

Canadian National Railway

CN Milton Logistics Hub Project

*Lighting Comparison Report for
Lighting Colour Temperature*

Prepared by:

AECOM Canada Ltd.
300 Water Street
Whitby, ON L1N 9J2
Canada

T: 905 215 1400
F: 905 668 0221
www.aecom.com

Canadian National Railway Company
935 rue de la Gauchetière Ouest
Montréal, Quebec, H3B 2M9

Date: October 01, 2020

Project #: 60579933

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Kristina Boka, P. Eng.
Manager, Design and Construction

August 28, 2020

Darren Reynolds
Director, CN Rail

Project #
60579933

Canadian National Railway Company
935 rue de la Gauchetière Ouest
Montréal, Quebec, H3B 2M9

Dear Ms. Boka / Mr. Reynolds:

**Subject: CN Milton Logistics Hub Project
Lighting Comparison Report for
Lighting Colour Temperature**

We are pleased to submit the Lighting Comparison Report for the CN Milton Logistics Hub Project for your review.

Sincerely,
AECOM Canada Ltd.

Aihua Zhang, P.Eng.
Senior Electrical Engineer
Aihua.Zhang@aecom.com

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Authors

<Original signed by>

Report prepared by:

Niketkumar Shah
Electrical Engineer, M.Eng., P.Eng.

<Original signed by>

Report reviewed by:

Aihua Zhang, P.Eng.
Senior Electrical Engineer, P.Eng.

Executive Summary

AECOM Canada Ltd. (AECOM) was retained by Canadian National Railway (CN) to provide engineering services for the CN Milton Logistics Hub Project (the Project). AECOM initiated preliminary design showcasing the location of high-mast poles and light poles in 2014-15. During the years from 2015 to 2020, AECOM progressed from 30% preliminary lighting design to the 90% detailed design.

In response to the IACC comments in the draft potential condition, Section 4.4, which states the evaluation of the amber light technology (assumed as 3000 K correlated colour temperature [CCT] light), CN has retained AECOM to evaluate amber light technology in comparison with white lights (5000 K CCT lights). The primary purpose of this report is to establish the impact on sky glow, glare, operational safety, cost implications, and impact on wildlife due to the application of the amber lights versus white lights.

New lighting calculations were undertaken for amber lights, as detailed in the report. Based on these calculations, a 2-3% reduction in the factor contributing to sky glow resulted in using amber lights. Moreover, both colour temperature lights are directed downwards with full cut off, i.e., no uplight, which is a more substantial contributor to sky glow. However, one of the studies reviewed suggested that amber light has a greater impact on the sky glow when viewed from a distance.

The compliance reports for the glare at the 26 receptors around the Project are included in appendices C and D. As per calculations; there is no difference in the glare intensity between amber and white lights.

The report also discusses the cost implications and safety aspects under amber and white lights. The white lights are lower in cost and more efficient as compared to amber lights. With the equivalent power consumption, white lights deliver higher output (in lumen) compare to amber lights. Also, the white lights are “scotopically enriched,” which means the space lit by white light when compared to that lit by amber lights will appear brighter to the human eye. A well-lit area is critical for people at the worksite to inspect work, read warnings and carry out other detail-oriented visual tasks, therefore increasing worker safety on site. Further, the report has included section on wildlife impact prepared by Stantec which discusses the adverse effect on wildlife due to lighting.

The report concludes with the results achieved from calculations of the five critical factors, namely sky glow, glare, operational safety, cost implications, and impact on wildlife. The amber lights are high in cost and have a negative impact on operational safety, whereas amber lights have a slightly lower impact on sky glow but no change in the glare. The calculations were carried out using the latest version of AGi32.

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1. Evaluation of amber lights in comparison to white lights

1.1 Introduction

This section of the report evaluates the feasibility of amber light, as required by draft Condition Section 4.4, regarding the use of lighting being a source glare and sky glow. Further, it discusses the cost implications of using white lights against amber lights and operational evaluation of using white lights for industrial applications such as an intermodal terminal. Herein, an amber light is assumed to have 3000 K correlated colour temperature (CCT), while white light is assumed to have 5000 K CCT. The amber light has a wavelength of around 550 nanometers, and the white lights have a wavelength of about 400 nanometers.

Following are the five critical factors are discussed in detail to address the impact of the amber and white light:

1. Impact on sky glow;
2. Impact on glare;
3. Cost implication;
4. Operational safety; and
5. Adverse impact on wildlife.

1.2 Impact on sky glow

Illuminating Engineering Society (IES) Recommended Practice RP-8-18 – Design and Maintenance of Roadway and Parking Facility Lighting defines the term sky glow as that used to describe added sky brightness caused by the scattering of light into the atmosphere.

In accordance with the Commission Internationale de l'Eclairage (CIE) 150:2017 – Guide on the Limitation of the Effects of Obtrusive Light, second edition, sky glow is dependent on the following two major factors:

- i. upward light ratio (ULR): the proportion of light emitted above the horizontal plane; and
- ii. upward flux ratio (UFR): the ratio of luminous flux above the horizon resulting directly from all the luminaires reflected from the surface area intentionally and unintentionally lit to the flux above the horizon in the ideal situation where lights are concentrated only to the surface area lit intentionally.

The calculations of these two ratios for amber lighting and white lighting are included in Appendices A.1 and A.2, respectively.

Based on these calculations, for a fixture with no light coming out at 90–110° (above the horizon)¹, the ULR is zero (almost all dark sky compliant lamps have ULR 0).

Eliminating light above the horizontal plane from 2% to 0% will significantly reduce sky glow by at least 95% for the distant observer. As a result, lamps with either amber or white light specified for the CN Milton Logistics Hub Project (the Project) have zero uplight, and so there is no contribution due to ULR in sky glow for both colour temperature lights.

¹ Refer to Figure A. 1 for lighting distribution for white and amber light fixtures

From Tables A.1 and A.2 of Appendix A, it can be concluded that there is a reduction of 2-3% in factors affecting sky glow by switching to amber lights, which, in turn, can reduce skyglow by a certain percentage. It should be noted that sky glow is dependent on the spectral emission being inversely proportional to the fourth power of the wavelength. Since white light has a larger component of the blue light spectrum, which has a shorter wavelength compared to the yellow light spectrum, blue light scatters more in the atmosphere compared to yellow light. It overlaps with the spectrum of starlight, making it difficult for observation. Additionally, sky glow is also dependent upon reflection of light from suspended vapour/particles in the atmosphere (such as fog, cloud cover and dust). Because of software limitations, spectral emissions (due to fog, cloud, dust, Etc.) have not been factored in the calculations. However, the SkyGlow simulator developed by Miroslav Kocifaj, a senior researcher at the ICA Institute of the Slovak Academy of Sciences, was used to model the impact of LED street lighting on sky glow by US Department of Energy². As per the study, the light sources with higher short-wavelength energy experience more scatter in the atmosphere; longer wavelengths tend to travel further and will have a greater impact on sky glow when viewed from a distance.

Overall, the amber lights will provide a small (2-3%) reduction in the factors affecting sky glow relative to white light.

1.3 Impact on glare

Glare is the visual sensation caused by excessive and uncontrolled brightness. Harsh or contrasting lighting conditions reduce humans, birds and other organisms' ability to see. The most common example of glare is oncoming high-beam headlights that provide ample light but paradoxically result in poor visibility, potentially reaching hazardous conditions. Excessively bright and improperly aimed floodlighting can have similar adverse effects on the perimeter of a project.

The unit of measure for brightness from sources that can become glare is that of luminance, which is lumen per steradian, which equals a candela (cd).

The calculation of lighting intensities for amber and white lights are provided in Appendices C and D; they are based on 26 receptor locations, as shown in Figure A.3.

Also, as the maximum value of light intensity is directly proportional to the distance between the observer and glare source, the greater the distance, the higher the allowances would be, and the lower the light intensity.

While running the calculations, the result shows that the glare values for both amber and white lights are similar irrespective of the colour of the light. Appendix C and D shows the calculated intensity for both the colour temperature lights.

² US Department of Energy. *An Investigation of LED Street Lighting's Impact on Sky Glow*. April 2017.

1.4 Cost Implication

Luminaire Cost – There is a greater difference between the cost of amber and white lights. As per the price received from the supplier, the amber lights are 13.5% more expensive than white lights.

Table 1 shows the total cost of the light fixtures for amber and white light.

Table 1: Number of required poles and fixture heads based on CCT

Fixture Type	Total Quantity	Per Unit Cost for Amber light (CAD)	Total Cost for Amber Light (CAD)	Per Unit Cost for White light (CAD)	Total Cost for White Light (CAD)
High mast fixtures	178	2,990	532,220	2,645	470,810
Low mast fixtures	90	1,127	101,430	980	88,200
Wall mount fixtures	6	803	4,818	582	3,492
Total			638,468		562,502

By replacing the white light fixtures with amber lights, no additional poles or luminaire will be required. Table 2 indicates the number of poles of varying heights (12-30 m) required for the amber and white lights. Also, it indicates that there is no need for any additional poles and luminaire fixtures to achieve similar lux levels as for white lights. The lighting levels are shown in table A.3 and A.6.

Table 2: Number of required poles for amber and white lights

Label	Number of required poles for amber and white lights
Access road to Britannia Road	21
Access road to Tremaine Road	5
Building parking	2
Electrical and miscellaneous	4
Inbound-outbound gate	23
Interconnect road to Tremaine Road and gate	2
Terminal	30
Truck parking lot	6

Light efficiency - The efficiency of white lights is better than that of amber lights in terms of lux per watt. White lights used for this Project have 131 lux per watt, while amber lights have 126 lux per watt. White lights are therefore 4% more efficient than amber lights with white light providing more light output for the same power consumption.

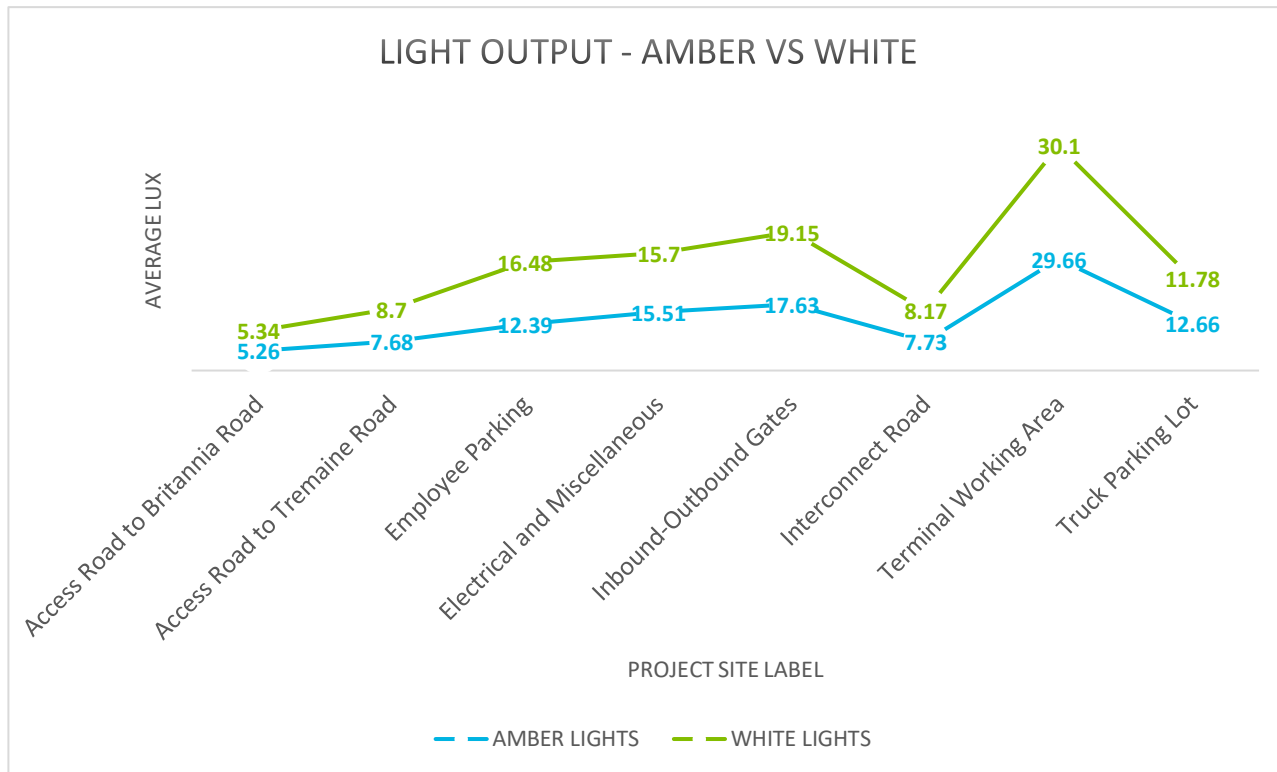


Figure 1: Achieved light levels for white and amber lights with equivalent wattage

Overall, for the same power consumption, white lights will have 4% more output lumen than amber lights. Moreover, amber lights will cost 13.5% more than white lights to construct for equivalent wattage. The operating cost for white light and amber light will be the same based on lumen maintenance and projected lamp life which is 100,000 hours and 242,000 hours respectively.

1.5 Operational safety

Visual Acuity– The Illuminating Engineering Society of North America (IES) has incorporated photopic, mesopic and scotopic as three ranges of human vision adaption level. These terms refer to the primary use of the cones, rods and/or other light-sensitive cells on the retina of the human eye. The cones give the fine visual acuity when one looks directly at something, but less precise peripheral vision, whereas rods are primarily responsible for giving the peripheral vision and providing information about contrast and movement.

The project site has different ranges of average lux for different areas. These range from 5 lux for an access road to 30 lux for the terminal area. The photopic which refers to cone vision generally covers the adaption of 30 lux and higher. The mesopic term refers to the range of human eye with both rods and cones active. It ranges from 1 lux to 30 lux. The scotopic refers to the range of human eye for rod vision and corresponds to adaption level below 1 lux. The peak sensitivity of the rod is at 507 nm in the blue-green part of the visible light spectrum.

Research indicates that the light that is white or cool in appearance, with more energy in the short-wavelength part of the spectrum, appears to be brighter than light that is warm in appearance. Such light sources are called “scotopically enriched” where greater stimulation of rods exists. The same space lit by white light will appear brighter

than the amber light to the human eye. Research³ has shown that for medium to high (photopic) light levels, it is easier to distinguish small details, warnings and colours under the white appearing light source. The white lights will be helpful for people at the worksite to inspect, read warning signs and undertake other detail-oriented visual tasks. For example, functions like seeing the container corner connectors so that the operator is sure they are secure. As far as safety is concerned, drivers get more reaction time under white lights compared to amber lights, which decrease the chance of collisions.

Cognitive performance – In the past, the light in the blue spectrum was not readily available and high-pressure sodium (HPS) or lower temperature lights were used extensively; however, due to technology advancement, higher temperature lights were used in industrial applications. In one study, it was found that the participants demonstrated significantly greater improvement in their performance on a task measuring their ability to switch between tasks. Moreover, exposure to light at higher CCT or white colour leads to greater improvements in go/no-go task performance. The accuracy of the task was high with participants averaging approximately 80% correct on no-go trials.⁴

Sample lighting standards⁵ or projects where white lights are accepted or implemented:

- i. Ministry of Transportation – Among the list of accepted luminaire photometric lists, there are lights with 4500 K CCT, which are near to white lights.
- ii. University of Toronto, Mississauga Campus – The campus recently got new white LED lights for campus parking lot and outdoor lighting.⁶
- iii. New Brunswick Southern Railway Exterior Lighting, Saint John – Floodlight luminaire having white light (5000K CCT) installed for outdoor lighting.⁷
- iv. CP Rail Yards Retrofit, Moose Jaw / Lacombe / Lloydminster, SK – New wall mount fixtures are having white light installed for outdoor lighting.
- v. CN Rail Lighting Retrofit, Saskatoon, SK – New wall mount fixtures are having white light installed for outdoor lighting.

On the whole, the white lights provide a greater level of visual acuity for workers on-site, allowing them to perform tasks more safely. When an area is lit at the same lux level with the amber vs white lights, safety will be lower/compromised in amber light conditions. Since a higher lux is output from the actual white fixtures to be used in this application, this comparative difference in safety is increased.

1.6 Adverse impact on wildlife

This section on wildlife impact due to lighting is prepared by Stantec. Artificial lights can have an impact on wildlife migration, breeding, predator-prey relationships and circadian rhythms (Longcore et al. 2018, Gaston et al., 2012). In general, studies have found that blue and white lights are more disruptive to wildlife than yellow, amber or green lights (Longcore et al. 2018 and Gaston et al., 2012). White lights may have a more adverse effect on wildlife, in part because they have an increased spectral range (i.e., the light spectrum contains all colours), and more wildlife species will perceive some part of the spectrum (Gaston et al., 2012). Blue lights may have a more adverse effect, in part because the shorter wavelength scatters more readily and results in more skyglow compared to yellow or amber lights (Kinzey et al., 2017). Additionally, blue light is involved in regulating the circadian clock of diurnal and nocturnal species (Bourgin and Hubbard, 2016).

³ *Visual search under scotopic lighting conditions by Vivian C. Paulun, Alexander C. Schütz, Melchi M. Michel, Wilson S. Geisler, Karl R. Gegenfurtner Vision Res. Author manuscript; available in PMC 2017 Oct 17*

⁴ *Effects of new light sources on task switching and mental rotation performance Ferlazzo F., Piccardi L., Burattini C., Barbalace M., Giannini A.M., Bisegna F. (2014) Journal of Environmental Psychology, 39, pp. 92-100*

⁵ *The standards referenced here are as per the current date. These standards change time to time.*

⁶ *Information sourced from lighting supplier Hubbell*

⁷ *Information sourced from lighting supplier Cooperlighting*

Artificial light may change how species interact with the environment and may provide an advantage to some species while disadvantaging others. Wildlife species have adapted to be more sensitive to different parts of the light spectrum depending on their life-history strategy (i.e., nocturnal or diurnal, Gaston et al., 2012 and Bourgin and Hubbard, 2016). Blue light has been found to cause an alerting response in both nocturnal and diurnal species (Bourgin and Hubbard, 2016).

The effects of artificial light have been well documented on wildlife species that migrate at night, including birds, turtles, fish and insects, which may become disoriented by the light and migrate off-course (Longcore et al., 2018). Less research has been conducted on the effects of specific parts of the light spectrum (i.e., colour); however, some studies have documented different species-specific responses to blue, green, red, amber and white light. Wood mice will avoid red light less than white or green light (Spoelstra et al., 2014). Bees, butterflies, moths and frogs are, on the other hand, more attracted to blue and white lights than amber light, which may increase their exposure to predators (Longcore et al., 2018 and Gaston et al., 2012). Blue and green light can affect the foraging behaviour of bats (attraction or avoidance depending on species, Spoelstra et al., 2014). The magnetic compass for nocturnally migrating birds requires light from the blue-green part of the spectrum; red light can disrupt their orientation. A study in the North Sea found that nocturnal migrating birds showed increased reactions (i.e., disorientation) to light as the colour was shifted from blue, to green, to red, to white. Researchers concluded that the red portion of the light spectrum may be interacting with the bird's internal compass (Poot et al., 2008 and Marquenie et al., 2013).

Overall, research into the effects of light colour on wildlife is emerging, with limited published material comparing the effects of different spectral ranges on wildlife. However, based on the literature review, there is evidence that amber light may have a lower impact than lights in the white or blue spectrum for some species, including some insect and bat species. There is no conclusive evidence in the research reviewed that migrating birds are less affected by amber light than light from the white or blue spectrum.

2. Conclusions

Multiple factors contribute to the sky glow produced at any location, and level likely changes with the combination of those factors. The contribution to sky glow due to this Project is one of the many sources of light at night in the surrounding areas.

The main factor affecting the sky glow is uplight, and it is almost nil for the fixtures selected for this Project. However, it is observed that the UFR value is 2% lower with amber lights compared to white lights. Altogether, the sky glow will be dependent on atmospheric conditions discussed in Section 1.2. Since blue light has a shorter wavelength, the white light will generate more sky glow compare to amber light; however, in the study indicated in Section 1.2 of this report, it was found that longer wavelength amber lights will contribute more to sky glow when viewed from a distance.

Regarding the glare effect, calculations indicate that there are very minor or no changes in the lighting intensity values due to changes in the colour temperature of lights. The calculations are shown in Appendix D and E.

Moreover, there is a significant saving in fixtures cost with white lights compared to amber lights. Also, white lights are 4% efficient in terms of Lumens per Watt compare to amber lights.

In accordance with Illuminating Engineering Society (IES) Recommended Practice RP-8-18 – Design and Maintenance of Roadway and Parking Facility Lighting, the observation distance reduces for lower temperature lights resulting in poor visibility, such as amber light. In work sites such as CN's Milton Logistics Hub, trucks, cranes and personnel move throughout the site. The colour rendering under white light is better than that under amber light. Therefore, workers can quickly and accurately recognize a warning sign earlier and take the necessary actions. In general, white light provides higher visibility compared to amber light improving operational safety for applications such as an intermodal terminal.

As per the section regarding impact on wildlife from Stantec, artificial lights can have an impact on wildlife migration, breeding, predator-prey relationships and circadian rhythms. In general, studies have found that blue and white lights are more disruptive to wildlife than yellow, amber or green lights. Artificial light may change how species interact with the environment and may provide an advantage to some species while disadvantaging others. Based on the literature review, there is evidence that amber light may have a lower impact than lights in the white or blue spectrum for some species. However, it was found that there is no conclusive evidence in the research reviewed that migrating birds are less affected by amber light than light from the white or blue spectrum.

3. Appendix A

A.1. Calculation of the Upward Light Ratio (ULR)

The upward light ratio (ULR) is the proportion of flux of luminaire emitted at and above the horizontal plane. Also, in accordance with the Luminaire Classification System (LCS) graph specified in the CN Milton Logistics Hub project, (Figure A.1), the light emitted between angle 90° and 110° is zero from both white light and amber light.

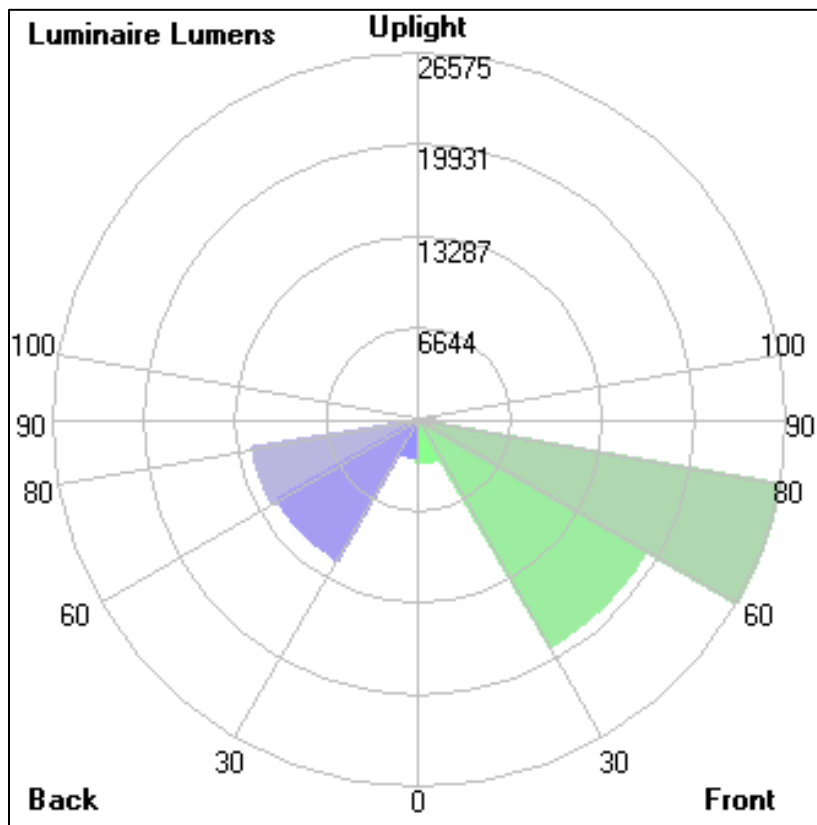


Figure A.1: LCS for amber and white luminaire fixtures

R_{UL} is calculated in accordance with Equation A1 and is equal to zero for both types of light fixtures.

$$R_{UL} = \frac{R_{ULO}}{R_{LO}}$$

Equation A1: Upward light ratio of the luminaire

where,

R_{UL} is the upward light ratio of the luminaire,

R_{ULO} is the upward light output ratio of the luminaire, and

R_{LO} is the total light output ratio of the luminaire.

Based on the above, when the fixture has no light coming out at 90–110°, the ULR is zero; mostly all dark sky compliant lamps have ULR zero. As a result, both lamps with amber colour and white colour specified in the CN Milton Logistics Hub project have zero upright.

A.2. Calculation of the Upward Flux Ratio (UFR)

The upward flux ratio (UFR) is the ratio of the luminous flux above the horizon resulting from luminaires, reflection from surfaces that are intentionally lit and reflection from the surrounding area because of spill light to the luminous flux above the horizon in the hypothetical situation.

While using white light fixtures, the value of UFR for the CN Milton terminal area is reduced by 3.6% compared to the UFR values achieved by using white light fixtures.

The maximum lux of UFR for the white light and amber light lamps are included in Table A.1.:

Table A.1: UFR for the terminal area for white lights and amber lights

Label	Upward flux ratio (UFR)		Approximate total reference area (m ²)	Average maintained illuminance requirement (lux)
	White Lights	Amber Lights		
Terminal area	1.63	1.57	323082	30

To identify the illuminance level due to reflection, the calculation grid was drawn over the whole project area at a height of 31 m from the gradient, with the meter direction pointing towards the horizontal plane, so that it calculates only the reflected light from the ground surface and containers. For this calculation, the following reflectance values are assumed:

- i. Top of the container at 9 m above gradient: 0.99;
- ii. Terminal area: 0.2;
- iii. Roads and gate area: 0.2; and
- iv. Neighbouring area: 0.2.

Table A.2: Calculation of light output at 31 m height, with meter pointing towards the horizontal plane

	White lights (lumens)			Amber lights (lumens)		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Calculation grid at 31 m above gradient, with meter pointing to the horizontal plane	25.8	0	1.34	25.2	0	1.32

A.3. Glare

In accordance with CIE 150:2017, the limits of luminous intensity of a bright luminaire are dependent on the viewing distance (d) between the observer and the bright part of the luminaire in direction to the observer, also known as luminaire's projected area (A_p).

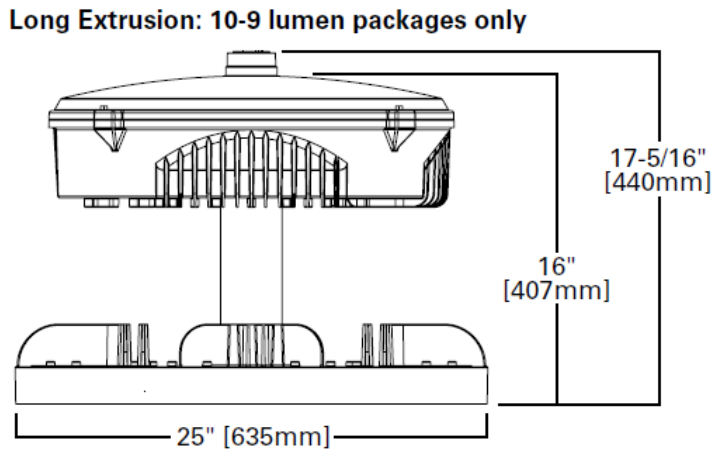


Figure A.2: LED luminaire with long extrusion configuration

The light-emitting area A can be calculated according to Equation A2.

$$A = \pi r^2$$

Equation A2: Light-emitting area calculation

where,

A is the light-emitting area of the luminaire; and

r is the diameter of the luminaire.

Based on Figure A.2

the diameter of the luminaire is 0.635 m; therefore, the radius is equal to $0.635 \times 0.5 = 0.3175$ m

$$A = \pi 0.3175^2 = 0.317 \text{ m}^2$$

The projected area A_p can be calculated based on aiming angle above the downward vertical and azimuth to the observer side normal to the subject area,

The projected area A_p is calculated according to Equation A3.

$$A_p = A \cos (90 - \text{aiming angle above the downward vertical}) \quad \text{Equation A3}$$

In accordance with Section 3.6.5.2 of CIE 150:2017 and Table 8, the pre-curfew of E2 is 10d and the pre-curfew of E3 is 15d. The post-curfew of E2 and E3 are the same 5.1d.

The lighting calculation of lighting intensities for amber lights and white lights are provided in Appendices C and D based on 26 receptor locations used in the Stantec lighting report.

As per CIE Standards, pre-curfew is from dusk until 11:00 PM local time, when the area being illuminated is more likely to be in use. Post-curfew is from 11:00 PM to 7:00 AM local time. It is noted that the lighting intensities of amber lights and white lights are compliant with the required standard for pre-curfew for both E2 and E3; however; for the post-curfew, few poles will need on-field installation of overall shields and baffles to control the light intensity. The poles will be marked out on the final design drawings and detailed instructions will be provided to the Electric Contractor to advise the installation of shields or baffles on-site to achieve the required lux levels following CIE 150:2017 Standards.



Figure A.3: Locations of receptors used in the calculation

A.4. Lighting calculation

Table A.3: Illuminance level with amber lights

Label	Average (lux)	Maximum (lux)	Minimum (lux)	Average/Minimum
Access road to Britannia Road	5.26	15	2	2.63
Access road to Tremaine Road	7.68	24	2	3.84
Building parking	12.39	30	6	2.07
Electrical and miscellaneous	15.51	39	4	3.88
Inbound-outbound gate	17.63	43	5	3.53
Interconnect road to Tremaine Road and gate	7.73	19.4	2.3	3.36
Property line – upper	0.11	2	0	NA
Property line – lower	0.04	2	0	NA
Terminal	29.66	46	9	3.3
Truck parking lot	12.66	26	5	2.53

Table A.4: Illuminance level with white lights

Label	Average (lux)	Maximum (lux)	Minimum (lux)	Average/Minimum
Access road to Britannia Road	5.24	15	1	5.2
Access road to Tremaine Road	8.70	24	2	4.35
Building parking	16.48	34	5	3.3
Electrical and miscellaneous	15.70	39	4	3.93
Inbound-outbound gate	19.15	49	4	4.79
Interconnect road to Tremaine Road and gate	8.17	20.4	2.5	3.27
Property line – upper	0.10	2	0	NA
Property line – lower	0.03	2	0	NA
Terminal	30.10	48	9	3.34
Truck parking lot	11.78	27	2	5.89

4. Appendix B – Lighting calculations for Amber light fixtures

5. Appendix C – Lighting calculations for White light fixtures

6. Appendix D - Compliance reports for luminous intensity for surrounding receptors for Amber light

7. Appendix E - Compliance reports for luminous intensity for surrounding receptors for white light
