A **CANADIAN URBAN INSTITUTE** PROGRAM

LIGHTSAVERS CANADA

LED LIGHTING FOR PARKING FACILITIES

A LIGHTSAVERS PRIMER

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I. INTRODUCTION

1. PURPOSE

This primer provides a practical guide for parking lighting managers for converting their lighting to light emitting diodes (LEDs). It outlines the reasons to consider converting to LEDs relative to incumbent technologies, the factors to address in a business case, design standards, the importance of an in-house champion, the technical aspects of procurement and commissioning and options for financing, including incentives. The lighting options covered are LED linear tubes and low bay canopy lamps for parking garages and outdoor parking area lighting. The issues related to adaptive controls are also included. Related reference material to be used in conjunction with this primer is listed in Appendix A. This LED parking lighting primer is made possible by financial contributions from Natural Resources Canada (NRCan) and the Independent Electricity System Operator (IESO).

2. LEDS IN PARKING LIGHTING

Canadian parking area lighting has been dominated by high pressure sodium (HPS), metal halide (MH) and fluorescent luminaires[1]. However, LED technology is emerging as an energy efficient replacement option for traditional lighting, offering significant energy, economical, safety and environmental benefits. LEDs emit more lumens per Watt and reduce light wasted on untargeted areas through their directional lighting. Although requiring a higher capital cost, effective implementation of LEDs can result in energy savings between 30-70%, increased service life, lower maintenance costs and enhanced lighting quality.

According to the 2015 parking lighting scan performed by LightSavers[2], Canada has up to 7.8 M parking lights, comprising approximately 3.6 M in parking lots and 4.2 M in garages. Ontario alone is estimated to have between 1.4 M and 2.7 M parking lights.

Parking lot lighting is similar to streetlighting in application, with the most common existing practice being HPS. For streetlighting, LEDs are the most common technology for new installations and retrofits at end of life. LED lighting's demonstrated performance in streetlighting and the decreasing supply cost is raising the interest for LED applications in new and retrofit parking installations. LED lights are more efficient, longer-lasting and provide better light colour. For example, the owner of a 120,000 sq. ft. parking lot in Pittsburgh retrofitted 157 250-Watt HPS fixtures with 70 dimmable LEDs and reduced electricity use by 87% and annual energy bills by $25,400.[3] .

Parking garage lighting has been slower to adopt LEDs partially due to the availability of energy efficient linear fluorescent lamps (LFLs). T8 LFLs offer competitive energy savings and service lives, but are reaching their maximum technological potential and are limited in their control and dimming abilities. Previous major trials on T8 LED tube trials have focused on indoor office applications and have not consistently found them to outcompete LFLs.[4] Parking garage trials have demonstrated significant reduction in energy consumption and maintenance costs. A 195-stall Ontario parking garage replaced 148 T12 fluorescents with 185 LED tubes to a result of 35% in energy savings.[5] With advancements in lighting regulations and qualified products lists, LED implementation is evolving as an accessible and beneficial lighting option for retrofits and new builds.

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[1] *Technical Bulletin No. 8: Parking Lighting(2006)*. Canadian Parking Association. http://www.canadianparking.ca/files/Bulletin_8%20Parking%20Lighting.pdf?1317663266
[2] *The Markey for LED Lighting In Canada's Parking Infrastructure (2015).* LightSavers. www.canurb.org/lightsavers
[3] *LEDs and bi-level controls deliver healthy 87% energy savings at the Contra Costa County Pittsburg Health Center parking lot (2012)*. http://etap.energy-solution.com/wp-content/uploads/2012/04/ETAP_ContraCostaCounty-Bi-levelLighting_CaseStudy.pdf
[4] *CALiPER Application Summary Report 21: Lienar (T8) LED Lamps (2014)*. US Department of Energy (DOE). http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_21_t8.pdf
[5] *Hanard Investment Ltd. Parking Garage LED Scale-up (2015).* LightSavers. www.canurb.org/lightsavers

II. THE VALUE PROPOSITION

1. OPPORTUNITIES

The main drivers for LED conversion of parking lighting are potential energy and cost savings, reduced maintenance and improved public safety. This is a short summary of the various benefits that can be achieved for parking facilities.

1.1. ENERGY AND GHG SAVINGS

Energy savings were the initial driver for using LEDs. Energy conservation translates to cost savings and reduced greenhouse gas (GHG) emissions. Potential savings vary between types of lamps being replaced. . Table 1 below presents potential energy savings of LED conversion examples relative to the most common incumbent parking lights (linear fluorescents, HPS fixtures and MH area lights) without controls.

Table 1: Potential energy savings of LED retrofits of parking lighting

Incumbent Fixture Example	Typical LED Replacement	Potential Energy Savings
175 W MH	70 W LED area lights	60%
100 W HPS	55 W LED light-bars	45%
40 T12 Fluorescent	22 W Linear LED	45%
32 W T8 Fluorescent	22 W Linear LED	30%

Further energy savings of up to 30% can be obtained through installation of adaptive controls. Controls are implemented to limit lighting energy use to only what is required. Often luminaires emit excess light at the beginning of their service lives to ensure design levels are met at the end. Controls are used to dim areas that are over lighted because of this, or because of historically over-cautious lighting designs. Controls can also match light levels to usage, such as pedestrian or vehicle traffic. Typical incumbent technologies have restricted controllability as they are limited by the specifications of their ballast. For example, fluorescent, HPS and MH lamps require a dimmable ballast for dimming abilities, which is currently not common practice. The majority of LED luminaires are manufactured to be fully dimmable and are well suited to controls.

1.2. REDUCED MAINTENANCE REQUIREMENTS

The second largest contributor to LED cost savings is reduction in maintenance due to increased service life and prolonged warranties. These result in longer periods between luminaire replacements and minimal costs for lamp failures during warranty coverage. LED technology potentially has the longest rated lumen-maintenance life, defined by IES as the elapsed operating time in hours when the specified percentage of lumen depreciation or lumen maintenance is reached.[6] Table 2 outlines ranges of the expected service life for common incumbent technologies and LEDs. LEDs have the potential to extend lighting life by two to ten times.

Table 2: Expected lumen-maintenance life of different lighting technologies

Lighting Source	Lumen-Maintenance Life (hours)
Metal Halide	8,000 – 20,000
High Pressure Sodium	15,000 – 40,000
Linear fluorescents	20,000 – 40,000
LED	50,000 – 100,000

[6] *Approved Method: Measuring Lumen Maintenance of LED Light Sources (2008).* IES. Purchase at: http://www.ies.org/store/

End of life occurs when the lighting source no longer operates correctly. For HPS, MH and fluorescent lights this is characterized by the lamp going out and/or not restarting (referred to as catastrophic failure). There is a low probability of catastrophic failure for LED technology, so end of life is typically considered to occur when lumen output reaches 70% of its initial value. Replacement of a single parking lamp can be a significant cost for asset managers as it often includes labour costs of qualified technicians. Planned group relamping is common practice to reduce these costs and minimize the chance of individual catastrophic failure. However, this shortens the operational life of luminaires that may have lasted longer. As catastrophic failures of LEDs are not expected (and should be covered under warranty should they occur), lighting managers have the potential to achieve full economic life of the product and schedule planned group relamping. Maintenance costs are also reduced with the extended warranties provided by manufacturers, often significantly longer than those for existing lighting technology. It is recommended to attain a five year warranty for any LED product at minimum, with some outdoor parking area LED lighting offering ten years.

1.3. IMPROVED PUBLIC SAFETY AND AESTHETICS

Improving safety, when existing illuminance no longer meets lighting standards and/or poor lighting quality comprises security, is a common reason for retrofitting HID parking lighting. According to IES RP-20-14, parking facility lighting should provide recommended minimum illuminance levels, along with reasonable quality.

Lighting quality is assessed based on colour rendition, colour temperature, glare and obtrusive light (see IES RP-20-14). The colour rendering index (CRI) measures a light source's ability to present an object's natural colour. Values range from zero to 100, where 100 indicates the most realistic colour rendering. A high CRI is important for both public safety and aesthetics. IES RP-20-14 recommends a CRI greater than 60 for applications requiring enhanced security, and a generally higher CRI for easy identification of vehicles. It should be noted that CRI measures can only be compared between separate light sources if their colour temperature is the same. The typical CRI values of different lighting technologies are presented in Table 3 below.

Table 3: Typical CRI values for common parking area lighting technologies

Lighting Technology	Colour Rendering Index
HPS	22-30 (yellow/orange glow)
T12 Fluorescent	62
T8 Fluorescent	85
MH	60-90
Indoor LED (DLC qualified)	80
Outdoor LED (DLC qualified)	65

Correlated colour temperature (CCT), recorded in Kelvin, measures how "warm" (2700 K to 3000 K) or "cool" (4000 K to 6500 K) a light source appears, where 4800 K represents direct sunlight. Most lighting technology has a broad range of colour temperatures available from 2600 K to over 6000 K, except for HPS which ranges from 1900 K to 2100 K and LED which can reach up to 10 000 K. For parking area lighting, case studies have shown positive public perception for LED conversions of HPS and MH, resulting in CCT of 3500 K and above. When choosing the lighting colour, asset managers should consider the blue light component as it is perceived brighter by the human eye than other colours under the same light levels. This can cause increased glare and circadian disruption. LED technology typically emits more energy in the blue part of the spectrum. Because to this, the International Dark-Sky Association recommends LED CCT does not exceed 4000 K.

For parking lot lighting, uplight (light emitted above 90 degrees), adds to undesirable sky glow, wastes energy and risks light trespass. As shown in Figure 1, the directional nature of LED lighting produces negligible obtrusive light and improves aesthetics by directly illuminating targeted areas. However, for flat panel or recessed light fixtures in parking garages, luminaires should direct 1-2% of light upwards to avoid causing a "cave-effect", which occurs when ceilings are not illuminated and can feel unsafe.

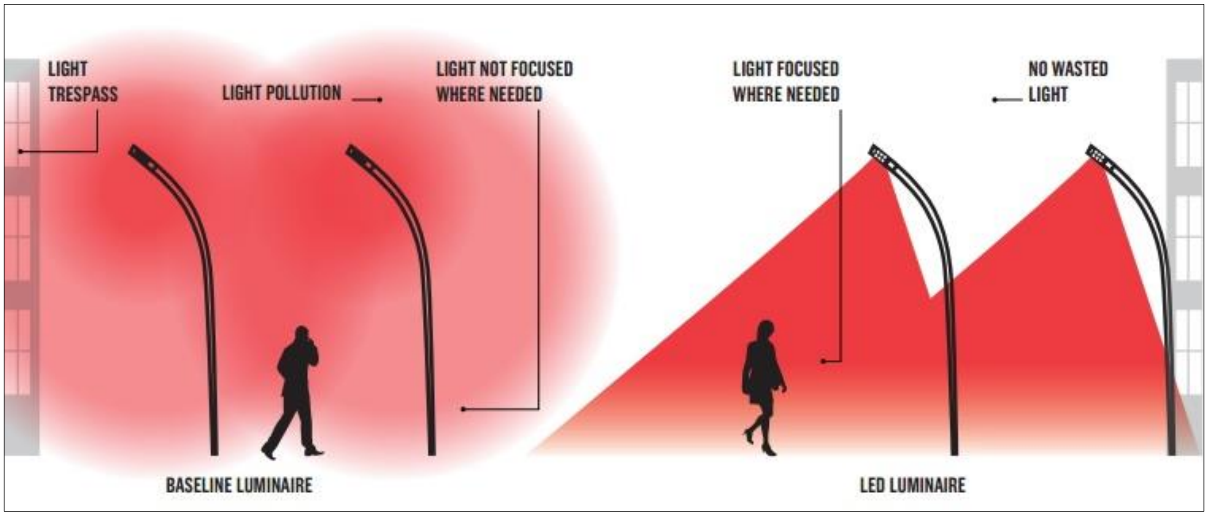

Figure 1: Benefits of directional LED lighting for outdoor areas[7]

2. CHALLENGES

As with any new technology, there are challenges to initial implementation. LED lighting has been shown to benefit the streetlight market but is it still a relatively new option for parking illumination, particularly in parking garages. The main challenges relate to project championing, initial capital costs, diverse technologies and thermal management.

2.1. CHAMPIONING

Any change needs a champion. A champion is someone who believes in the end-result and is prepared to overcome barriers to get there. The early adopters of LEDs were supported by incentive programs that made the business case easier to communicate to decision makers. Unlike streetlighting, parking areas are mostly privately owned and vary in site-conditions, meaning LED retrofits are often awarded on a site-by-site basis. One main champion in streetlighting can invoke a municipal-wide change. This would require many more champions which is often not realistic. An LED conversion will be more successful if it is part of a bigger organizational program with an in-house champion having decision making authority.

2.2. INITIAL CAPITAL COSTS

Likely the biggest challenge for lighting asset managers choosing to convert to LEDs is the capital cost. Although it may be the longest lasting lighting technology, it also has the highest initial cost per lumen. It may also be that the incumbent lighting has not been fully depreciated, resulting in additional capital cost incurred. Beyond capital cost, purchasers should consider the total ownership cost, which includes energy and maintenance costs throughout the life of the fixture, to find the most cost-effective option. As shown in Figure 2, LED fixture costs are decreasing

[7] *Global Outdoor LED Trials: Analysis for Lighting Managers.* LED: LightSavers. The Climate Group.
http://static1.squarespace.com/static/546bbd2ae4b077803c592197/t/552ea432e4b0e4e51050bceb/1429120050403/Meta-analysis.pdf

annually as the technology is advancing and becoming more widely implemented. This decreases the price gap between technologies and shortens the LED payback period.

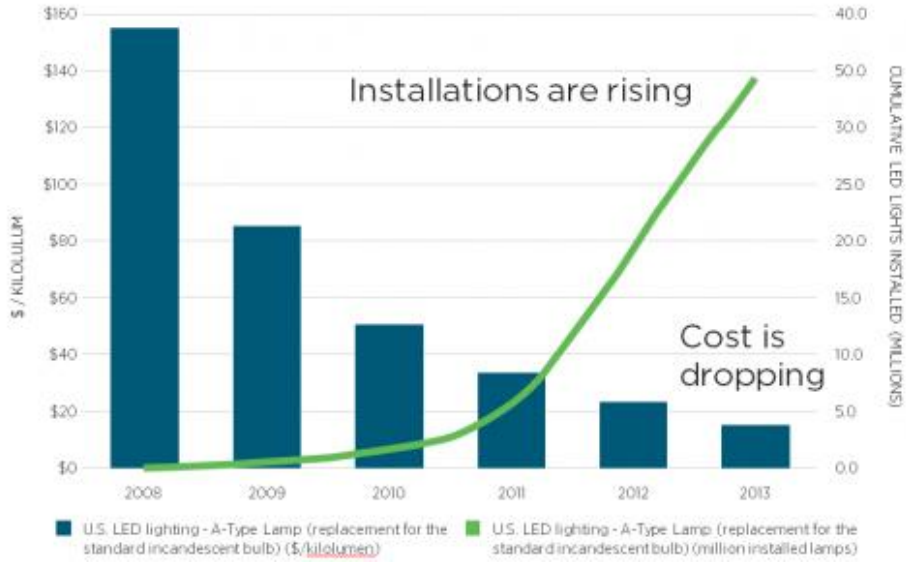

Figure 2: Average cost of LEDs per 1000 lumens and estimated number of LEDs installed in the U.S. (sourced from the U.S. Office of Energy Efficiency and Renewable Energy[8])

2.3. DIVERSE TECHNOLOGIES

The LED market for parking lighting involves substantial differences between wiring configuration, luminous intensity, construction and physical appearance. Replacement options for MH and HPS parking area luminaires are fairly standardized as the technology is well developed. Incumbent low bay canopy and overhead parking area fixtures can be retrofitted by removing the HID lamp and ballast and replacing these parts with an equivalent LED lighting source and driver. Replacing linear fluorescents in parking garages is not as straightforward because of the four viable types of linear LED retrofits. There are three different lamp options available to replace LFL in an existing fixture. These are classified by the Underwriter's Laboratory (UL) as Type A, B and C and further discussed in Section IV. Type C luminaires can also be packaged as complete troffer LED retrofit kits which replace entire fixtures. It is expected that as linear LED technology advances, one of the four options will outcompete the others in technical performance and cost. At present, lighting asset managers need to evaluate the options using cost-benefit analyses to determine which best suits their situation.

2.4. THERMAL MANAGEMENT

LED system designers and asset managers must be aware that the performance of many LED components is sensitive to the operating temperature. Improper thermal management has been one of the main causes of early LED failures. This is particularly important for outdoor parking areas and unheated parking structures where newer technology is being implemented. Outdoor incumbent technologies have advanced to mostly withstand changes in temperature, however, thermal management of LEDs is still progressing.

Colder temperatures usually strain incumbent lighting, whereas LED performance decreases with increasing temperature. Some characteristics experience recoverable change and others, such as service life, can experience non-recoverable degradation. Likely the most notable change is the light output. Relative luminous flux (percent of initial lumen output) will decrease up to a specified junction temperature (the maximum operating temperature of

[8] *Building Technologies Office 2014 Highlights(2015).* Office of Energy Efficiency and Renewable Energy. U.S. Department of Energy. http://energy.gov/eere/buildings/building-technologies-office-2014-highlights

the semiconductor), typically 150 °C, but past this temperature, catastrophic failure may occur. Figure 3 graphs this relationship using the Cree XLamp XB-D LED as an example. When procuring LEDs, product data sheets should be available to outline the luminaire's performance characteristics at varying temperatures.

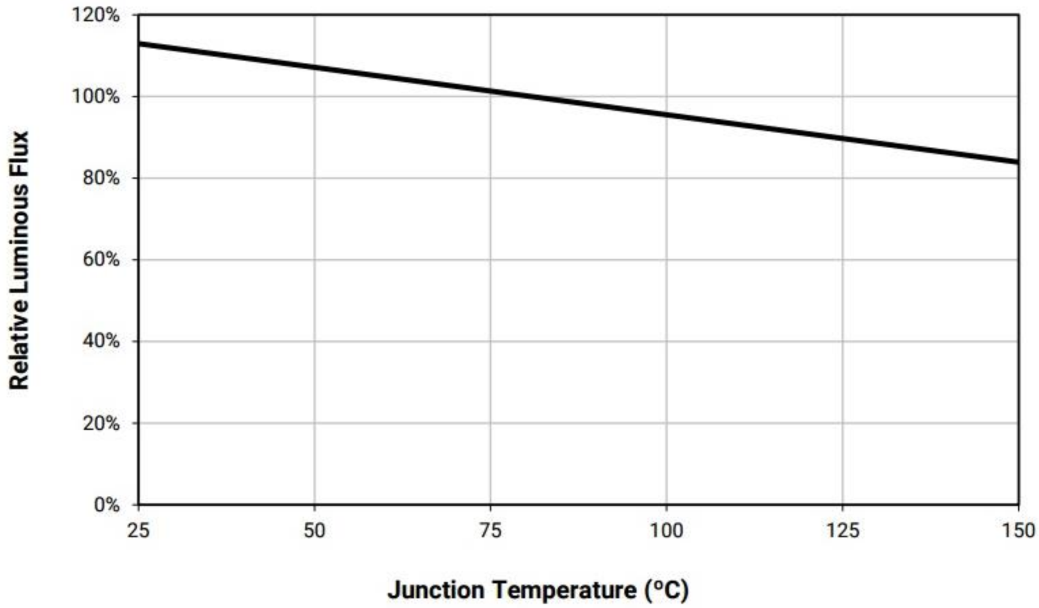

Figure 3: Relative flux depreciation of the XLamp XB-D with increasing junction temperature[9]

[9] *Product Family Data Sheet: Cree XLamp XB-H lEDs (2014).* Cree Inc. http://www.cree.com/~/media/Files/Cree/LED%20Components%20and%20Modules/XLamp/Data%20and%20Binning/ds%20XBH.pdf

III. PARKING LIGHTING DESIGN STANDARDS

Lighting requirements of parking areas are firstly determined by local municipal bylaws, and secondly by IES standards for conditions that may not be addressed in the bylaws.

LightSavers reviewed the parking lighting bylaws of five Canadian municipalities to analyse general trends. Safety and security are the primary issues addressed, with facial recognition being a key parameter. The average illumination requirement for parking structures is 54 lux (5.0 foot-candles) and for lots is 10 lux (1.0 foot-candle). These requirements are higher in some municipalities for areas of high crime, city-owned lots and 'big box' developments. Lighting uniformity standards are important for describing lighting pattern smoothness and outlining acceptable degrees of intensity of light and dark areas. These are expressed as illumination max to min or average to min ratios, with lower values representing more uniform lighting. All municipal bylaws reviewed set a max to min standard of 15:1 and an average to min standard of 4:1.

The municipal bylaws summarized above generally match the guidelines of the IES RP-20-14 Lighting for Parking Facilities. However, IES further differentiates according to ambient light characteristics of the surrounding environment light. Table 4 outlines five lighting zones for parking lots classified by IES RP-20-14. .

Table 4: IES classified lighting zones of parking lot surrounding areas

Zone I.D.	Title	Definition	Lighting Recommendations
LZ0	No ambient lighting	Surrounding areas will be adversely affected by lighting, such as disrupting biological cycles of flora and fauna. Human vision is adapted to total darkness.	• Extinguish lighting when not needed • Minimal lighting
LZ1	Low ambient lighting	Areas may be adversely affected by lighting. Human vision is adapted to low light.	• Uniform and continuous not required • Extinguish lighting after curfew
LZ2	Moderate ambient lighting	Areas of human activity where vision is adapted to moderate light levels.	• Lighting used for safety and convenience • Uniform and continuous not required • Match lighting to traffic after curfew
LZ3	Moderately high ambient lighting	Areas of human activity where vision is adapted to moderately high ambient lighting.	• Lighting used for safety, security and convenience • Uniform and/or continuous suggested • Match lighting to traffic after curfew
LZ4	High ambient lighting	Areas of human activity where vision is adapted to high light levels.	• Lighting required for safety, security and convenience • Mostly uniform and/or continuous • In some areas, lighting can be matched to traffic after curfew

IES standards also present lighting guidelines for both horizontal and vertical illuminances. Horizontal illuminance refers to lighting levels measured on ground surfaces and, historically, was the main lighting standard. Vertical illuminance refers to lighting levels measured when the meter head is oriented 90 degrees from nadir and is, on average, 1.5 m from ground. Vertical illumination controls visibility of vertical objects, such as pedestrians, and is important for facial recognition abilities.

For parking lots, IES recommended illuminance values are given for five different lighting zones at pre- and post-curfew times. Curfew time refers to the time in the morning when outdoor lighting is turned off. These values are outlined across three different applications, as shown in Table 5.

Table 5: IES RP-20-14 Recommended maintained illuminance values for parking lots

Application*	Schedule	Recommended Maintained Illuminance Targets (lux)		Uniformity Ratios	
		Horizontal Min	Vertical Min	Avg:Min	Max:Min
Asphalt Surfaces LZ1, LZ2, LZ3 & LZ4	Pre-curfew	5	2.5	4:1	15:1
	Post-curfew	2	1	4:1	15:1
Concrete Surfaces LZ1, LZ2, LZ3 & LZ4	Pre-curfew	10	5	4:1	15:1
	Post-curfew	2	1	4:1	15:1
Transaction Areas LZ1, LZ2, LZ3 & LZ4	Pre-curfew	10	5	4:1	15:1
	Post-curfew	2	1	4:1	15:1

*LZ0s for all applications have minimum recommended illuminance of 0 lux and no uniformity guidelines

As shown by Table 5, the average municipal standards meet or exceed IES recommendations for parking lots. Minimum illuminance standards are higher in bylaws for areas with high crime risk.

Parking lot lighting should also minimize backlight, uplight and glare rating. Specific guidelines for these are presented in IES RP-20. Backlight and uplight of outdoor lighting fixtures are defined in Figure 4. Glare obstructed vision caused by excessive brightness, with effects varying between individuals. There are two general types of glare. Discomfort glare creates a sensation of annoyance or possible pain, whereas disability glare impairs vision without discomfort. To minimize effects of backlight, uplight and glare, IES RP-20 outlines acceptable standards for each parameter under the BUG (Backlight, Uplight and Glare) rating system.

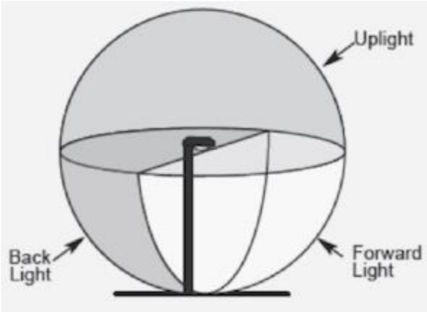

Figure 4: Backlight and uplight emitted by a typical HID outdoor light[10]

IES recommended illuminance values for parking garages are outlined in Table 6 (where sections are empty, there is no recommended value). These guidelines now consider the use of occupancy sensors. If garage lighting does not include sensors, the standards for minimum illuminance and uniformity ratios are taken as the "motion" scenario.

[10] *Figure sourced from* all LED lighting *in 7 LED Terms of Art You May Not Know (2013).* http://www.allledlighting.com/author.asp?section_id=543&doc_id=561029

Table 6: IES recommended maintained illuminance for parking garages

Application	Occupancy Sensor or Schedule	Recommended Maintained Illuminance Targets (lux)		Uniformity Ratios	
		Horizontal Min	Vertical Min	Avg:Min	Max:Min
General Areas	Motion	10	5		10:1
	No motion	2	1		10:1
Drop-off/Pick-up & Vehicle Transaction Areas	Motion	10	5	4:1	10:1
	No motion	2	1	4:1	10:1
Lobbies, Elevators & Pedestrian Transaction Areas	Motion	15	7.5		5:1
	No motion	2	1		5:1
Scheduled Events Operation of Pedestrian Areas	Motion	40	20		5:1
	No motion	2	1		5:1
Vehicle Entries & Exits*	Daytime	500	250		10:1
	Nighttime	10	5		10:1
Pedestrian Stairs*	Pre-curfew	50	25	4:1	
	Post-curfew	25	12.5	4:1	

*Occupancy sensors do not meet standards for these areas

As shown by Table 6, the average municipal parking garage illuminance bylaw of 54 lux exceeds IES targets for all areas of a garage, except for vehicle entries and exits that must be greater to ease visual adjustment from daylight to indoors. Of the municipal bylaws analysed, four did not address vehicle entries and exits specifically, and parking area managers are recommended to follow IES standards.

IES standards identify lighting controls as a method of energy conservation, however, the majority of municipal Codes do not yet include specifications for them and require constant illumination of garages. Toronto parking lighting bylaws were rewritten to include controls in 2011 after a parking garage LED trial that included the use of controls was completed by the Toronto Community Housing Corporation (TCHC) in 2011.They now allow the use of sensors as long they are designed for fail-safe operation, are not impaired by the presence of smoke, and control an area no larger than 240 square meters.

IV. TECHNICAL PROCUREMENT

Procurement complexity differs between new and retrofit installations. New installations for LEDs are less complex and can be procured in essentially the same manner as any other light source – with specifications developed for the required light properties, lifespan, warranties, etc., and proposals obtained to meet them. For retrofits, as discussed in Section II, procurement differs in complexity depending on the incumbent fixture, especially for garage lighting.

1. LIGHTING SPECIFICATIONS

Procuring LED retrofits or new installations should start with defining the desired outcomes such as lighting levels. Then specifications to deliver these outcomes should be developed outlining the requirements for materials, technical performance and installation. These criteria should incorporate industry standards and municipal regulations. The *Model Technical Specifications for Procurement of LED Luminaires in Canada*[11] by LightSavers Canada is also good reference. Previous parking LED case studies such as those summarized in Appendix B can be used to understand the issues to be addressed.

Examples of some key specifications for parking lot and garage luminaires that meet or exceed IES and DesignLights standards are as follows (confirm most recent specifications during project design phase):

1.1. PARKING LOT LIGHTING

i. Luminaire shall, at minimum, meet the lighting levels and uniformity requirements of the local municipal Codes.
ii. Luminaire shall be qualified by the DesignLights Consortium.
iii. Luminaire manufacturers shall provide photometric reports per IES LM-79-08.
iv. Manufacturer shall provide a minimum five year warranty for lumen output.
v. Luminaire shall pass the 3G vibration test per ANSI C136.31.
vi. LEDs shall have a CCT of 4000 K ± 500 K.
vii. The colour rendering index shall be a minimum of 65.
viii. Illuminance shall be limited to 90°.
ix. Minimum initial luminaire efficacy (the amount of lumens emitted per watt) shall be 85 lm/W.
x. The luminaire shall have a maximum total harmonic distortion (THD) of 20% at full input power.
xi. Luminaire shall be rated for -20 °C to +40 °C operation.
xii. Luminaire shall be UL-listed for wet locations.
xiii. Driver shall have expected service life of 100,000 hours at full load with 25 °C ambient temperature.
xiv. Coating for housing finishes shall meet or exceed a rating of six per ATSM D1654 after 1,000 hours of Salt Fog testing per ASTM B117.

1.2. PARKING GARAGE LIGHTING

i. Luminaire shall, at minimum, meet the lighting levels and uniformity requirements of the local municipal Codes.
ii. Luminaire shall be qualified by the DesignLights Consortium.
iii. Luminaire manufacturers shall provide photometric reports per IES LM-79-08.
iv. Manufacturer shall provide a minimum five year limited warranty for lumen output.
v. Luminaire shall pass the 3G vibration test per ANSI C136.31.
vi. LEDs shall have a CCT between 3500 K and 4000 K

[11] *Model Technical Specification for Procurement of LED Luminaires in Canada Version 2.0 (2015).* LightSavers Canada. http://www.canurb.org/lightsavers/

vii. The colour rendering index shall be a minimum of 80.
viii. Illuminance cutoff shall occur at 24° on the driver approach side to minimize disability glare.
ix. Suspended luminaires shall provide 1-2% illuminance as uplight to mitigate the "cave-effect".
x. Minimum initial luminaire efficacy (the amount of lumens emitted per watt) shall be 85 lm/W.
xi. The luminaire shall have a maximum total harmonic distortion (THD) of 20% at full input power.
xii. Luminaire shall be rated for -30 °C to +50 °C operation.
xiii. Luminaire shall be UL-listed for, at minimum, damp locations.
xiv. Luminaire shall be mounted at a minimum height of 7 feet.
xv. Driver shall have expected service life of 100,000 hours at full load with 25 °C ambient temperature.

2. LUMINAIRE INSTALLATION

A key difference between LEDs and all but incandescent lights is in how the applied voltage is controlled. In fluorescent, MH and HPS fixtures a ballast regulates current supplied to the lamp and provides, briefly, high voltage to start illumination. For LEDs, a driver regulates the power supplied to adjust for changes in the electrical properties of the luminaires in response to temperature. All drivers should have dimming capabilities, whereas only specialized ballasts are dimmable. Ballasts and drivers are similar in that they ultimately control the connected lamp's service life. They are expected to have a longer maintenance life than luminaires, however, if they fail this is considered end of life for the entire lighting fixture as maintenance is required.

Typical new and retrofit LED and driver options are described below for parking lots and garages.

2.1. PARKING LOTS

Installed LED parking lot lights are typically high-mounted area lights for shoebox style, cobra-head or other fixture types. For new installations, procurement usually involves purchasing the luminaire, fixture type and pole as one product. For retrofits, LEDs generally use existing fixtures and poles. The exception is when existing housing does not provide adequate thermal management. In this case, manufacturers may offer entire retrofit kits. For simple retrofits, replacing HID luminaires with LEDs takes an average of 15 to 20 minutes and follows these basic steps:

1. De-energize the luminaires at breaker.
2. Open lens frame and remove existing lamp from housing.
3. Unplug, disconnect and remove existing ballast.
4. Install LED driver.
5. Install LED lighting source threaded into the existing socket and connected to the driver.
6. Remove LED protective covering and close lens frame.

Each LED luminaire will come with product-specific instructions that are more detailed and may vary from above.

2.2. PARKING GARAGES

LED lighting options for garages are more diverse than those for lots. Typically LED garage canopy/ceiling luminaires or linear LED tubes are used.

For a garage canopy fixture, the existing lamp and ballast can be simply replaced by an LED luminaire and its corresponding driver using a similar method as presented for simple parking lot retrofits. Entire fixtures can also be replaced and is recommended if the lighting system is significantly aged and/or new wiring is required.

LED tubes are typically used to replace linear fluorescents lamps (LFLs) but can also replace other HID lighting. There are four retrofit options. The first is to replace the entire fluorescent troffer with a LED retrofit kit (including a new fixture). For lamp-to-lamp replacements, there are three different types of linear LEDs suitable, classified by by the Underwriters' Laboratory (UL) as the following[12]:

Type A
These contain an internal driver which operates using the existing LFL ballast. These are sometimes called "plug-and-play" luminaires, as they require the simplest installation process and replace T8 fluorescents bulb-for-bulb. No electrical or structural modifications are needed. However, the LED service life, certifications, dimming abilities and controllability are restricted to those of the existing LFL ballast. Luminaire efficiency is also reduced due to power used and lost by the ballast. Type A lamps are not compatible with all LFL ballasts; the existing fixture's compatibility must be evaluated prior to retrofitting.

Type B
These contain an internal driver that is powered by the main voltage supply. Existing ballasts are removed and luminaires are wired directly to the sockets. Type B LEDs require less maintenance and are more energy efficient than Type A because they are not restricted by the LFL ballast, and do not lose energy through it. However, installation of Type B LEDs is generally more expensive because it requires electrical modifications and presents increased danger with possible exposure to the main line voltage. Type B products are also still limited in dimming capabilities.

Type C
These operate with a remote driver to power the LED. Electrical modifications are required to replace the existing ballast with the driver. Installation is safer than Type B because the low-voltage driver is connected to the socket and not the line voltage. This is the most efficient type of linear LED luminaire; is highly compatible with existing LFL fixtures; and can have full dimming capabilities. However, capital costs are highest for Type C replacements.

Out of the four options, the best linear LED performance in parking garages is achieved through entire fixture replacements. Complete fixtures are the only option for LED tube installations for new construction. However, for retrofits, complete fixtures have the greatest procurement and installation costs. As mentioned in Section II, Owners should assess total ownership costs to fairly evaluate each LED conversion option.

3. ADAPTIVE CONTROLS

Adaptive lighting controls are technical solutions for adjusting the light output to the amount actually required to achieve design standards[13] If local bylaws permit, adaptive controls can be integrated with LED installations to increase energy savings. If bylaws do not permit, Owners should still consider implementing a lighting system with control compatibility and/or executing a controls trial to demonstrative their effectiveness. The technology is rapidly becoming common practice.

For parking lots and garages the following four types of controls are typically used:

1. **Photocontrols/photosensors** control luminaire operation in response to the amount of natural light (infrared and/or ultraviolet) detected. In above ground parking garages, photosensors are used for daylighting when direct sunlight can illuminate the structure to meet requirements. IES recommends a sensor mounted 5 ft. high at a distance of 10-20 meters from the perimeter. When the photocontrol detects vertical illumination to be double the minimum requirement, luminaires from the sensor forward are turned OFF or dimmed. In parking lots, photocontrols turn ON lights at sunset. Owners

[12] *Considering LED Tubes(2014).* General Electric (GE) Lighting. http://www.gelighting.com/LightingWeb/na/images/16339-GE-LED-Tube-Lighting-Refit-Solutions-Whitepaper_tcm201-69385.pdf
[13] *Adaptive Controls for Roadway and Parking Lighting: A LightSavers Primer (2015).* LightSavers Canada. http://www.canurb.org/lightsavers/

must ensure photocontrols implemented are compatible to LEDs as some are sensitive to the high inrush of current.

2. **Time clock controls** are often used with photocontrols to turn garage and lot lights OFF (or percent dimmed) at a certain time of night, usually at what is considered after business hours. They measure the length of each night and adjust themselves as the seasons change.
3. **Astronomical time clock controls** predict times of sunset and sunrise to turn turn ON and OFF luminaires based on a parking area's latitude and longitude. They benefit from not needing to be outdoors to sense sunlight, however, cannot detect the effects of heavy clouds or shadowing.
4. **Occupancy sensors/motion detectors** are used more commonly in parking garages than lots, and control luminaire operation in response to vehicle and pedestrian traffic. IES recommends implementation of sensors at key points of entry, as well as throughout the interior. They can enhance security by signalling presence of movement to pedestrians. Motion detectors use either passive infrared, ultrasonic or a combination of both sensors. In garages with concrete walls, passive infrared sensors are recommended as the concrete may absorb the ultrasonic waves.

Adaptive controls can be installed to control individual fixtures or as a networked system. The latter is most effective and common in modern designs. As a network, controls can communicate interactively with each other and other equipment. Luminaires can be controlled as a single group, separate groups or individually. Interactive systems also have the ability to monitor, diagnose and report luminaire issues. Factors they can report include ON/OFF status, loss of power and/or communication, internal temperature, energy consumption, light source failure, total time energized and time to next relamping. Controls will either be wired (with line voltage control wires or low voltage wires), often less expensive for new construction, or wireless. Wireless signalling increases the flexibility of a system but may also increase costs.

V. BUILDING THE BUSINESS CASE

A business case is typically based on a comparison of benefits, costs and risks. Either a simple payback analysis or a lifecycle cost analysis (LCCA) can be used to determine the financial benefits to be expected from LED lighting designs for parking. The payback method ignores operating and maintenance expenses over the life of the fixture, which are key components in evaluating long-lasting technology. A LCCA includes the return on investment (ROI), which can be total cost of ownership or total value of ownership, including maintenance costs, energy costs and inflationary pressures.

Generally, business cases will support LEDs as replacements for HPS and MH technology as these scenarios have been thoroughly tested and shown to significantly reduce energy consumption and costs. Championing LED conversions of linear fluorescents is more challenging because of linear LEDs being a newer technology, and the business case likely showing a smaller return on investment (ROI). Like incentives for streetlighting, incentives for on-site trials can be used to determine the best conversion to LEDs from fluorescents.

As with all technological advancements, purchasers may fear that a system just acquired will become obsolete as soon as it is installed. With energy saving technologies however, the trade-off is that the longer you wait to take action, the more energy you will waste. This cost, although not often considered, should be included in business cases involving energy conserving technologies.

1. LIFECYCLE COST ANALYSIS (LCCA)

Performing a LCCA is a thorough method to compare the benefits, costs and risks of different lighting designs. For basic understanding, the key steps of a LCCA are listed below, taken from the Life-Cycle Costing Manual for the Federal Energy Management Program (1996)[14]:

1. Define problem and state objectives
2. Identify feasible alternatives
3. Establish common assumptions and parameters
4. Estimate costs and times of occurrence for each alternative
5. Discount future costs to present value
6. Compute and compare LCC for each alternative
7. Compute supplementary measure if required for the project prioritization
8. Assess uncertainty of input data
9. Take into account effects for which dollar cost or benefits cannot be estimated
10. Advise on the decision

For reference, the case studies presented in Appendix B include the economic analysis conducted for each project.

The most clearly defined financial benefits are energy cost savings and reduced maintenance cost over a defined period. An analysis should be taken over a long enough period to account for the relatively long life of the LED fixtures. The highest return is typically going to be achieved in locations with continuous lighting, such as parking garages. An associated social benefit is the reduction in greenhouse gases. This will be highest where the electricity generation has a high GHG component.

The cost factors to be considered in evaluating different lighting systems include:

[14] *The Life-Cycle Costing Manual for the Federal Energy Management Program (1996).* National Institute of Standards and Technology (NIST). http://www.nist.gov/customcf/get_pdf.cfm?pub_id=907459

- Installation cost of the system
- Energy costs (including any change in rate structure offered by the electricity utility) which should consider the avoided cost achieved by replacing the incumbent technology
- Maintenance costs for the lighting system, as well as the control equipment and support network
- Expected life of the equipment
- Incentives that may be available for the installation

The non-energy benefits are rarely considered in the business case, and it will take some time for the experience to develop to monetize safety or comfort benefits. A LCCA considers the energy savings, equipment costs and maintenance or replacement costs and timing required for the implementation of LED lighting. It does not consider the cost of a crash or a vehicle-caused fatality, and it assumes that the safety level is not affected by the changes to the lighting technology.

The associated risks of LED installations to be analysed include:

- Reliability of the supplier
- Accuracy of the energy consumption predictions
- Percent product failure before end of service life
- Installation complexity
- Increased electricity rates

Experience has shown that for any lighting equipment, some luminaires arrive from the supplier not functioning. It is recommended that asset managers ensure either the manufacturer's or shipping warranty covers this failure. Furthermore, outlined specifications of the lighting source are not always met in practice. There is a higher risk of this with newer technology, but is reduced in LED products that are ENERGYSTAR or DesignLights qualified. Typically, five percent of LED products are expected to fail during their service life, for which the warranty will cover the units that fail within the warranty period. Owners are also recommended to ensure luminaire installers are experience with the type of LEDs being used as complex electrical modifications may be required.

2. COSTING TOOLS

To complete the economic analysis, LightSavers recommends using one of the following three tools to determine what lighting design is more economical in the long-term.

The **National Institute of Standards and Technology's Building Life-Cycle Cost (BLCC)** software performs the LCCA for energy and water conservation projects. The software expands on the methodology and criteria outlined by the Federal Energy management Program (FEMP) to compute the lifecycle costs of two or more alternative designs. The U.S. DOE CALiPER program used BLCC to evaluate the present value lifecycle cost and payback for linear LED lamps installed in existing fluorescent troffers.
The program and relevant support material is found at: http://energy.gov/eere/femp/building-life-cycle-cost-programs.

The **Street and Parking Facility Lighting Retrofit Financial Analysis Tool** was developed by the U.S. DOE MSSLC in partnership with the Clinton Climate Initiative and FEMP. It specifically evaluates energy-efficient lighting alternatives by computing energy and energy-cost savings, maintenance savings, GHG reductions, net present value and simple payback. Including GHG emission calculations is not common for financial tools and encourages the quantification of non-energy benefits. This program requires fairly detailed lighting and structure data and may be too complicated for initial estimations.
The program and relevant support material is found at: http://energy.gov/eere/ssl/retrofit-financial-analysis-tool

The **Super-efficient Equipment and Appliance Deployment (SEAD) Street Light Evaluation Tool** is a Canadian Excel-based program developed by CLASP. It calculates the expected energy use, light performance and lifecycle cost of streetlighting upgrades. The program is simpler than the MSSLC Retrofit Tool but is limited to outdoor lighting used both in roadway and parking lot areas, but can be a good starting point for the economic analysis of any lighting retrofit project.
The program and relevant support material is found at: http://superefficient.org/sltool

3. PROVINCIAL INCENTIVES

Government and utility incentives can play a critical role in the business case for new installations or retrofits with LEDs and/or adaptive controls. Throughout Canada, most rebates and incentives are awarded on a municipal basis and parking area managers should research their local opportunities. The Provinces of British Columbia, Ontario and Québec offer generic energy load reduction incentives. The programs in effect at the time of writing (July 2015) are as outlined below.

3.1 BRITISH COLUMBIA

The **Power Smart Partner Program** of BC Hydro offers programs and incentives for mainly commercial and industrial businesses. As part of this the Power Smart Express program provides partial financing for replacements of inefficient technologies with energy-efficient alternatives, including lighting. The Eligible Configurations List outlines product replacements for certain existing lighting technology that are eligible for incentives. LEDs are classified based on their initial lumen output and wattage.

Details are found at: https://www.bchydro.com/powersmart/business/programs/express.html

BC Hydro also offers implementation funding; a project (or a bundled of projects) qualifies if:

- annual energy savings are estimated at a minimum of 50,000 kWh from proven energy saving technology, where the project is measurable and sustainable; and
- the project is hardwired or permanent in nature and has an estimated payback of greater than two years before incentives.

Details are found at: https://www.bchydro.com/powersmart/business/programs/partners/project-implementation.html

3.2 ONTARIO

The Independent Electricity System Operator (IESO) manages the **SaveONenergy** conservation programs and benefits for homes and businesses implementing energy-saving measures. As part of the SaveONenergy Retrofit Program, businesses are eligible for the greater of either $400/kW of demand savings or $0.05/kWh of first year electricity savings for lighting projects which comply with the following:

- an estimated demand reduction of 1 kW or first-year annual energy savings of 2,000 kWh; and
- energy savings incurred for at least 48 months.

Details are found at: https://saveonenergy.ca/Business/Program-Overviews/Retrofit-for-Commercial.aspx

SaveONenergy also outlines general lighting and adaptive controls incentives for lights that are ENERGYSTAR certified and fixtures that are DLC certified. Small businesses can apply for:

- the first $1,500 in lighting upgrades to be funded, along with potential financial incentives covering 50% of the remaining project; and
- up to $40 per occupancy sensor.

Details are found at: https://saveonenergy.ca/Business/Program-Overviews/Lighting-Incentives.aspx

There are also prescriptive measures available for outdoor lights based on a unit incentive cost per fixture.

3.3 QUEBEC

Hydro Quebec has several **Energy Efficiency Programs**, including Buildings and Industrial Systems programs. Buildings smaller than 10,000 m^2 are eligible for at least $2,500 in financial assistance for energy conserving projects. Retrofit projects for industrial systems are eligible for the smallest of these three amounts:

- $0.15/kWh savings;
- 50% of total costs; or
- amount required to reduce payback to one year, with cost recovered solely with energy savings.

More details are found at: http://www.hydroquebec.com/business/energy-efficiency/programs/

Incentives and rebate programs change regularly; Owners must determine their eligibility on a case-by-case basis.

VI. COMMISSIONING

Commissioning involves initiating a new system, monitoring performance and modifying components to meet expectations. As defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 202-2013[15], co-sponsored by IES, commissioning is:

> *A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements.*

This is important for long term functionality and sustaining performance quality. As outlined by IES DG-29-11 (see Appendix A), there are four typical phases to the commissioning process, each described below[16].

1. PRE-DESIGN PHASE

Commissioning begins prior to project design to ensure objectives and requirements are well defined and easily monitored throughout the entire project process.

1.1 COMMISSIONING TEAM

Prior to designing the new lighting system, a Commissioning Team is formed. This group includes a Commissioning Authority, the owner, lighting designer and other professionals as needed. The Commissioning Authority can be in-house but is recommended to be third-party consultant to promote objective commissioning. The team develops the Commissioning Plan to be implemented throughout the process.

1.2 COMMISSIONING PLAN

This is a project-specific roadmap that outlines Commissioning procedures including a schedule of activities and major milestones. It assigns roles and responsibilities to each team member, and establishes how project quality will be verified and documented.

1.3 OWNER'S PROJECT REQUIREMENTS (OPR)

This is developed as a formal pre-design commissioning document and identifies the expected end results of the lighting project as defined by the owner. Initial requirements can be listed in broad or specific detail depending on the owner's objectives. This document acts as common reference throughout the completion of the design and construction processes.

2. DESIGN PHASE

The design phase is when concepts and strategies for the lighting system become increasingly detailed and specific. Following completion of the OPR, the design team develops the Basis of Design (BOD) document to outline how the project design plan will fulfill requirements. This includes descriptions of the lighting system (and controls system if used), energy efficiency targets, manufacturers and maintenance requirements. The Commissioning Team, along with the owner, reviews the BOD to confirm compliance with the OPR. Once approved, functional test procedures and documentation formats are developed to monitor the commissioned components of the lighting system.

[15] *Standard 202-2013 – Commissioning Process for Buildings and Systems (2013).* ASHRAE (ANSI approved; IES co-sponsored). Purchase at: http://www.techstreet.com/ashrae
[16] *Summaries of the commissioning phases are based off: Introduction to The Commissioning Process (2012).* Lighting Controls Association. http://lightingcontrolsassociation.org/introduction-to-the-commissioning-process/

3. CONSTRUCTION PHASE

It is the responsibility of the Commissioning Team to coordinate and direct commissioning activities during the construction phase using consistent protocols and documentation. Commissioning work will mainly be completed by the contractor and design team.

3.1 PERFFORMANCE TESTING

During installation, the contractor will follow procedures outlined by the design team to test the new lighting components to ensure they meet performance requirements. This typically involves the following six actions:

1. **Equipment verification** to certify procured lighting equipment arrives onsite in approved condition. This can be done through random sampling of each product to test it meets the manufacturer's specifications.
2. **Installation verification** to certify equipment is installed per the approved design plan.
3. **System activation** to program, calibrate and adjust the lighting system based on site conditions and OPR.
4. **Functional testing** to certify equipment operation fulfills BOD and owner's criteria.
5. **Resolving installation issues** by the contractor prior to project completion.
6. **Owner approval** of all test reports.

3.2 SYSTEMS MANUAL

In preparation for post-installation operation, the Commission Team develops a Systems Manual for the owner's reference. This is a composite document that details the operation and maintenance requirements of the new lighting system. It is used during the occupancy and operations phase of the project to confirm performance benchmarks, programming, calibration settings and manufacturer information. Along with providing a Systems Manual, in-house personnel may also require training of new operations and maintenance procedures.

4. OCCUPANCY AND OPERATIONS PHASE

On-going commissioning is recommended post-installation. The owner and other in-house personnel can use the Systems Manual developed in the construction phase to ensure the lighting system meets the OPR and to access the resources necessary if the system fails. It is also recommended that the original Commissioning Team revisits the installation site after 10 months to conduct evaluation on the operating system. At this time, the Team can revise commissioning procedures if needed and resolve outstanding problems.

VII. APPENDICES

APPENDIX A: RELATED REFERENCE MATERIALS

As LED is an evolving technology, lighting asset managers should reference product qualifications, guidelines and related resource banks during the procurement process. They should also evaluate available incentive programs and the technical qualifications required for eligibility.

The following resources are applicable for LED parking lighting (confirm most recent versions):

1. QUALIFICATION LISTS

a) ***DesignLights Consortium (DLC) Qualified Products List (QPL)***
Provides a list of commercial LED products which have met the DLC's minimum performance, energy efficiency and other requirements. As of July 2015, there were just over 114,000 products listed, including linear LED bulbs and fixtures for garages. It should be used as a secondary resource after the ENERGY STAR qualified products list.
https://www.designlights.org/QPL

b) ***ENERGY STAR Certified Products***
A U.S. Environmental Protection Agency (EPA) program that certifies energy efficient products based on third-party testing in EPA-recognized laboratories. As of July 2015, ENERGY STAR listed just under 9,000 certified LED light fixtures and almost 6,000 certified LED light bulbs. These lists do not yet include outdoor linear LEDs or troffer LED retrofit kits for parking garages.
https://www.energystar.gov/products/certified-products

2. RELATED RESOURCES

a) ***Alliance for Solid-State Illumination Systems and Technologies (ASSIST)***
A collaboration group started by the Lighting Research Center to encourage adoption of solid-state lighting (SSL) by providing researched information on SSL. Publications include: *Recommendations for Evaluating Parking Lot Luminaires.*
http://www.lrc.rpi.edu/programs/solidstate/assist/

b) ***American National Standards Institute (ANSI)***
This is a standards organization that has established Committee C136 for street and outdoor lighting products. It is made up of users and manufacturers, and handles about 50 standards.
http://www.ansi.org/

c) ***Better Buildings Alliance***
A consortium developed by the U.S. Department of Energy (DOE) to promote energy efficiency in commercial buildings. Applicable resources include technical specifications for parking lot and structure lighting.
https://www4.eere.energy.gov/alliance/

d) ***Canadian Parking Association (CPA)***
A national organization for parking facility managers and suppliers to improve parking management through knowledge sharing.
http://www.canadianparking.ca/

e) ***Illuminating Engineering Society (IES or IESNA)***
A North American professional association with a chapter structure with members across Canada and the US. They prepare lighting design standards through committees.
http://www.ies.org/

a) ***Lighting Facts website***
A program of the U.S. DOE that provides information on lighting manufacturers and their LED products. The listed manufacturers distribute reliable and tested products along with performance reports.
http://www.lightingfacts.com/

f) ***International Commission on Illumination***
A United Nations body based in the UK with international representation to develop and/or contribute to standards development.
http://www.cie.co.at/

g) ***Municipal Solid-State Street Lighting Consortium (MSSLC)***
A North American consortium established by the US Department of Energy as a user's group (owners and power utilities) to allow members to share technical specifications, financing guides and demonstrations related to LED street and area lighting demonstrations and evaluate new products on the market intended for those applications.
http://energy.gov/eere/ssl/doe-municipal-solid-state-street-lighting-consortium

h) ***Use of Occupancy Sensors in LED Parking Lot and Garage Applications: Early Experiences***
A report prepared for the U.S. DOE that describes in-field experiences of occupancy sensor installations on LEDs in two parking garages and two parking lights.
http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21923.pdf

3. APPLICABLE GUIDELINES AND STANDARDS

a) ***Better Buildings Alliance (BBA) High-Efficiency Troffer Lighting Specification***
A factsheet of specifications developed for LED and fluorescent troffers in commercial lighting.
https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/troffer_factsheet.pdf

b) ***Better Buildings Alliance LED Site Lighting Performance Specification***
Specifications developed by the BBA and Pacific Northwest National Laboratory for LED conversion of high-intensity discharge (HID) parking lot lighting.
https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/led-site-lighting-performance-specification.pdf

c) ***CBEA High-Efficiency Parking Structure Lighting Specification***
Issued in 2012 by the Commercial Building Energy Alliance (CBEA), now the BBA, this document outlines lighting specifications for replacing HID lights with more energy efficient options in parking garages.
http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/creea_parking_structure_spec.pdf

d) ***CPA Technical Bulletin No. 8: Parking Lighting***
A document prepared in 2006 to present general guidelines to consider when designing parking lighting systems. It provides basic information on different lighting sources and where is best to apply them.
http://www.canadianparking.ca/files/Bulletin_8%20Parking%20Lighting.pdf?1317663266

e) ***IES G-1-03 Guideline of Security Lighting***
A document prepared by the IES as a guideline for design and implementation of security lighting, including illuminance requirements for various property types.
Purchase at: http://www.ies.org/store/

f) ***IES DG-29-11 The Commissioning Process Applied to Lighting and Control Systems***
Requirements for commissioning procedures, methods and documentation of newly constructed lighting and control systems to achieve performance expectations.
Purchase at: http://www.ies.org/store/

g) ***IES LEM-7-13 Lighting Controls for Energy Management***
Outlines energy-saving strategies, design considerations, equipment, communication protocols and commission for lighting control systems installed in interior and exterior areas.
Purchase at: http://www.ies.org/store/

h) ***IES LM-79-08 Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products***
An approved method for procedures and precaution of reproducible measurements of total luminous flux, electrical power, luminous intensity distribution and chromaticity.
Purchase at: http://www.ies.org/store/

i) ***IES RP-20-14 Lighting for Parking Facilities***
Recommended guidelines developed by IES for the design of fixed lighting in parking lots and multi-level parking structures.
Purchase at: http://www.ies.org/store/

j) ***IES RP-31-14 Recommended Practice for Economic Analysis of Lighting***
Provides first- and second-level analysis methods used for determining the business case for less familiar lighting technologies.
Purchase at: http://www.ies.org/store/

k) ***IES TM-15-11 Luminaire Classification System for Outdoor Luminaires + Addendum A***
A Technical Memorandum to characterize backlight, uplight and glare ratings.
Purchase at: http://www.ies.org/store/

l) ***IESNA LM-64-01 Guide for the Photometric Measurement of Parking Areas***
Provides information and guidance on lighting measurement practices for parking areas.
Purchase at: http://standards.globalspec.com/std/997508/ies-lm-64

m) ***Model Lighting Ordinance (MLO)***
Developed by IES and the International Dark-Sky Association (IDA) to provide recommended practices for communities lacking anti-light-pollution laws and ordinances
http://www.ies.org/PDF/MLO/MLO_FINAL_June2011.pdf

n) ***Model Technical Specifications for Procurement of LED Luminaires in Canada, Version 2.0***
A LightSavers guide on LED performance, electrical and mechanical criteria, focussing on streetlighting but can be applied to parking area and garage lighting with minor adjustments.
http://www.canurb.org/lightsavers/

APPENDIX B: CASE STUDIES

1. AJAX GO TRANSIT STATION

In 2013, GO Transit built a new above ground parking garage in Ajax Ontario. Following their commitment to sustainable practices and previous LEED certified structures, GO installed 900 high-efficiency LEDs for the 6-level garage's interior and exterior lighting system.
Details:

Description	Value
Parking garage size	1000 stalls
Total number of LEDs installed	900
Operating hours - Exterior - Interior	 4380 hrs / yr 8760 hrs / yr
LED service life	11 to 23 yrs
Average electricity rate of the City	$0.11 / kWh
Total garage construction cost	$44.8 M
Annual energy savings (compared to HPS scenario)	42%
Simple payback	5 yrs

GO Transit capitalized on already existing development fund from the Provincial and Federal government that reduced the costs of initial installation.

2. HANARD INVESTMENTS

In 2013, Hanard Investments Ltd. retrofitted a multi-residential parking garage from 168 T12 linear fluorescent lamps to 370 LED tubes. The project was initially proposed due to safety concerns and the need for higher quality lighting.

Details:

Description	Value
Parking garage size	195 stalls
Total number of LEDs installed	370
Operating hours	8,760 hrs / yr
LED Service Life	6.5 yrs
Average electricity rate of the City	$0.11 / kWh
Capital cost (including installation)	$22,500
Annual energy savings	30,000 kWh (35%)
SaveONenergy incentive	$1,940

Along with the LED conversion, the walls were painted white to help increase lumen levels and visibility. The project has had positive public reactions, with many residents feeling safer.

3. LONDONDERRY MALL SHOPPING CENTRE

The Londonderry Mall in northeast Edmonton, AB, recently began a $100 M renovation project, which included LED conversion of the parking garage and lot lighting. The Property Manager, 20 Vic Management Inc., engaged Hammerschlag + Joffe electrical engineers to design a new LED lighting system to replace the 1000 watt incumbent fixtures.

Details:

Description	Value
LED Service Life	11 yrs
Average electricity rate	$0.11 / kWh
Capital cost	$900,000
Annual energy savings	2.4 MWh (81%)
Annual maintenance savings	$20,000
Annual Return on Investment	35%
Simple payback	3 yrs

Replacing the parking lighting increased visual appearance and overall lighting uniformity. Existing emergency lighting did not meet current Codes and was upgraded with the retrofit. Aesthetics were improved and expected to receive positive public reactions.

4. MAYFAIR SHOPPING CENTRE

The Mayfair parking garage LED project managed by Ivanhoé Cambridge was originally intended to improve security. The shopping centre in Victoria BC had 160 HPS fixtures, mostly 150 watt, replaced with 108 watt LEDs. The project was then expanded to replace 25 parking lot 150 watt HPS fixtures to 108 watt LEDs and 780 indoor 32 watt T8 fluorescents to 12 watt linear LEDs. The high wattage of the outdoor LEDs was chosen to ensure lighting levels were increased.
Details:

Description	Value
LED Service Life	11 yrs
Average electricity rate	$0.075 / kWh
Capital cost	$180,000
Annual energy savings	222,000 kWh
Annual energy cost savings	$16,700
Annual maintenance savings	$5,000
BC Hydro Incentive	$55,000
Simple payback	6 yrs

This project, completed in 2014, found LED lighting levels are not comparable to older lighting technologies; the same lumen output is perceived brighter from LEDs than HPS lamps. The overall retrofit was well received by the public who felt safer and more comfortable in the parking garage.

5. WALMART CANADA

The Mississauga-Meadowvale Supercentre in Ontario completed an LED retrofit project of its parking lot by 2014. Thirty-two 1,000 watt MH lights (four poles with eight luminaires each) were replaced with 32 Philips Roadview 270 watt LED fixtures. The retrofit included adaptive controls and a thermal management system to increase LED lifetime.

Details:

Description	Value
Parking lot area	250,000 sq. ft.
Operating hours	4,200 hrs / yr
LED Service Life	100,000 hrs
Capital cost	$67,000
Annual Energy savings	108,000 kWh
Annual electricity cost savings	$5,400
Annual maintenance cost savings	$29,000
Simple payback	3 yrs

The new LEDs also increased security with a brighter and safer appearance.

6. WALMART U.S.

In 2009, Walmart installed its first LED parking lot lighting design as part of the newly constructed Leavenworth, Kansas Supercentre. Walmart worked with the U.S. DOE Solid-State Lighting Technology GATEWAY Demonstration Program to evaluate LEDs as an alternative to either 1,000 watt MH or 400 watt MH luminaires. LEDs selected were GE Lighting products that reduced energy consumption by at least 50%.

Details:

Description	Value
Parking lot area	500,000+ sq. ft.
Operating hours	4,200 hrs / yr
LED Service Life	10 years
Leavenworth melded electricity rate (**A**)	$0.056 / kWh
Average national electricity rate (**B**)	$0.1022 / kWh
LED energy savings - from 1,000 W MH - from 400 W MH	 71% 56%
Simple payback with electricity rate **A** - from 1,000 W MH - from 400 W MH	 4.6 yrs 2.7 yrs
Simple payback with electricity rate **B** - from 1,000 W MH - from 400 W MH	 2.7 yrs 1.9 yrs

Since this initial project, Walmart continues to use LEDs in new parking lot constructions, with over 300 projects as of April 2012.

7. UNIVERSITY HEALTH NETWORK

The Toronto General Hospital, owned and operated by the University Health Network (UHN) in Ontario, had 180 and 125 watt MH parking lighting fixtures converted to 79 and 53 watt LEDs, respectively. Prior to the retrofit in

2014, UHN performed a detailed analysis on available lighting technologies, including trialing a variety of LEDs. The Philips QLP G3 LED fixture was chosen.

Details:

Description	Value
Parking garage size	37,700 sq. ft. (74 stalls)
Total number of LEDs installed	68
Operating hours	8,760 hrs / yr
LED Service Life	11 yrs
Average electricity rate of the City	$0.11 / kWh
Capital cost	$35,000
Annual energy savings	52,000 kWh (56%)
Annual maintenance savings	$5,000
Lifecycle savings	$41,800
Simple payback	3 yrs

Retrofitting the hospital's underground parking garage was initiated by the need to replace aging technology. The existing MH fixtures were frequently failing and emitted poor lighting quality and distribution. The retrofit also improved security and public comfort.