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ARTICLE

THE EFFECTS OF STREET LIGHTING ON LIGHT POLLUTION IN OTTAWA

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Recipient of a Silver Medal at the Canada Wide Science Fair; the Honeywell Aerospace Award at the Ottawa Regional Science Fair; the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Award at the Ottawa Regional Science Fair; and a Third Place Medal in the Junior Category at the Ottawa Regional Science Fair.

The world is losing its dark skies due to light pollution. Light pollution is defined as "any adverse effect of artificial light" (International Dark Sky Association [IDSA], n.d.a). 83% of the world's population (including 99% of American and European populations) and 23% of the world's land area are affected by light pollution (Falchi et al, 2016). Artificial lights, defined as any non-natural lights from human-made sources cause sky glow and make it difficult for humans to continue to experience the dark sky. The International Astronomical Union recognizes an unpolluted night sky as a "fundamental socio-cultural and environmental right" (IAU, 2009). Lighting sources that are less than the 500 nm (higher colour temperature) range have been shown to be more harmful for astronomy than lighting sources that are greater than the 600 nm (lower colour temperature) range (Green et al, 2022). Outdoor artificial lights that are > 3000K shine a blue-range and bright light that is harmful to humans and the environment (National Parks Service, 2022). Artificial lights of 2700K or below would have a less damaging impact on the night sky (Green et al, 2022).

Exposure to artificial lights at night has significant health and behavioral effects with medical and ecological consequences (Navara and Nelson, 2007; Falchi et al, 2016). In humans, artificial light at night is associated with an increased risk of breast, prostate, and colorectal cancer, obesity, diabetes, and cardiovascular disease (Cao et al, 2023; Stanhope et al, 2021; Cho et al, 2015; Al-Naggar & Anil, 2016). Melatonin production, which is responsible for natural circadian rhythm, has been shown in humans and other animals to diminish with increased light intensity (Dominoni & Nelson, 2019). Disruptions to circadian rhythm, including from exposure to artificial lights at night, have been linked to mood disorders and metabolic functions (Walker, 2020; Cho et al, 2015; Tancredi et al, 2022). Sensitivity is greatest to light in the blue range (450 - 485 nm) (Dominoni & Nelson, 2019). Artificial lights of 2700K or below reduce the potential negative effects on human melatonin levels (Chepesiuk, 2009).

In other animals, artificial lights at night have been shown to negatively affect behaviours, migration patterns, foraging, reproduction, communication, breeding cycles, and the habitat of many nocturnal species (Sanders et al, 2021; Longcore et al, 2004). 30% of vertebrates and more than 60% of invertebrates, including 75% of insects, worldwide are nocturnal (Hölker et al, 2010; Gaston et al, 2017; Dalgleish, 2021). Sky glow disorientation from illuminated buildings kills more than 250,000 birds annually in Ottawa (Roy, 2017). In other environmental effects, light pollution increases air pollution, and electricity generation from excess lighting can produce CO2 (CIRES, 2011; Kocifaj et al, 2021; International Dark Sky Association, n.d.b).

The purpose of my research is to study the effects of various types of artificial street lights on light pollution and if the lights' intensity and colour meet recommended light standards. My hypothesis is that artificial lights used by the City of Ottawa contribute to light pollution because of their high colour temperature, high intensity, and blue-range wavelength. The research focuses on light pollution from sky glow, in which artificial lights at night cause the sky to be brighter (National Lighting Product Information Program, 2007).

METHODS AND MATERIALS

Four areas with different light conditions (downtown, suburban, industrial/commercial, and rural) were selected in the Greater Ottawa area. Using the Dark Sky Meter app (DDQ B.V. v3.0.9), the night sky was measured in those areas in Sky Quality Meter (SQM), a quantitative measurement of sky glow in units of magnitudes per square arc-second. SQM correlates directly with the nine-level Bortle scale, a qualitative scale based on visual sky features (Bortle, 2006). Three measurements of the sky at each location were taken in quick succession. The measurements for each location were averaged and then compared to the norms for the Bortle classes to establish the existence and level of light pollution at each type of location.

Using the Light Spectrum Pro app (EVO v4.3.0), the intensity, wavelength, and colour temperature of several different types of artificial lights were measured in the vicinity of the Governor General's residence, Rideau Hall, in Ottawa. Three measurements of each artificial light fixture were taken in quick succession and measured on the Kelvin and lux scales to determine the colour temperature and intensity of each fixture respectively. Colour temperature directly correlates with the colour spectrum: high-

er colour temperatures on the Kelvin scale are toward the blue range and lower colour temperatures are toward the red range (CIE [International Commission on Illumination], 1931). Visible light is in the 380-700 nm wavelength range (blue to red) of the electromagnetic spectrum (National Aeronautics and Space Administration, 2010). A nanometer measurement was also taken to determine the distribution of the wavelength of the light. Figure 1 provides a screenshot of one set of measurements.

The three Kelvin and lux measurements for each artificial lighting device were averaged. Based on the data, each type of artificial light was analyzed to evaluate the colour temperature, intensity, and colour wavelength, and these values were compared to standards from the scientific literature for colour spectrum, intensity, and colour wavelength of artificial lights that cause fewer harmful light pollution effects. These values were also compared to City of Ottawa standards for the area in which they were located and for road type (City of Ottawa, 2016; City of Ottawa, 2013).

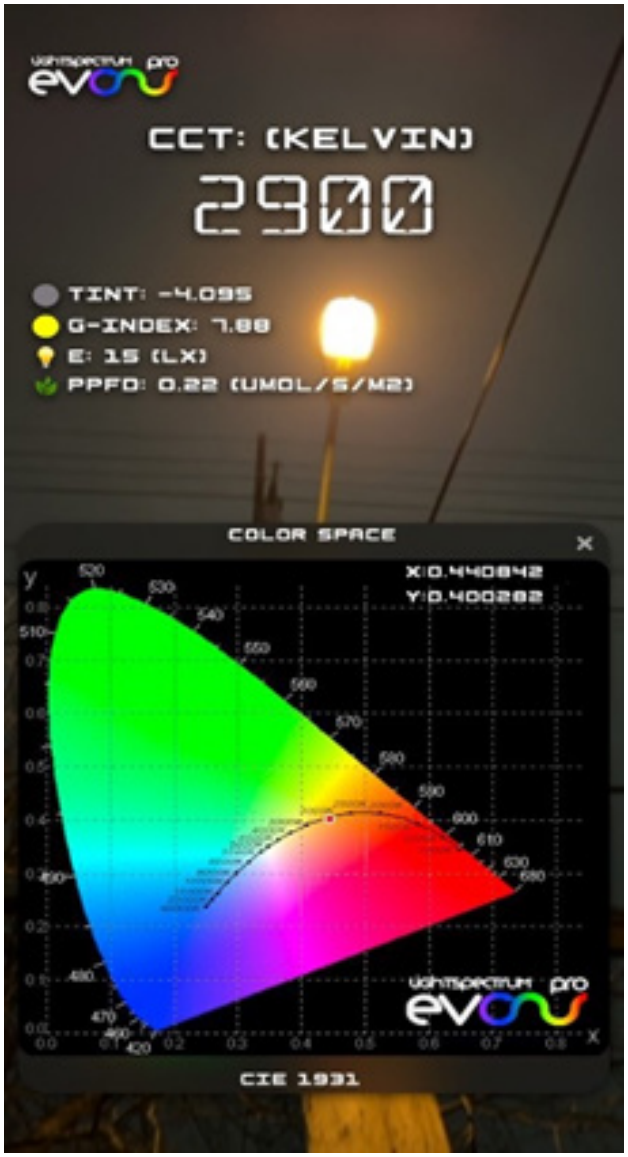

Figure 1: Screenshot from Light Spectrum Pro app (EVO v4.3.0)

The street light measurements were taken to evaluate their possible contribution to any light pollution in Ottawa that would be detected by the Dark Sky measurements. The variables of moon phase, weather, time of year, and time of day were controlled for each category of data. The distance from the light source was also controlled for in the streetlight data.

RESULTS

Dark Sky Data

Table 1 provides dark sky data for four locations in Ottawa showing Sky Quality Meter and Bortle Scale measurements. Figure 2 is an excerpt from the New World Atlas of Artificial Sky Brightness overlaid on a map of the City of Ottawa showing how different levels of artificial lighting conditions affect sky brightness in the four sites. According to the New World Atlas of Artificial Sky Brightness, the closest fully dark-sky site to Ottawa is more than 200 km west in Algonquin Provincial Park.

The geographic distribution and photographs of the four sites in Ottawa and their respective Bortle Scale measurements are shown in Figure 3.

On the Bortle scale, all four areas (rural, suburban, industrial/commercial, and downtown) show light pollution. The industrial/commercial site at the Canadian Tire Centre (Site 3) and the downtown site at the Byward Market (Site 4) show the most serious light pollution at the highest level of Class 9 on the Bortle scale. The suburban site in Centrepoint neighbourhood in Nepean (Site 2) is a Class 6 on the Bortle scale, which is defined as bright suburban sky, and the site's value is close to a Class 7, which is suburban/urban transition. The rural site (Site 1), a farm that is more than 40 km southwest of downtown Ottawa with not many artificial lights visible, is a Class 4 on the Bortle scale, which is defined as rural/suburban transition, and the site's value is close to Class 5, which is suburban sky.

Streetlight Data

Table 2 provides measurements for seven artificial lights around the neighbourhood of Rideau Hall with colour temperature in Kelvin, intensity of light in lux, and wavelength in nanometers.

The seven measured streetlights are all on "Local Roads" as defined by the City of Ottawa, which must meet more stringent light requirements than other road classifications (City of Ottawa, 2013).

As shown in Figure 4, the street light measurements for illuminance (light intensity) all exceeded the City of Ottawa's published standards for both roadway and intersection lights. As shown in Figure 5, the colour temperature of the majority (5 of 7 lights) of the measured street lights also exceeded the City of Ottawa's own standards for local roads. Two lights exceeded the City's maximum standard. This is noteworthy because the cur-

rent City of Ottawa's standards allow higher maximum levels than the international recommended levels for health and dark skies. As shown in Figure 5, all but one street light exceeded the maximum recommended levels for health and dark skies, according to the International Dark Sky Association (IDSA, 2010) and the American Medical Association (AMA, 2016). Only one light (light 6) met the City's and international recommended standards for colour temperature of light.

DISCUSSION

The research objective is to examine the effects of artificial lights on light pollution by measuring the colour temperature, intensity, and wavelength of various types of streetlights. The hypothesis is that the artificial lights used by the City of Ottawa contribute to light pollution because they are too blue and bright. This hypothesis proves to be true as the majority of the tested lights had high colour temperature, high intensity, and blue-range wavelength.

Based on the data, Ottawa appears to be an area of significant light pollution. Higher-colour temperature (blue-range) lights (4000K and above), corresponding to less than 500 nm wavelength, are damaging to the night sky (IDSA, 2010). The dark sky measurements ranged from a low of level 4 Bortle scale at a rural site to a high of level 9 Bortle scale at the downtown and the industrial/commercial sites. Even for an area with agricultural lands where not many artificial lights were visible, the night sky was still affected by glare, as shown in Figures 2 and 3. This is consistent with research showing that rural areas contribute 10% of emissions from artificial lights at night but experience almost 70% of the negative impacts of all skyglow cumulatively (Cox et al, 2022).

As shown in Figure 4, none of the lights measured met the City's standards for illuminance. As shown in Figure 5, the City of Ottawa's standards for colour temperature of light are set too high to meet recommended levels of the IDSA, the AMA, and the National Capital Commission (NCC, 2017), and the majority of lights measured failed to satisfy even the more permissive standards set by the City.

This project indicates that Ottawa suffers from the same light

Table 1 provides dark sky data for four locations in Ottawa showing Sky Quality Meter and Bortle Scale measurements.

Site	Date and Time	Location (Civic Address and GPS)	Type of Location	Sky Quality Meter (magnitudes per square arcsecond)	Bortle (9 level scale)	Moon Phase
1	Date: Jan 29, 2022 Time: 18:52 - 18:54	Civic Address: 758 John Kennedy Way, Almonte ON K0A 1A0 GPS: 45.22632339953021, -76.0972931170264	Rural	19.64 21.10 20.78 Average: 20.5	5 4 4 Bortle of the Average: 4	Waning Crescent (10%)
2	Date: Jan 29, 2022 Time: 19:40 - 19:42	Civic Address: Centrepoint neighbourhood Glenarden Court, Nepean, ON K2G 5V9 GPS: 45.33878766418905, -75.76491896172662	Suburban	18.79 18.96 19.17 Average: 18.97	7 6 6 Bortle of the Average: 6	Waning Crescent (10%)
3	Date: Jan 29, 2022 Time: 19:15 - 19:17	Civic Address: Canadian Tire Centre 1000 Palladium Dr, Ottawa, ON K2V 1A5 GPS: 45.291498834 -75.922996308	Industrial/ Commercial	17.28 17.84 17.72 Average: 17.61	9 9 9 Bortle of the Average: 9	Waning Crescent (10%)
4	Date: Jan 29, 2022 Time: 20:07 - 20:09	Civic Address: 55 Byward Market Square, Ottawa, ON K1N 9C3 GPS: 45.42795072072504, -75.69139125545018	Downtown	16.26 16.63 16.07 Average: 16.32	9 9 9 Bortle of the Average: 9	Waning Crescent (10%)

pollution commonly affecting urban areas around the world. The street light data suggests that the City of Ottawa may be installing bulbs in street lights that fail to satisfy its own lighting standards, and those standards are not as stringent as the recommendations of the IDSA and AMA. The bulb selections may be contributing to anthropogenic sky glow in the Greater Ottawa area.

In the last 25 years, light pollution has increased dramatically across the globe (Sánchez de Miguel et al, 2021; Falchi et al, 2016). From 1992-2017, global satellite emissions increased by 49% (Sánchez de Miguel et al, 2021). This increase is correlated with the introduction of LED lights. The actual impact of blue-range LEDs may be even worse than light pollution maps show because the satellites that measure observable light emissions are not sensitive to blue light emissions (Sánchez de Miguel et al, 2021). The true increase in light pollution could be as high as 270% globally and as high as 400% in some regions (Sánchez de Miguel et al, 2021). A simulation conducted by the researchers for the *New World Atlas of Artificial Night Sky Brightness* predicted a 2 – 3x increase in global light pollution if 4000K LEDs are adopted worldwide (Panko, 2016). Research indicates that high-correlated colour temperature blue-rich LEDs and metal halide are up to 8x brighter than low-pressure sodium and 3x brighter than high-pressure sodium lumen for lumen at close observation (Luginbuhl), suggesting caution should be exercised by cities before installing blue-rich white LEDs (Falchi et al, 2011; Flagstaff Dark Skies Coalition, 2021; IDSA, 2010; International Group of Experts for the Protection of the Night Sky, 2015; Greenberg, 2022).

For future research, more measurements of artificial lights and dark sky sites could be done throughout Ottawa using professional astronomy and photography equipment to build on these findings. Streetlights are only one factor in light pollution from artificial lights at night (Kyba et al, 2021). Other sources of artificial nighttime lights, such as billboards, parking lots, warehouses, arenas, airports, and commercial office buildings, could also be measured.

Suggested policy recommendations to address the harms of light pollution are to implement light standards of 3000K or less, put shields and dimmers on outdoor lights, reduce the number of artificial lights outside, and work with neighbourhood associations to bring light pollution concerns to city councils. The project highlights that the environmental and health benefits of a reduction in light pollution may be obtained by choosing warmer colour and lower intensity lights for outdoor artificial lights.

CONCLUSION

To measure how widespread the problem of light pollution is in Ottawa, dark sky readings were measured at four different sites: rural, suburban, industrial, and downtown. The colour and brightness of street lights in one neighbourhood were measured to test whether they met the City's lighting standards and international guidelines. In the sample, a significant majority of lights failed to meet the recommended lighting levels because they were too bright and too blue. Bluer and brighter lights cause skyglow, which lessens the darkness of the night sky. Skyglow harms humans' physical and mental health, animal behaviour, and ecosystems. Bright night skies negatively affect reproduction and migration of nocturnal animals and are linked to cancer, mood disorders, obesity, and cardiovascular disease in humans.

This research shows that the City of Ottawa suffers from the same light pollution that commonly affects urban areas around the world. It also shows that a number of the lighting fixtures in the City of Ottawa exceed the City's own standards, as well as internationally recommended standards, for both illuminance and colour temperature, and are thus a source of this light pollution. Hence, the hypothesis is supported.

This research suggests that the City of Ottawa should reduce the harmful light pollution effects of high temperature, blue spectrum, and high intensity artificial lights by revising its light standards to 3000K or less, as proposed by the National Capital Commission (2017), International Dark Sky Association (2010)

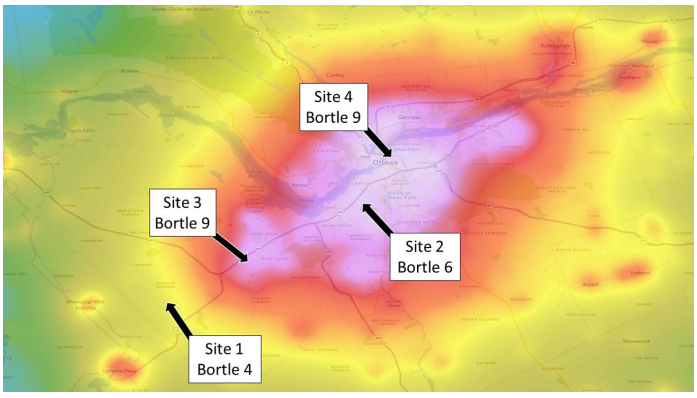

Figure 2: Map of four tested dark-sky site locations and Bortle classifications (Images: *New World Atlas of Artificial Sky Brightness*; **Google Maps)**

Figure 3: Map with photographs of four tested dark-sky site locations and Bortle classifications (Images: Canadian Tire Centre; Google Maps; Ottawa Tourism; Partridge Acres)

Table 2: Artificial Light Measurements

Light (Type and Watts) *Data from City of Ottawa	**Date and Time**	**Location (Civic address and GPS)**	**Kelvin**	**Lux (lx)**	**Wavelength (nanometers) and Distribution (%)**	**Moon Phase**
1 *High Pressure Sodium 93W	Date: Feb 16, 2022 Time: 20:01	Civic Address: 250 Springfield, Rockcliffe Park Village, ON K1M 0T3 GPS 45.44804468027899, -75.67764219752627	2900 2964 2931 Avg: 2932	15 14 14 Avg: 14.33	Yellow: 81% (575 nm) Green: 19% (520 nm)	Full moon (100%)
2 *High Pressure Sodium 93W	Date: Feb 16, 2022 Time: 20:06	Civic Address: Corner of Springfield and Mariposa, Rockcliffe Park Village, ON K1M 0T4 GPS: 45.44841901819041, -75.6778984380042	4822 4697 4821 Avg: 4780	12 12 12 Avg: 12	Yellow: 79% 580 nm Indigo: 4% 400 nm Green: 16% 550 nm Blue: 1% 460 nm	Full moon (100%)
3 *High Pressure Sodium 400W	Date: Feb 16, 2022 Time: 20:15	Civic Address: Corner of Howick and Mariposa Rockcliffe Park Village, ON K1M 0G9 GPS: 45.447938263195084, -75.6808788365964	4143 4136 4151 Avg: 4143	13 13 13 Avg: 13	Yellow: 76% 570 nm Green: 24% 530 nm	Full moon (100%)
4 *High Pressure Sodium 400W	Date: Feb 16, 2022 Time: 20:25	Civic Address: 330 Mariposa Ave. Rockcliffe Park Village, ON K1M 0T3 GPS: 45.449019366055296, -75.67774242680868	3466 3472 3454 Avg: 3464	10 10 11 Avg: 10.33	Yellow: 86% 575 nm Green: 14% 525 nm	Full moon (100%)
5 *Compact Fluorescent 15W	Date: Feb 16, 2022 Time: 20:36	Civic Address: The Rockeries Rockcliffe Drive, Rockcliffe Park Village, ON K1M 0H5 GPS: 45.45070508925937, -75.68844963051293	3148 3261 3142 Avg: 3184	9 8 9 Avg: 8.67	Yellow: 84% 580 nm Green: 15% 530 nm Orange: 1% 610 nm	Full moon (100%)
6 *High Pressure Sodium 93W	Date: Feb 16, 2022 Time: 20:45	Civic Address: Corner of Lisgar Rd and Belvedere Crescent, Ottawa, ON K1M 0E5 GPS: 45.4451288789823, -75.68124482548367	2306 2441 2323 Avg: 2357	25 23 23 Avg: 23.67	Yellow: 67% 570 nm Red: 3% 650 nm Orange: 16% 600 nm Blue: 3% 470 nm Green: 8% 550 nm Indigo: 2% 425 nm	Full moon (100%)
7 *LED 45W	Date: Feb 16, 2022 Time: 20:50	Civic Address: Corner of Minto Place and Maple Lane Rockcliffe Park, ON K1M 1G5 GPS: 45.44549617844303, -75.68070275246758	3890 4036 3894 Avg: 3940	18 22 18 Avg: 19.33	Yellow: 92% 575 nm Green: 5% 545 nm Orange: 3% 600 nm	Full moon (100%)

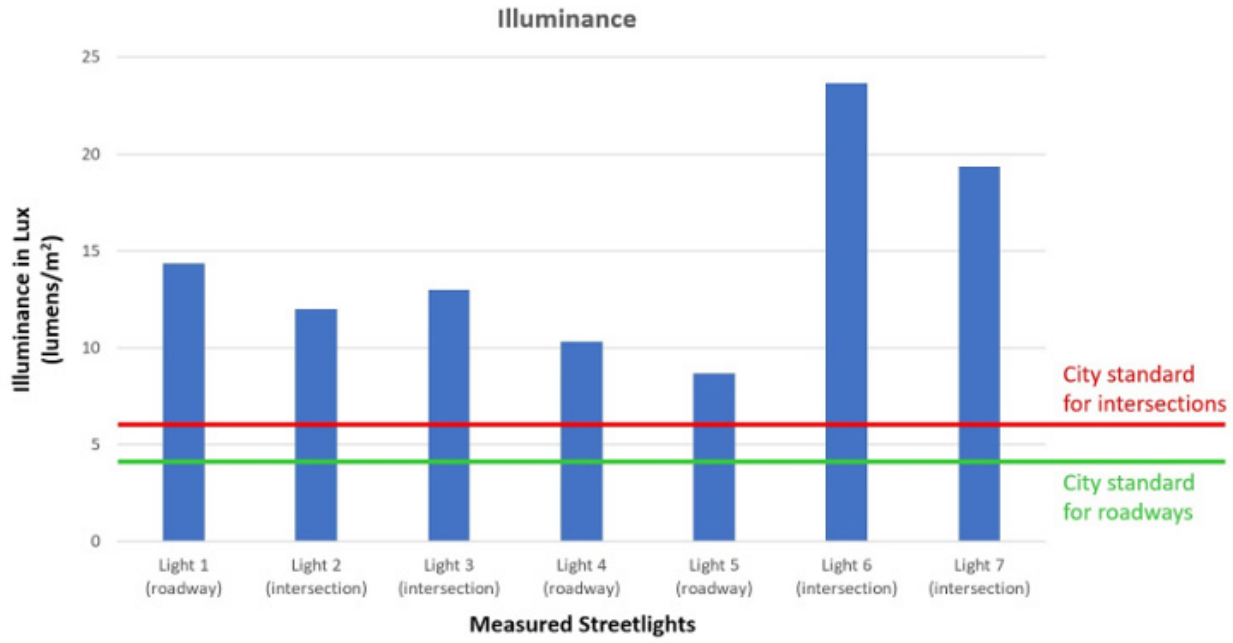

Figure 4: Illuminance of artificial lights compared to published standards

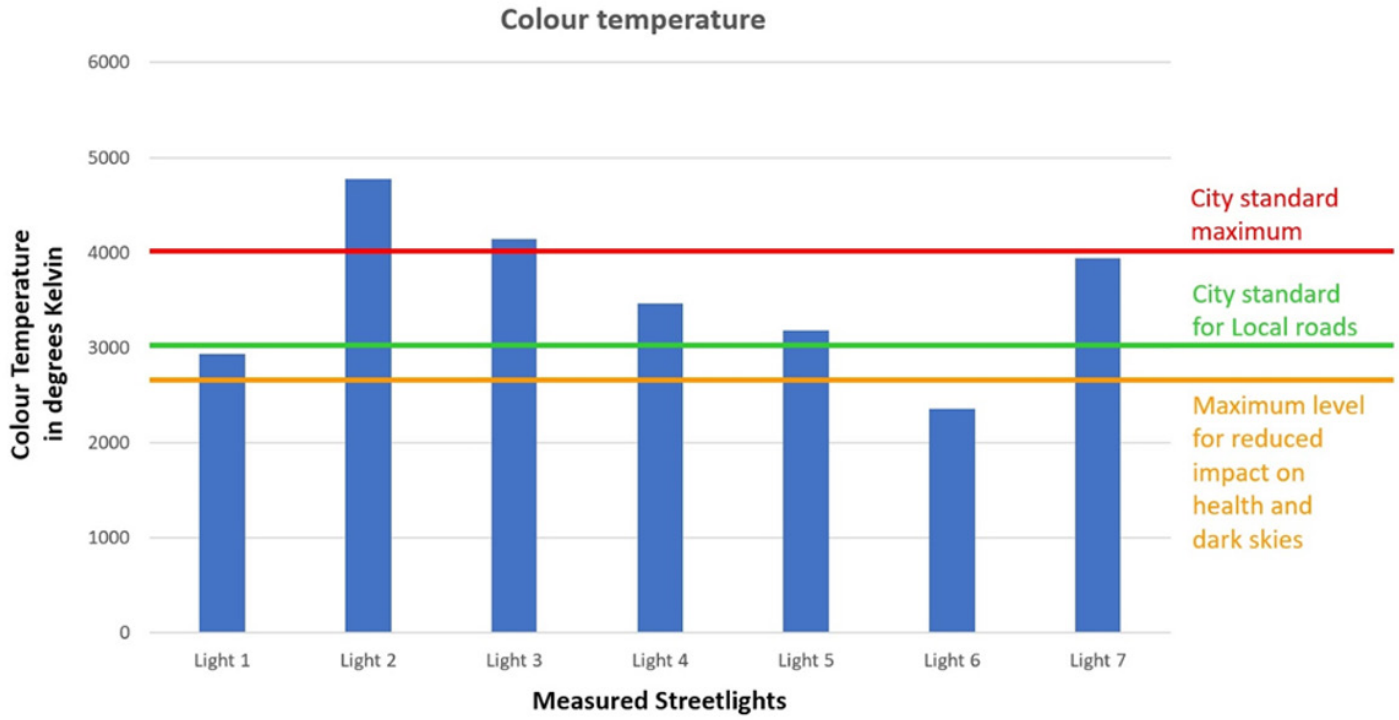

Figure 5: Colour temperature of artificial lights compared to published standards

and American Medical Association (2016), to better preserve our night skies and to protect the health of humans, other animals, and our environment.

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Tamsen F.J. Taylor is a grade 7 student at Ashbury College in Ottawa. She competes in swimming, diving, and skating, and, as it is often already dark when she leaves her practices, she loves observing the night sky. She has been fascinated how the sky appears darker at a rural barn, than it does at the suburban ice rink or downtown pool, and how the number of stars she can see varies dramatically. Her parents have reminisced about how dark the skies were when they were her age, which inspired her to study the loss of dark skies.