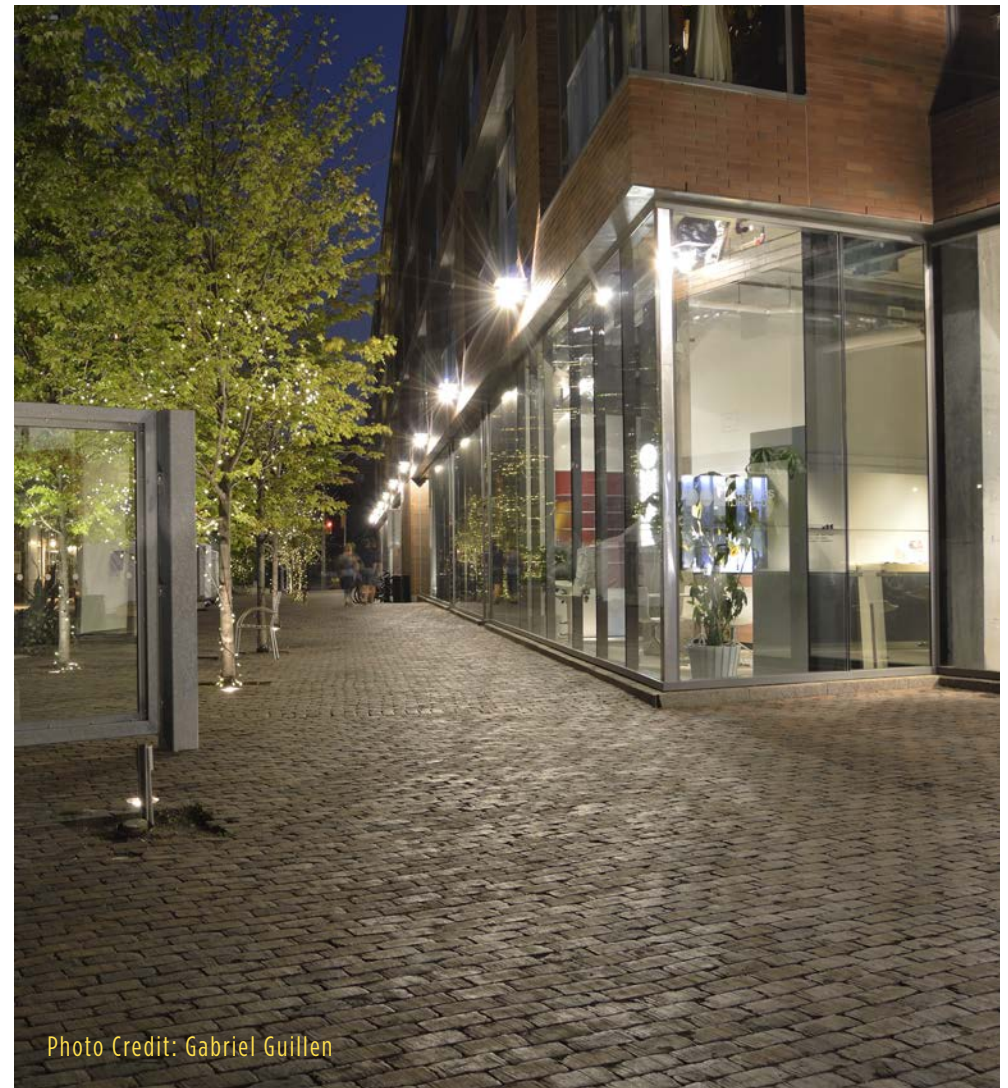


Photo Credit: Gabriel Guillen

Distillery District

Design Considerations

Street Lighting

The design of street lighting is advancing with new understanding of human vision, electronic lighting technologies, measurement techniques and increasing concern about energy use and light pollution. Although street lighting requires careful engineering design, computer-aided tools and other new technologies are available to produce a design that meets multiple requirements for effective lighting.

There are several important factors to consider in the design of street lighting. The minimum level of lighting that provides adequate visibility and uniformity for drivers, bicyclists and pedestrians should be used. Traditionally, the standards for light levels have been chosen from the Illuminating Engineering Society of North America (hereby referred to as IESNA) Standard RP-8 and the Transport Association of Canada (TAC) 'Guide for the Design of Roadway Lighting'. Toronto Hydro follows IESNA RP-8 guidelines. There is research that has indicated that levels lower than IESNA standards may be just as effective. This is a subject of significant scientific interest and ongoing research.



Photo Credit: Gabriel Guillen

**Danforth Avenue
Ferrier Avenue**

Street lights are visible in the distance, indicating ineffective shielding.

Street lighting should use ‘full cutoff fixtures’. These place light directly on the roadway surface with no uplight, and minimal glare to drivers and pedestrians. Street lighting should not be used to illuminate adjacent surfaces such as residential lawns and walkways. Local, low-level lighting is more effective in these situations.

On low-speed residential streets, it may be sufficient to provide lighting for sidewalks and rely on car headlights for lighting the roadway. The IESNA are currently considering this as an option for residential area lighting.

Ideally, sidewalks should be illuminated by separate full cutoff fixtures that are optimized for that task.

To avoid glare and light trespass to nearby residences the light source in a lighting fixture should not be visible from the residence.

‘**Smart Lighting**’ technology has the potential for considerable savings in energy consumption and reduced light pollution. Lighting fixtures are dimmed or turned off when they are not needed. For example, street lighting can be reduced late at night.

Particular care should be taken to avoid light trespass and glare into parks and natural areas.



Photo Credit: Gabriel Guillen

Bloor Street East | The Viaduct
Viaduct Bridge

Car Dealerships Car dealerships present a particular challenge for lighting design. In Toronto, some car dealerships are equipped with full cutoff fixtures that control glare and direct the light to the car lot.

However, many dealerships are very over-lit. Typical measured average values in Toronto dealerships range between 200 and 300 lux, with peak values as large as 800 lux.

This kind of overlighting is unnecessary, encourages competitors to increase their light levels, and increases energy use. Sky glow is especially affected by this volume of light, since car roofs are reflective.

Dealerships can use front row lighting on the car lot in the main display area. A 'best practice' for illuminance levels for front row lighting is 30 lux [Vermont].

The storage area, customer parking and other areas of the premises that are not sales related should be lit at the lighting level of a parking lot, at 10 lux. Lighting should be off between 11PM and 5AM.



Photo Credit: Gabriel Guillen



Photo Credit: Gabriel Guillen

Over-lighting | Dealerships

Gas Station and Convenience Store Canopy

Light sources in the canopy should be shielded so they are not visible from the property line.

The lighting of the area under the canopy should be adequate for the activities taking place, not to attract attention to the business.

The average horizontal illuminance under the canopy should be no more than 10 lux, with a uniformity ratio no greater than 3:1.

Lights should not be mounted on the top or sides of the canopy, and the sides of the canopy should not be illuminated.

Canopy lights are an excellent candidate for motion-sensing activation, where the lamps remain in a partially dimmed state until a car is detected.

Signs should meet the requirements of the City of Toronto Sign Bylaw. www.toronto.ca/signbylawunit



Gas Station Canopy | Shielded Canopy Light

Sports Facilities

Sports facilities are a very important part of city life. In many cases, these facilities are active in the evening and require lighting. However, because of the amount and intensity of the light, it is important to control for glare, light trespass and sky glow.



Photo Credit: Gabriel Guillen

Lighting requirements vary for different facilities. For example, a tennis court or soccer playing field can be lit with full cutoff fixtures. It is then reasonable to expect that no visible light source will exceed 1500 cd/m^2 in luminance, and the illuminance will not exceed 1 lux (vertical and horizontal) over ambient at the edge of the playing areas. A baseball diamond must illuminate the volume over the playing field, so it is inherently very difficult to control glare and spill light. In this case, whenever possible the field should be screened by tall vegetation or land form.

In all cases, the lighting should be on only when the facility is in use. Timers are not a completely effective control mechanism because they have to be set to the longest possible use time, and this often extends beyond the conclusion of the event. Additional controls, such as motion detectors, manual controls, or internet-based remote control, are recommended to minimize unnecessary lighting. This not only reduces light pollution, it reduces energy consumption and subsequent operating costs as well.

Cabbagetown | Baseball Field is illuminated and unused



Riverdale Park I Arena is illuminated and unused

Photo Credit: Gabriel Guillen

Parking Lots and Walkways

Parking Lot lighting helps people navigate from their cars to the nearby business, and then find and return to their car. Parking lot lighting also aids with security and the feeling of security.

However, the lighting of parking lots is a significant source of sky glow. Uplight is caused by low-angle radiation from the lighting fixtures themselves, as well as by reflections from the pavement and automobiles. In night-time satellite photography of Toronto (page 10), many of the hot-spots are plaza and shopping centre parking lots.

An average level of 10 lux provides adequate visibility for parking lots and walkways. Luminaires should be shielded to reduce glare.

In order to avoid light trespass onto adjacent properties, the pole height should be no higher than the buildings or trees around the perimeter of the parking lot. The luminaires may require shielding to control light spill. Parking lot lighting should be dimmed or extinguished after businesses hours, or no later than 11PM. Parking lot lighting should not be used to promote a business or illuminate a building facade.

The design of a new parking lot should include a lighting plan, which shows computer analysis of the surface light levels (in lux), horizontal and vertical light levels at the property boundary (in lux), and the surface brightness of the luminaires (in candela per m²).



Parking Lot | LED Lamps

Parking Lot | Mall

Security Lighting

Security Lighting must be carefully designed to be effective. Increased lighting levels do not necessarily result in greater security, especially if that light is a source of glare for observers. In particular, the common wall-mounted, horizontally aimed security lights interfere with and inhibit human night vision which reduces the security of an area, and adds to light trespass and sky glow.

The lighting for security should meet the requirements of light trespass and glare. Fixtures should include shielding so that the light sources are not visible from the property line, and should be aimed downward to minimize sky glow. Security lighting should be motion activated, and use the minimum illumination consistent with making the area visible.

West Sussex Lighting Study

A study in West Sussex, UK showed that crime increased in lit areas. In certain test areas, all-night lighting was installed; other areas were kept as control areas. West Sussex Police monitored the test and control areas for criminal activity patterns in comparison with the previous year. They also polled residents about their perceptions of the all-night lighting.

Polling results confirmed people believed the increased lighting prevented crime and most residents felt safer after the all-night lights were installed. Crime statistics, however, showed a 55% increase in criminal activity in the test areas as compared to the control areas as well as the county as a whole. West Sussex has subsequently decided not to install all-night lighting.

Subsequently, police reports have shown that darkness is often safer than areas that are lit. That's partly because neighbours soon learn to alert police if they see any lights on in a building. Additionally, there is a decrease in graffiti because well lit walls typically attract graffiti activity rather than dark ones.

San Antonio Lighting Study

Vandalism and graffiti have been successfully reduced in many American schools with the Dark Campus Policy that began in San Antonio in the 1970s. Vandalism and graffiti and the associated cost of repairs dropped immediately when security lights were removed or turned off.

Chicago Alley Lighting Study

For the six month period prior to the alley lighting improvement, the experimental area showed 205 reported incidents in the pre-period and 287 in the post-period – a 40 percent increase. In three of the major crime categories measured, there was an increase noted.

Facade and Architectural Lighting

Facade lighting, if necessary, should be directed downward and toward the building. No amount of light should be emitted above the horizontal. Facade lighting should be extinguished between 11PM and 6AM.

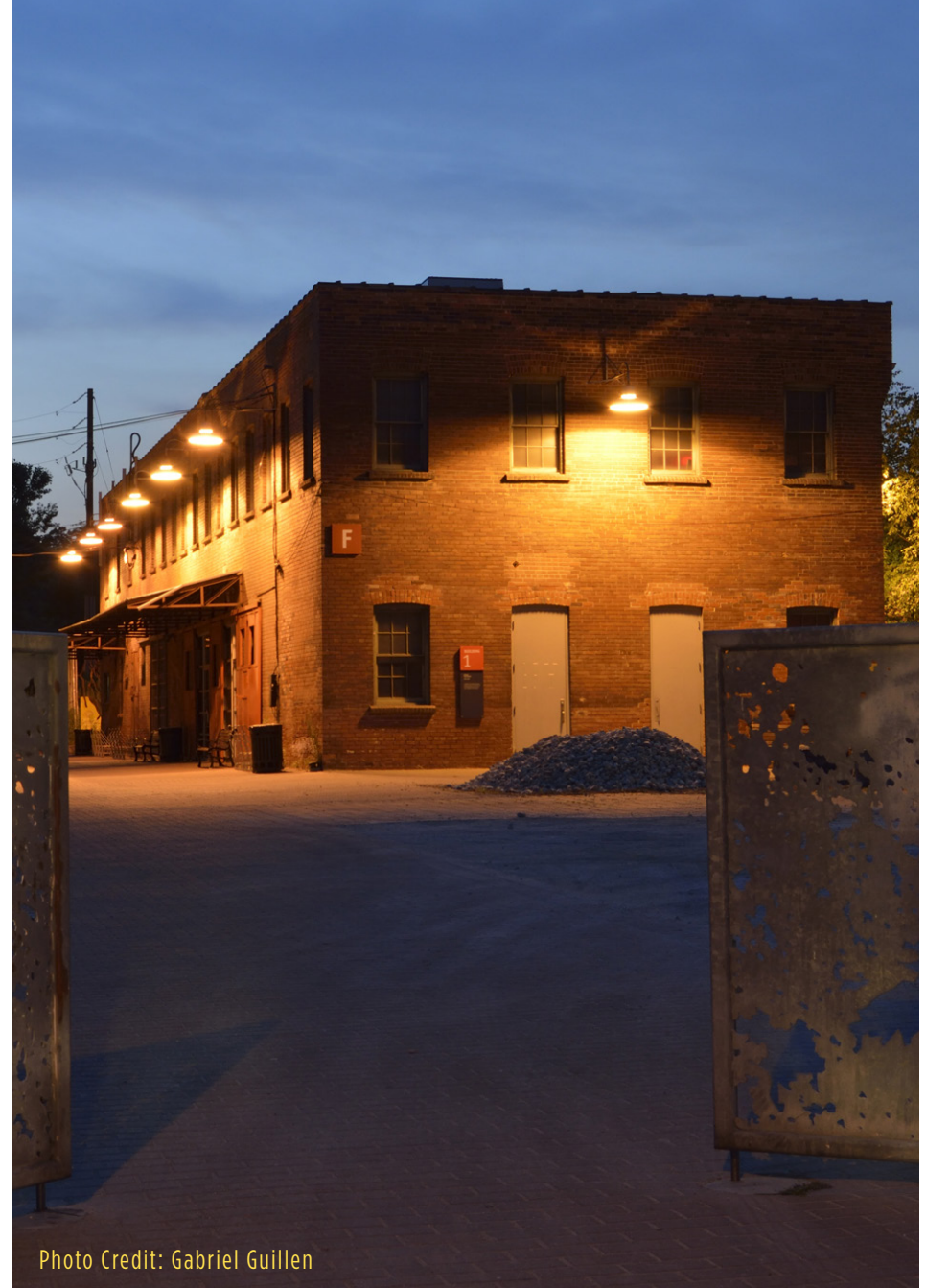


Photo Credit: Gabriel Guillen

Brick Works Facade | Good Facade Lighting

Park and Natural Heritage Areas

Toronto City Parks make an enormous contribution to city life. Parks provide access to sports and recreational activities, and provide opportunities to experience nature. These experiences range from the formal gardens of Centre Island to the semi-wilderness of the Don Valley Trail.

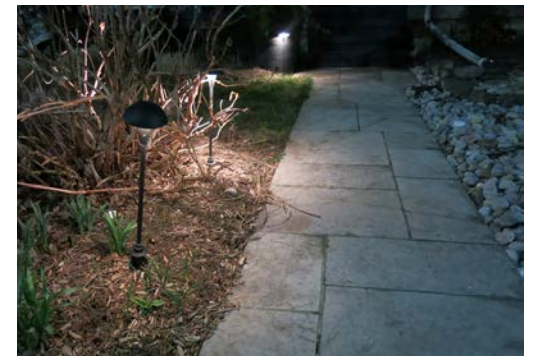
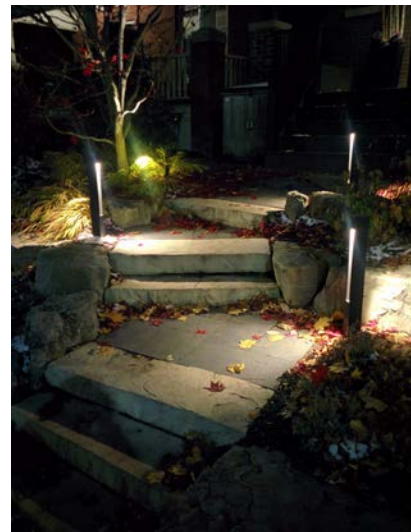
The natural world includes the night sky, and our parks should support that experience. This is especially critical for children raised in the City. The arch of stars in the Milky Way has not been visible in Toronto since the early 1980's. Many children and adults have never seen a star-lit sky within the city, and are not aware of its wonders.

Careful lighting design that minimizes glare and overlighting can allow some view of the night sky. Stairs and walkways should be lit with shielded downlighting, so that paths and stairs are visible without glare. Traditional wall packs, which project light horizontally, are not effective lighting solutions, and should be replaced by architectural down-lighting and area lighting, where the direct light is shielded from human vision.

Increased lighting is not necessarily more effective in increasing security and may in fact worsen visibility. Security lighting in parks and heritage areas should be subject to the same criteria as path and area lighting: minimal lighting for human vision and the absence of glare. Humans can see quite well in moonlight, which is about 1 lux light level.

Where a light level is mandated – as in the Toronto Municipal Code, which requires 50 lux at exits, stairs and ramps, and in the Ontario Building Code – light should be carefully contained by shielding and focused on the mandated area.

Path Lights



Photos credit: Peter Hiscock



Photo credit: Lynn Hilborn

Urban Star Park

In Toronto, we have a wonderful system of urban parks and natural areas that allow us some experience of nature. The concept of an 'Urban Star Park' extends that concept to the night sky, returning it again to our natural environment.

By controlling artificial illumination and glare in a park-like setting, it is possible for visitors to have some experience of the night sky and night wildlife. Sky glow from city lights prevents the viewing of features like the milky way, but planets and star constellations are visible and recognizable. The park then becomes a destination for science students, amateur astronomers and other city-dwellers who would like to know more about the night sky.

The landscape design of an Urban Star Park places hills and vegetation to block sources of light that interfere with night vision. Path navigation and safety is by flashlight or motion-activated low intensity lamps which are mounted close to ground level and shielded from direct view.

The location of Toronto next to Lake Ontario provides unique opportunities for Urban Star Parks in waterfront parkland.

Globular Cluster M13

Andromeda Galaxy

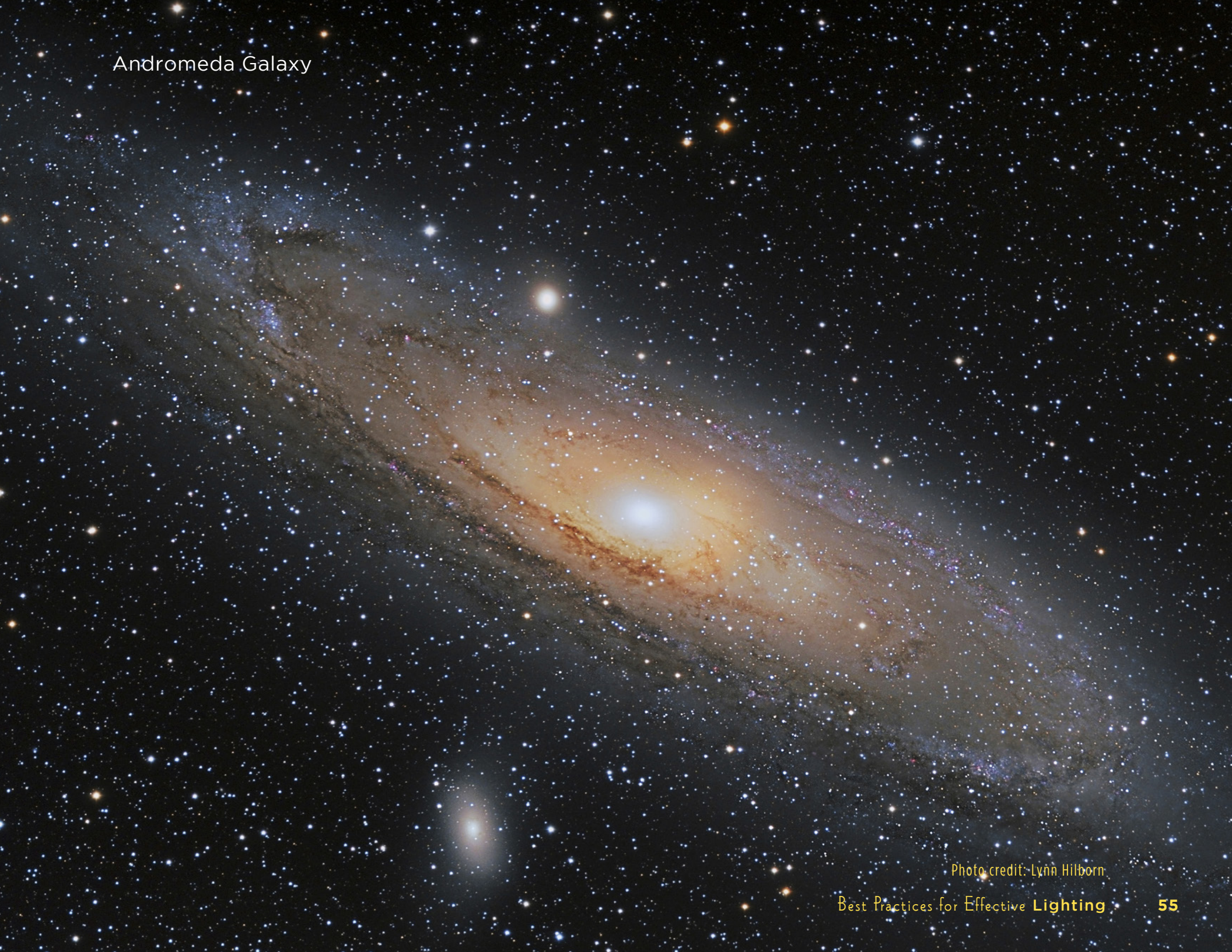
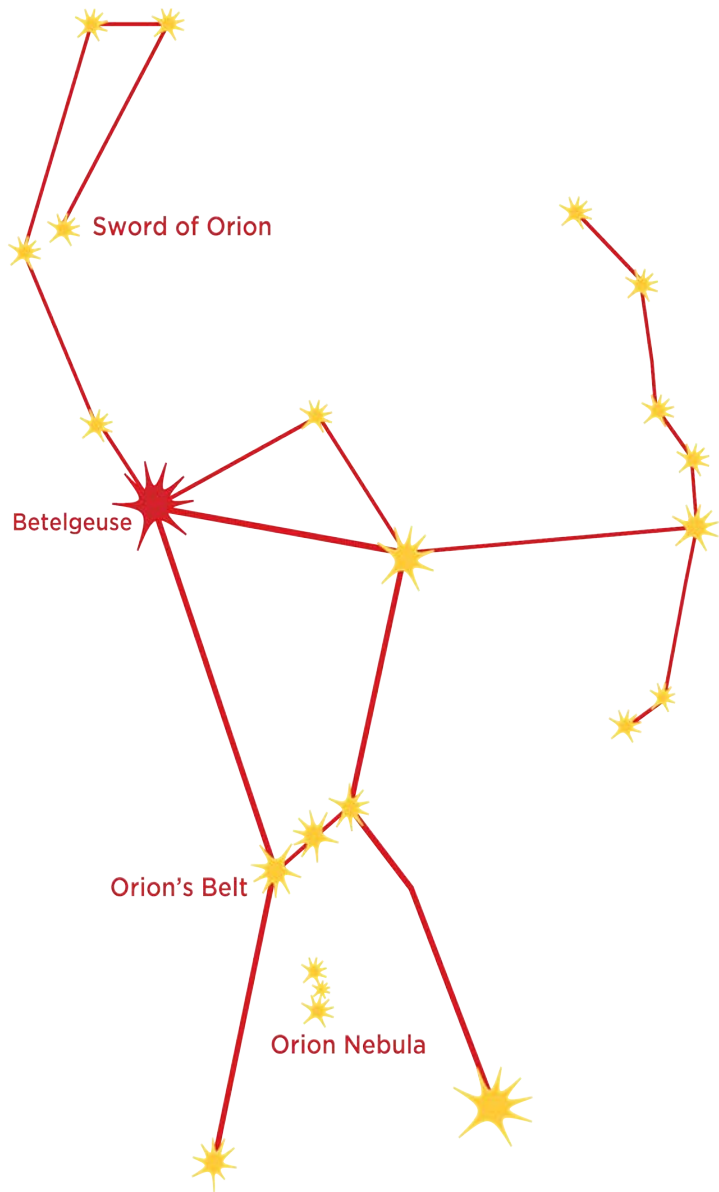


Photo credit: Lynn Hilborn



Stars in the Night Sky

The constellation of Orion, The Hunter, contains stars at the beginning and end of their lives.

Readily visible in the Northern Hemisphere in winter months, it is marked by the four corner stars and the three stars of Orion's Belt.

Betelgeuse, in the upper left corner, is a 'red giant star' - many times bigger than our sun, varying in brightness and nearing the end of its life.

Without light pollution, the **Sword of Orion** becomes visible and dissolves into many smaller stars and the beautiful Orion Nebula.

Illustration Credit: Monika Hoxha

The image is a side-by-side comparison of the Orion constellation. The left half shows the constellation in a dark, clear night sky, where the stars are sharp and numerous. The right half shows the same constellation in a sky with significant light pollution, where the stars are much fainter and the background is a hazy, greyish glow. The text 'Orion Constellation' is centered at the top in white. Below it, 'Without Light Pollution' is written in yellow on the left side, and 'With Light Pollution' is written in red on the right side.

Orion Constellation

Without Light Pollution | With Light Pollution

Photo Credit: Jeremy P. Stanley, flickr.com/Light pollution: It's not pretty

7 Appendices

Appendix A: Lighting and Energy Efficiency

What's the best way to reduce lighting energy consumption?

The best way to save lighting energy is to use more efficient lamps, moving from incandescent to CFL (compact fluorescent) or LED (light emitting diode, solid state) light sources. By dimming the lights when not in use, significant energy savings can be generated.

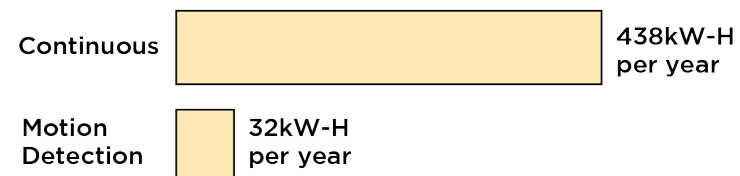
The best option is to turn off unused lights and to effectively direct the light only where it is needed. This not only reduces energy consumption, it extends the life of the lamp, reducing the cost to the consumer and reducing the number of lamps sent to landfills.

Here's an example:

The bar chart shows the energy consumption of one, hundred-watt security lamp over the course of a year.

A motion detector reduces the energy used by 92%.

For an outdoor lamp, turning it off or putting it on a motion detector reduces light trespass onto an adjacent properties and sky glow, which lights the sky unnecessarily. It also provides a “visual alarm” for security.



The calculations assume:

Continuous mode:

12 hours ON time per day, 365 days per year

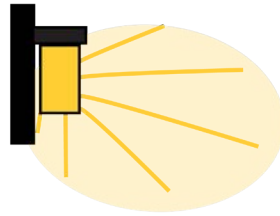
Motion Detection mode:

50 minutes ON time per evening, 365 days per year

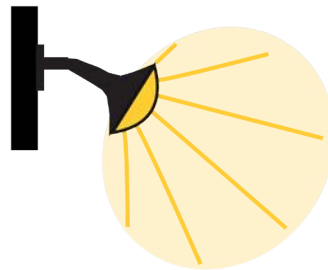
Ineffective Lighting

Fixtures that produce Glare and Light Trespass could disturb your neighbours, as well as waste energy.

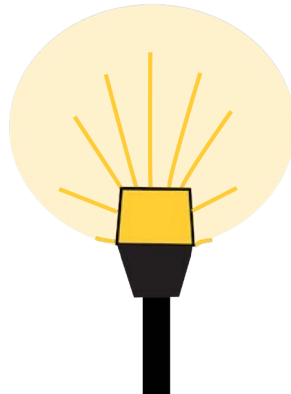
Typical wall light



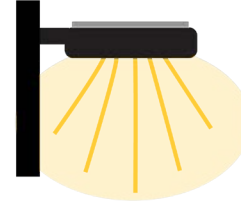
Area floodlight



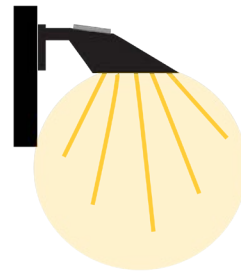
Typical yard light



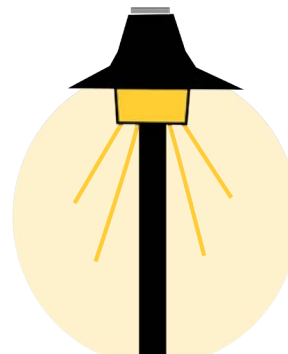
Darksky-friendly wall light



Area floodlight with hood



Yard light with reflector



Effective Lighting

Fixtures that shield the light source minimize Glare and Light Trespass. It saves money and energy.

Appendix B:

Lamp Cutoff Ratings and the BUG Rating

Lamp cutoff ratings indicate how much light is outputted from the fixture at different angles. Low angle radiation, at 120 degrees (slightly above the horizontal) is a more significant contributor to local sky glow and spreads the city glow far beyond its boundaries. Radiation at zero degrees lights the desired surface.

ESNA Cutoff Designations are as follows:

The angles are measured from nadir, that is, from a vertical line through the fixture. For example, light output at 90 degrees indicates light emitting horizontally from the fixture.

The lamp installation must be exactly horizontal. Even a small deviation from the horizontal can substantially increase glare, light trespass and uplight.

	Radiation at 80 to 90 degrees*	Radiation at 90 degrees and above**
Full Cutoff	Less than 10%	Zero
Cutoff	Less than 10%	Less than 2.5%
Semi-Cutoff	Less than 20%	Less than 5%
Non-Cutoff	Not Limited	Not Limited

* The percentages are in candela as a percentage of the total lumen output of the lamp.

For example:

10% indicates fewer than 0.1 candela per lumen. Candela is lumen per steradian of solid angle, so the numerical value total light output in those zones is significantly higher.

**Percentage of total lamp lumens.

Reference:
Lighting For Exterior Environments IESNA RP-33-99

Lamp Cutoff Ratings and the BUG Rating

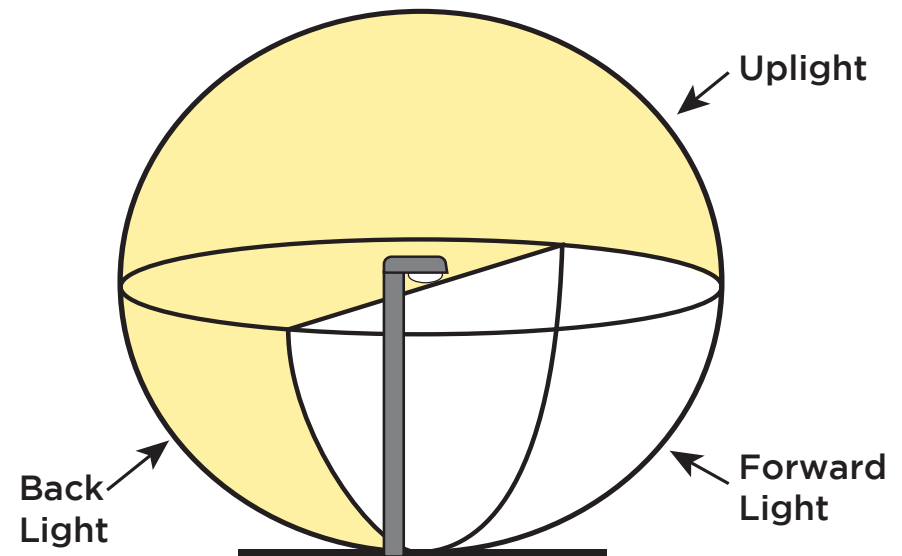
The BUG (back, uplight and glare) rating was introduced by IESNA to evaluate luminaire optical performance related to light trespass, sky glow and high angle brightness control. As shown in the diagram, the output from the lamp is grouped into three sections: Back, Uplight and Forward Light. The overall rating of the lamp is given as a series of three values: eg, B1 U2 G1, where a smaller number represents less light output.

To arrive at the BUG rating, the output of the lamp is measured in each of the sections in the diagram and compared to maximum allowable value to determine its rating. The largest subsection rating then becomes the rating for that section.

In general, the uplight rating of a lamp is U0, although that may be relaxed to U1 or U2 for decorative lamps in commercial areas. The ideal glare rating objective is G0. The backlight rating will depend on the application.

A great deal depends on the installation and surroundings of the fixture. Ultimately, a satisfactory installation generates sufficient light for the purpose, and meets the numeric requirements of no vertical or low-angle uplight, minimal trespass onto other properties, and produces low levels of glare. The BUG rating is an indicator of satisfactory performance, but the results should be checked with a full design analysis.

Diagram of Bug System



Reference:
The BUG System: A New Way to Control Stray Light from
Outdoor Luminaires International Dark Sky Association
www.aal.net/content/resources/files/BUG_rating.pdf

Illustration with permission from
Luminaire Classification System for Outdoor Luminaires, TM-15-1.
Published by the Illuminating Engineering Society of North America

Appendix C: Lighting and Ecology

**Female Adult Water
Flea Daphnia**



Photo credit: Hajime Watanabe, Flickr

An ecological system is a complex web of relationships between organisms and their surroundings. Artificial light at night fundamentally changes the environment for which all life has evolved. Living things respond in a variety of ways to impacts on the environment. Some examples of the effect of light at night are well known - moths gathering around a street lamp, or the harvesting of fish with spotlights - but the long term impacts and changes to the ecosystem are not well understood. These changes can also have a dramatic effect on humans.

For example, plankton and daphnia (water flea, shown in the image), are at the bottom of the aquatic food chain. Both organisms are inhibited by light from their normal behaviour, rising to the surface at night. This has an impact on a variety of animals, up to the fish consumed by humans.

Plants are also affected by light at night. Changes in the length of the day and night trigger phototropism, which enables the plant to detect the beginning or end of growing season or the time to pollinate. Artificial light interferes with these natural activities.

Minimizing the Impact of Artificial Light on an Ecosystem

Turn lights off when they are not needed Reduce the impact on nocturnal insects, animals and on plants.

Direct light exactly where it is needed – and nowhere else.

Minimize the environmental impact and sky glow.

Use new lighting methods

Example:

Buried LED lamps in coastal highway

Consider the impact of spectrum

Example:

Some insects are particularly sensitive to ultraviolet light.

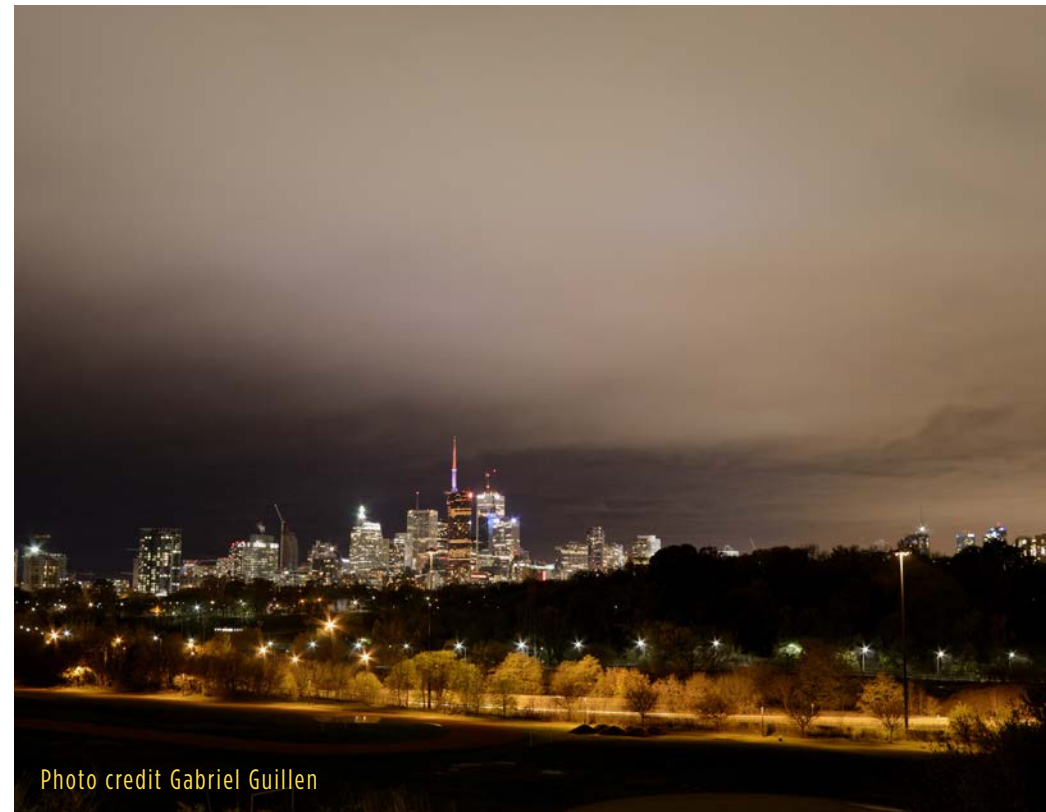


Photo credit Gabriel Guillen

Sky Glow over Toronto



Photo credit Gabriel Guillen

Appendix D: Light Pollution and Quality of Life

Two-thirds of the U.S. population and more than one-half of the European population have lost the ability to see the Milky Way with the naked eye. Moreover, 63% of the world population and 99% of the population of the European Union and the United States* live in areas where the night sky is brighter than the threshold for light-polluted status set by the International Astronomical Union**.

A view of the night sky has been an integral feature of our place on earth for all of human existence, until the coming of electric light in the last hundred and fifty years. Our children, and their children, should be able to see the night sky. It gives us a sense of place within the universe.

* Excluding Alaska and Hawaii.

** The artificial sky brightness is greater than 10% of the natural sky brightness above 45° of elevation.



M8 to M16 Star Field

Photo credit: Lynn Hilborn

Appendix E:

Human Vision and Health

Much of human interaction with our surroundings depends on our sense of vision. The eye-brain system allows us to see and interpret our surroundings. The eye is a marvelous instrument, but it does have limitations, especially in the presence of light pollution.

Referring to the diagram on the next page, light enters the eye through the iris, a variable-sized aperture, which controls the brightness of the image to avoid over or under exposure. A lens then focuses an inverted image onto the retina, the image sensors at the rear of the eye. The image is pre-processed in the retina (to emphasise edges and movement, for example). This edited version of the image is sent to the brain.

The eye can adapt to an enormous range of brightness levels, ranging from moonless night to bright sun at noon, a range of 10^{12} :1 (million million to one). This is accomplished through several mechanisms.

- The retina itself can instantly accommodate a range of 100:1.
- The iris further adjusts brightness over a range of 16:1, in a few seconds.

- There are two types of photoreceptor cells, rods and cones, each covering a different range of brightness. The rods provide low-brightness night vision without colour and are sensitive to movement. They are incredibly sensitive to light, and can respond to a few tens of photons. The cones become active in brighter light and can detect colour. A chemical reaction optimizes the selection of rod and cone vision over a period of about 30 minutes, further adapting to light level.

In addition to the rods and cones used for vision, there are additional light sensitive cells, the photosensitive Retinal Ganglion Cells (pRGC cells). These cells connect in the brain to the suprachiasmatic nucleus (SCN), which is the clock regulating the day-night rhythm of waking and sleeping.

Mammals that are blind (no rod or cone cells) are still affected by ambient light. Photoretinal Ganglion Cells are especially sensitive to blue light, and are thought to regulate other aspects of physiology such as melatonin production, body temperature and alertness.

Although the eye can use these mechanisms to adapt to different levels of brightness, it cannot adapt to large changes in a short period of time. A dark adapted eye can be blinded by bright light, which causes a loss of dark adaptation. A light adapted eye cannot see into shadows. This has important implications for lighting design.

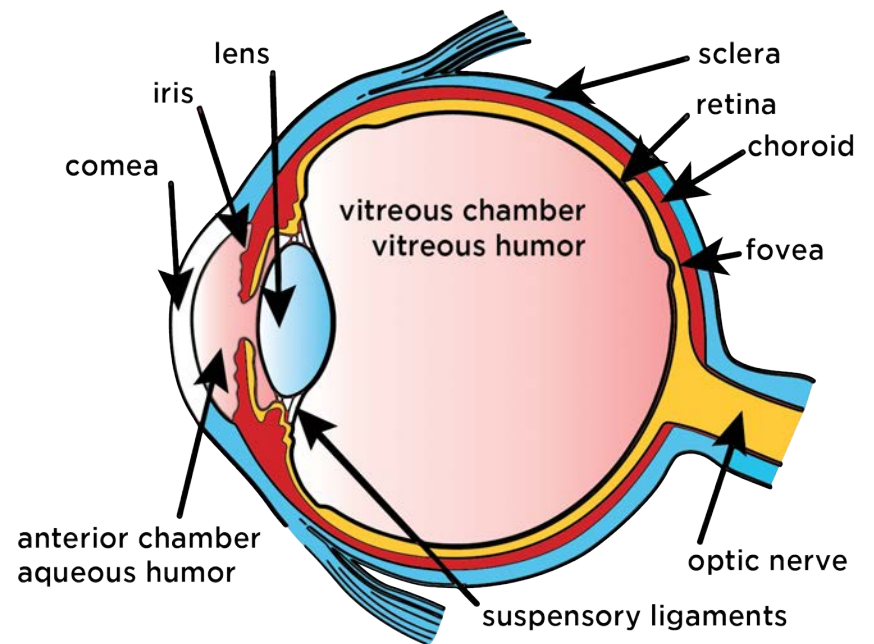


illustration credit: "Three Main Layers of the Eye" by Holly Fischer

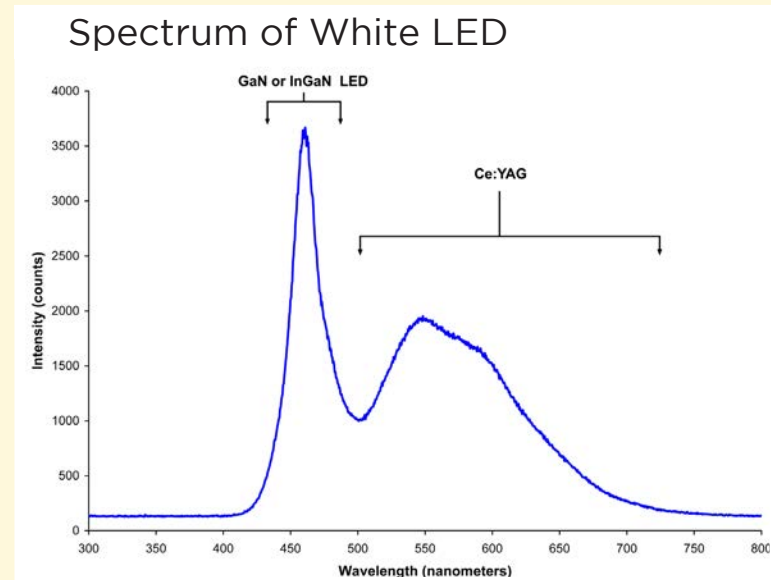
For much of human history activities were defined by a day-night cycle, with active wakefulness during the day and rest at night, called the circadian rhythm. In humans and many other mammals this cycle of wakefulness and sleep is synchronized to the 24 hour cycle of light and darkness by light detectors. In humans, these detectors are photosensitive retinal ganglion cells located in the eye. These cells are particularly sensitive to blue light, and so are known as blue-sky receptors.

Bodies repair and restore themselves during the resting portion of the day-night cycle. Exposure to high levels of light during resting hours - particularly blue light - has been shown to disrupt the circadian rhythm and suppress the production of the hormone melatonin, which enables the release of the restorative hormones. Melatonin suppression is implicated in certain types of breast and prostate cancers.

Therefore the precautionary principle suggests that the trespass of light into sleeping areas may be an area of concern. This is a subject of significant scientific interest and ongoing research. This is particularly true for light sources with a high colour temperature (above 3000K), which is true for some compact fluorescent lamps, blue LEDs and some white LEDs. White LEDs have a strong blue component that is combined with other colours to produce white light. The ideal solution is to prevent light trespass by properly shielding nearby sources, such as security and street lighting. In areas of heavy light pollution, opaque curtains are advisable. Bedroom night lights should be as dim possible and red or amber in colour.

Further reading on Health Effects of LED Street Lights issued by Toronto Public Health can be found at Built Environment page on the City of Toronto official website: www1.toronto.ca/wps/portal/contentonly?vgnextoid=4e-ca7a1ba20c8510VgnVCM10000071d60f89RCRD

The natural 24-hour cycle of light and dark helps maintain precise alignment of circadian biological rhythms, the general activation of the central nervous system and various biological and cellular processes, and synchronize of melatonin release from the pineal gland. Pervasive use of nighttime lighting disrupts these natural processes and causes potentially harmful health effects.



Most white LEDs operate by generating blue light which is then absorbed and re-radiated over a range of wavelengths to simulate white light. However, it has a large component of blue light, which is the wavelength most likely to cause potentially harmful health effects.

Reference: American Medical Association Report 4 Of The Council On Science And Public Health (A-12) Light Pollution: Adverse Health Effects of Nighttime Lighting



Sleeping

Photo Credit: Gabriel Guillen

Appendix F: Glossary (1)

Ballast An electrical device for controlling the current in a gas discharge lamp.

Bollard A lighting fixture, consisting of a short, ground-mounted post with light source at the top. Bollard lighting can be effective as path illumination because it is close to the ground. To be effective, the light from the bollard must be directed downward.

BUG Rating A method of describing the output direction of light from a source, an alternative to the Cutoff rating. See Appendix B.

CIE Commission Internationale de l'Eclairage — International Commission on Illumination. An international body for standards in illumination, based in Vienna, equivalent to IESNA.

CRI Colour Rendition Index (CRI) of a light source is a measure of its ability of to show object colours as they would appear in natural light. Incandescent lamps have a CRI of 95, fluorescent of 65, LEDs between 20 and 90. Notice that CRI is not a measure of colour temperature.

Colour Temperature A numerical value, in Kelvin, characterizing the colour of light from a source. Values over 4000K, have a cool, blue-white hue. Lower values, like 3000K and below, have a warmer hue, similar to an incandescent lamp.

Cones Photodetector cells in the human eye that activate at a high level of illumination. Cones are concentrated in the centre of the detecting area of the eye (the retina) and are responsible for colour and photopic vision. Cones, rods and pRGCs are responsible for the human detection of light.

CPTED Crime Prevention Through Environmental Design, the concept that crime may be reduced through careful design of the urban environment – including lighting. See Appendix H, page 76.

Cutoff Rating	A method of describing the output direction of light from a source. See Appendix B.
Dark Adaptation	The process of the human eye adjusting to low levels of light to aid night vision. Dark adaptation occurs slowly and is destroyed quickly by exposure to a bright source of light.
Dark Sky Fixture Seal of Approval	Dark Sky Compliant fixture must have the Dark Sky Fixture Seal of Approval which provides objective, third-party certification for lighting that minimizes glare, reduces light trespass and doesn't pollute the night sky. If a Dark Sky Fixture Seal of Approval is not available fixtures must be full-cutoff and with a with a colour temperature rating of 3000K or less.
Foot-candle	The unit of measurement of illuminance in the imperial system, now obsolescent. 1 foot candle = 10.7 lux.
Gigawatt-Hour	A unit of energy, equal to 1000 Megawatt-Hours.

Glare	The sensation of seeing a light source which is much brighter than its surroundings, sufficient to cause discomfort or disability in vision. A glare source may be measured by its luminance (brightness) in candela per m ² .
HID Lamp (High Intensity Discharge)	A source of light that is created by passing an electrical current through a gas, typically neon, mercury vapour or sodium. HID lamps have a greater luminous efficacy than incandescent lamps.
IESNA	Illuminating Engineering Society of North America. IESNA standards are commonly used to establish street lighting levels.
Illuminance	A unit of measurement that describes the amount of light that falls on a particular area. It is commonly used to characterise the effectiveness of lighting illumination. The metric unit of measurement is lux. (see also foot candle).
Incandescent Lamp	A source of light that is created by heating a metal (usually tungsten) to a white-hot temperature. Incandescent lamps have low luminous efficacy, so they are not used in street lighting.

Appendix F: Glossary (2)

Induction Lamp A high-power fluorescent lamp, suitable for street lighting.

Kelvin A unit of temperature measurement based on an absolute thermodynamic temperature scale (zero degrees celsius is equal to 273 Kelvin).

LED Lamp (Light Emitting Diode) A source of light that is created by passing an electrical current through a semiconductor material. The light source is tiny compared to HID and incandescent sources.

Light Pollution The unwanted intrusion of light from a source on one property, across a boundary, into another property. Light trespass is characterized by horizontal or vertical illuminance (in lux), or luminance (in candela per m²) measured at the property line.

Light Trespass A unit of energy, equal to 1000 Megawatt-Hours.

Lumen Metric unit of luminous flux from a light source.

Luminaire A unit of measurement that describes the amount of light that is emitted from a particular area, within a solid angle. Luminance indicates how bright the source will appear to the human eye. It is measured in metric units (candela per m²).

Luminous Efficacy The luminous efficacy of a light source is a measure of its efficiency in producing light, for a given input in electrical power. It is measured in lumens per watt.

Luminosity Function The luminous efficacy of a light source is a measure of its efficiency in producing light, for a given input in electrical power. It is measured in lumens per watt.

Lux Metric unit used to measure the level of illuminance. (See table in page 38 for typical values of illuminance.)

Megawatt Hour	A unit of energy measurement. This is equal to 1000 kilowatts of electricity used continuously for one hour.
Melatonin	A hormone secreted by the pineal gland that is involved in the regulation of sleeping and waking cycles and enables the release of other restorative hormones.
Mesopic Vision	The image generated by the human eye for light levels between photopic and scotopic vision. Mesopic vision applies for night time illumination of streets in residential neighbourhoods.
Milky Way	The galaxy containing the planet Earth and its solar system, visible from non-light polluted locations as an arch of stars overhead.
Overlighting	Light levels that exceed those necessary for proper vision.

Photopic Vision Metric unit of luminous flux from a light source.

Precautionary Principle If an action or policy has a suspected risk of causing harm to the public or the environment, the burden of proof that it is not harmful falls on those taking an action that may or may not be a risk.

Photosensitive Retinal Ganglion Cells pRGCs are a type of neuron in the human retina. They play a major role in synchronizing circadian rhythms to the 24-hour light/dark cycle and contribute to the regulation of melatonin from the pineal gland. Cones, rods and pRGCs are responsible for the human detection of light.

Rods Light sensitive cells in the human eye that activate at low level illumination – so called scotopic vision. Rods are more sensitive than cones, but do not respond to colour. Rods are located in the periphery of the detecting area of the eye. Cones, rods and pRGCs are responsible for the human detection of light.

Appendix F: Glossary (3)

Scotopic Vision The response of the eye to different colours. The eye is most sensitive to green, with decreasing sensitivity to colours at the extremes of the spectrum – violet and far red. The response curve changes with light level.

Shielding A descriptive term for light fixtures, used to indicate the degree to which the light is directed properly and shielded from causing glare, light trespass and sky glow.

Sky Glow Illumination of the night sky by wasted light, most noticeably above cities, towns and some rural industrial sites.

Smart Lighting A feature of lighting fixtures that enables them to be dimmed or turned off when they are not needed. For example, street lighting can be reduced late at night. Smart lighting has the potential to substantially reduce energy consumption and reduce light pollution.

Uniformity Ratio A measure of the evenness of illumination within a given area, often applied to street lighting. Equal to the ratio of average to minimum illumination.

Urban Star Park A city park in which the lighting is designed to support viewing of the night sky.

Wall Pack A wall-mounted light fixture that shines horizontally. Wall packs are often used to light an area near a building, such as a parking lot. When used that way, they cause considerable glare.

Appendix G:

Image Locations for Effective and Ineffective Lighting

Locations shown in Effective and Ineffective Lighting, pages 20 and 21.
Listed clockwise, starting in upper left corner.

Effective lighting: Toronto and Vaughan (page 20)

- 1) Path light Queens Quay West near Westin Hotel
- 2) Full cutoff street lamp St Clair Avenue West near Caledonia Road
- 3) Smart Centre near Bathurst Street and Rutherford Avenue
- 4) Full cutoff street lamp St Clair Avenue West near Avenue Road
- 5) Spot light Queens Quay West near Spadina Avenue
- 6) Full cutoff fixtures near Coxwell and Danforth Avenues
- 7) Full cutoff fixture near The Queensway near HWY 427
- 8) Smart Centre near Bathurst Street and Rutherford Avenue (bus shelter lighting)
- 9) Leslie Street south of Lake Shore Boulevard
- 10) Fairview Mall near Don Mills Road and Sheppard Avenue East
- 11) Yorkdale Shopping centre Dufferin Street near HWY 401 (Central photo)

Ineffective lighting, Toronto: (page 21)

- 1) Mill Street near Parliament Street
- 2) Bloor Street near Runnymede Street
- 3) Caledonia Road south of Lawrence Avenue
- 4) Lake Shore Boulevard near Carlaw Avenue
- 5) Fairview Mall near Don Mills Road and Sheppard Avenue East
- 6) Withrow Park
- 7) Queens Quay West near Bathurst Street
- 8) Bay Street and Wellington Avenue
- 9) Hogarth Avenue near Bayview Avenue
- 10) Queens Quay Terminal
- 11) Toronto Music Park on Queens Quay West
- 12) Bay Street near Lake Shore Boulevard (Central photo)

Appendix H: CPTED Notes on Safety and Security

CPTED (Crime Prevention through Environmental Design) Guideline <http://cptedontario.ca>

- When creating lighting design, avoid poorly placed lights that create blind-spots for potential observers and miss critical areas. Ensure potential problem areas are well lit: pathways, stairs, entrances/exits, parking areas, ATMs, phone kiosks, mailboxes, bus stops, children's play areas, recreation areas, pools, laundry rooms, storage areas, dumpster and recycling areas, etc.
- Avoid overly bright security lighting that creates blinding glare and/or deep shadows, hindering the view for potential observers. Eyes adapt to night lighting and have difficulty adjusting to severe lighting disparities. Using lower intensity lights often requires more fixtures.
- Use shielded or cut-off luminaires to control glare.
- Place lighting along pathways and other pedestrian-use areas at proper heights for lighting the faces of the people in the space (and to identify the faces of potential attackers).
- Light areas where needed.
i.e. parking spaces versus parking aisles.

Appendix I: Glare Standard

To avoid glare, the recommended maximum ratio of a light source to its surrounding area is 100:1 [1]. However, this cannot be applied to light sources at night since the surrounding is close to zero and any light source whatsoever exceeds this ratio. Glare is closely related to the brightness of a light source: technically, the luminance of the light source, expressed in candela per square metre (cd/m²).

Osterhaus [2] shows a luminance limit that depends on the angle from the viewer. Close to on-axis, the suggested limit is 582 cd/m². Off axis by 45 degrees the limit is 2570 cd/m².

Linney [3] suggests a luminance limit of 1500cd/m². This threshold seems to correspond reasonably well to the threshold of discomfort for a light source viewed on-axis.

There are many other definitions of glare, some highly technical and difficult to apply without specialized equipment such as computer analysis of light levels and the geometry of the lighting arrangement.

The single-figure limit of 1500cd/m² has the great virtue of simplicity and corresponds reasonably well to perceived glare. We recommend this level as the maximum allowed brightness of a visible light source.

Appendix J:

Further Reading

Light Pollution in General Guidelines and Bylaws

Skyglow

The first World Atlas of
the artificial night sky brightness
P. Cinzano, P F. Falchi and C. D. Elvidge
Mon. Not. R. Astron. Soc. 328, 689-707 (2001)
www.lightpollution.it/cinzano/download/0108052.pdf

Light Pollution and Energy

Natural Resources Canada,
Office of Energy Efficiency
[oee.nrcan.gc.ca/corporate/statistics/neud/dpa/
tablestrends2/res_ca_1_e_4.cfm?attr=0](http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/res_ca_1_e_4.cfm?attr=0)

Light at Night and Human Health

Ecological Consequences of
Artificial Night Lighting
Catherine Rich, Travis Longcore,
Editors Island Press, 2006
ISBN 1-55963-129-5

Property Standards

Chapter 629 of the Municipal code
www.toronto.ca/legdocs/municode/1184_629.pdf

Green Development Standard

www.toronto.ca/planning/environment/pdf

Bird Friendly Development Guidelines

www.toronto.ca/lightsout/pdf/development_guidelines.pdf

Best Practices Bird Friendly Glass

[www1.toronto.ca/CityOfToronto/CityPlanning/
Environment/Files/pdf/B/BFBestPracticesGlass_
FinalAODA.pdf](http://www1.toronto.ca/CityOfToronto/CityPlanning/Environment/Files/pdf/B/BFBestPracticesGlass_FinalAODA.pdf)

Sign Bylaw Project

www.toronto.ca/signbylawproject/index.htm

Ontario Building Code

www.ontario.ca/laws/regulation/120332

City of Toronto Accessibility

Design Guidelines

[www.toronto.ca/parks/pdf/engagement/accessibility_
guidelines.pdf](http://www.toronto.ca/parks/pdf/engagement/accessibility_guidelines.pdf)

Urban Star Park Guidelines (RASC-USP)

Royal Astronomical Society of Canada,
www.rasc.ca/dark-sky-site-guidelines

Appendix J: Further Reading con't

Outdoor Lighting Manual for Vermont Municipalities

Chittenden County Regional Planning Commission, 1996

Dark Sky and Efficient Lighting Community Handbook

Strathcona County , Alberta

www.strathcona.ca/files/Files/at-CPIA-Dark-Sky-Energy-Efficient-Lighting.pdf Further Reading (3)

Applied Scotobiology in Luminaire Design

R. Dick, Lighting Research Technology.2014;Vol. 46: pp. 50-66

www.csbg.ca/articles/APPLIED_SCOTOBIOLOGY.PDF

Guidelines for Outdoor Lighting

R. Dick, Summer 2013

www.csbg.ca/articles/GOL.PDF

The Contribution of Street Lighting to Light Pollution

Peter D. Hiscocks, Sverrir Guomundsson
Journal of the Royal Astronomical Society of Canada,
October 2010, pp 190-193

Urban sky glow affects daytime pollution levels

environmentalresearchweb.org/cws/article/news/44690

Results of Modelling Sky Glow

C. Baddiley

www.baddileysuniverse.net/ModelResults.aspx

Image of Toronto at Night: Image Science and Analysis Laboratory, NASA-Johnson Space Center.

“The Gateway to Astronaut Photography of Earth.”

eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS026&roll=E&frame=12469

The BUG System: A New Way to Control Stray Light from Outdoor Luminaires

International Dark Sky Association

www.aal.net/content/resources/files/BUG_rating.pdf

Lighting systems using Light-emitting Diodes: Health Issues to be considered

ANSES: French Agency for Food, Environmental and Occupational Health and Safety, 2010

www.anses.fr/Documents/PRES2010CPA14EN.pdf

WUS Department of Energy

apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_energy_efficiency.pdf

Glare, References

[1] Recommended Luminance Ratios And Their Applications In The Design Of Daylighting Systems For Offices. Werner Osterhaus, 2002

[2] Design Guidelines for Glare-free Daylight Work Environments
Werner Osterhaus, 2009

[3] Maximum Luminances and Luminance Ratios and their Impact on Users' Discomfort Glare Perception and Productivity in Daylit Offices, Andrew Scott Linney \ Thesis, Victoria University of Wellington, Master of Building Science, 2008.
researcharchive.vuw.ac.nz/bitstream/handle/10063/651/thesis.pdf

[4] Measuring Luminance with a Digital Camera
Peter Hiscocks, 2011
www.ee.ryerson.ca/~phiscock/

[5] Luminance Calibration with JPEG-Encoded Images
Peter Hiscocks, 2012
www.ee.ryerson.ca/~phiscock

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Toronto Green Standard

Compliance

Best Practices



Toronto Green Standard



PLANNING A GREAT CITY
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