Let there be darkness[1]

LED security lights effects on trees and green city landscape:

Human and wildlife circadian rhythms, mental well-being, road safety and the view of our night sky

David Garlovsky, BSc, MSc, Certificate in Social Phenomenology
Affiliation: Schools & Homes Energy Education Project/Solar-Active and Recovery Insulation
84 Upper Valley Road, Sheffield S8 9HE, United Kingdom
Contact: david@solar-active.com

ABSTRACT

There is a growing trend for urban areas in the UK, USA and elsewhere to change over-roadway and residential lighting from high-pressure sodium [HPS] to blue-rich LEDs, often simply on the basis of saving energy, yet without health- or environmental-impact assessments. The views presented in this paper are from a historical perspective based on research conducted by the author in the City of Chicago. A literature review was also conducted of research that showed blue-rich LEDs' effect on human health and well-being, wildlife circadian rhythms, road safety and the view of our night sky. Studies also now provide evidence on a national scale of the relationship between the amount of artificial night-time light and budburst in woodland trees.

The purpose of this paper is to raise awareness of the potential impact on urban and rural areas of blue-rich LEDs to ensure that city designers and arbourists make informed decisions about the choice of street and road lighting.

It is not a newly discovered problem that there are harmful effects of street lighting as botanists were made aware of the deleterious effects of incandescent street lighting on trees 81 years ago by Matske in 1936. Horticulturalists learned of such effects on both wild and domesticated plants from research by Cathey and Campbell in 1975.

Research in 1974 by the Chicago Audobon Society and District 14 Environmental Education Project was ignored. The City installed HPS lamps primarly based on the report of a consulting arbourist, and the HPS lamps were more energy efficient, yet 11% failed after 13 months. There were effects on young trees, with 60% of a group of saplings suffering death or damage to growth over their first spring and summer. The Chicago politicians installed the street lights to show residents the city was taking proactive steps to address our primal fear of darkness, and the idea that lighting systems would reduce crime was politically popular.

Research has shown that making choices about the kind of roadway lights we use, simply on the basis of energy consumption, is shortsighted. Energy-saving measures need to be linked to health and ecology considerations. Soybean farmers learned not to plant in fields adjacent to HPS roadway lighting. The night-time illumination can reduce crop yield by 20–40%.

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In the UK, Public Health England recommend using CCT 2700K blue-rich LEDs to minimize glare and discomfort. Street lighting should be tested ‘in situ’ before a lighting scheme is rolled out to ensure it does not cause harm to human well-being, trees and wildlife. It is crucial for local communities be involved in deciding how streetscapes, including trees and lighting, are planned, managed and maintained.

Key words: blue-rich LEDs, HPS lamps, well-being, circadian rhythms.

BACKGROUND

As a resident and environmental education teacher/trainer of the City of Chicago District 14 Environmental Education Project in the 1970s, I first became interested in the effects of street lighting on residential-street trees, wildlife and humans. At the time, we were planting trees and shrubs in and around school buildings, and in vacant-lot gardening projects.

In my review of City of Chicago records and local newspapers, I discovered that every four years, and always in election years, residential streetlights were replaced. The City of Chicago politicians' policy was to replace security street-lighting systems, as this was often seen to address the primal fear of darkness. For instance, in 1974 the decision to replace mercury vapour (MV) residential streetlights with 85,000 400-watt, high-pressure sodium (HPS) lamps was based on the City being advised that HPS lamps would address the politically popular idea that the city was taking proactive steps to reduce crime and save energy. The elected city ward alderman also had the recommendation from its appointed consulting arbourist, which revealed that there had been no harmful effects observed of the HPS lamps on any trees. As a result, legislation to purchase the HPS lamps was passed at the City Council meeting held in July 1974.

The arbourist's recommendations were based on two weeks' observation of 210 trees in Chicago, Cleveland, and Milwaukee, and telephone interviews with officials in 16 cities in the US. The report by the arbourist was considered inadequate that no harm would befall Chicago's trees because the selection of trees for the study was biased. (Ruddat, 1975). An example of his sampling procedure showed that mature trees comprised 90% of his sample, while the young trees being planted would be most vulnerable. In addition, at the Chicago Avenue site 16 honey locusts were planted. It was found that 10 of these young trees were dead or damaged.

Research by Chicago Audubon Society (CAS) in collaboration with the Chicago District 14 Environmental Education Project questioned the value of the arbourist's observations and conversations, indicating that there were no harmful effects due to HPS lamps. The field surveys conducted by CAS showed that 11% of the HPS lamps failed after 13 months. The surveys also observed and recorded the effects of the HPS lamps on the young trees being planted, with 60% of a group of saplings suffering death or damage to growth over their first spring and summer. (Ruddatt, 1975). It was also observed that young trees growing under the HPS lamps were eight times more likely to be holding their green leaves (Figure 1: Leaf hold near HPS lamp) at the time of the first killing frost than those growing under MV lamps. As a result, the young trees under HPS lamps became vulnerable to frostbite. The HPS lamps also had a bad effect on privet, roses and chrysanthemums. A breaking of dormancy of hybrid and wild rose specimens, privet, pachysandra and chrysanthemums within 15 feet of the light standards was observed in December. (Gewirth, 1973)

Figure 1 Leaf hold near HPS lamp

A report of the analysis of the surveys was presented at a private meeting of the City of Evanston's (which borders the northern boundary of the City of Chicago) elected councillors and officers. The City of Evanston was considering installing HPS lamps. It was decided not to install the HPS lamps on Evanston's residential streets. The effect of street lighting on roadside trees is not a newly discovered problem. Botanists were aware of the damage of incandescent street lighting to trees 80 years ago (Matzke, 1936).

TRANSITION FROM HPS LAMPS TO BLUE-RICH LEDS: ISSUES AND PROBLEMS

There has been a growing trend for urban areas in the UK, USA and elsewhere to transition from HPS lamps for roadway and residential-street security lighting to cool-white (blue-rich) LEDs at an alarming pace during the past several years. The rush to replace roadway-lighting systems with blue-rich LEDs is a real cause for concern, and needs to be urgently addressed.

Funding for this change-over to blue-rich LEDs in the UK has been encouraged by the UK Technology Strategy Board (TSB) Future Cities Demonstrator programme (TSB, 2014) The focus has been on establishing wireless technology to provide more efficient roadway-security lighting while cutting CO_2 emissions.

Through a literature review, it was found that there is evidence of a large body of research to show that making choices about the kind of lights used on residental streets and roadsides, simply on the basis of energy consumption, is shortsighted. The analysis of this research has shown that by changing urban lighting from HPS lamps to blue-rich LEDs, "we may – and again, the emphasis is on may – be upsetting the ecological balance in unexpected ways." (Ashdown, 2016)

The problem is that UK local authorities, such as the Westminster City Council, as well as Balfour Beatty and CU Phosco, a UK designer and manufacturer of outdoor lighting equipment, support the installation of blue-rich white LED street lights. The initiative is supported with funding from the TSB to cut energy bills in order to reduce carbon emissions, but without the requirement of health- or environmental-impact assessments – even though it is recognised that blue-rich white light is detrimental to human and wildlife circadian rhythms.

Studies have also found that energy-saving measures need to be linked to health and ecology considerations, such as the presence of heavy metals in the manufacture of

LEDs. A study published in late 2010 in the journal *Environmental Science and Technology* (Seong-Rin, et al., 2012) found that LEDs contained lead, arsenic and a dozen other potentially dangerous substances.

"LEDs are touted as the next generation of lighting," says Oladele Ogunseitan (Seong-Rin et al., 2012, one of the researchers behind the study. Yet, as we find better products that do not deplete energy resources, we must be vigilant about any toxicity that may be in the supply chain of these products.

SKY GLOW AND ROAD SAFETY

Blue-rich LED streetlights are the nemesis of astronomers due to unacceptable levels of light pollution for astronomical observations, as they emit more blue light on a per-lumen basis than the HPS lamps they are replacing. Two studies have also concluded that to focus simply on CCT LEDs to reduce sky glow misses the problem, as it is caused by all of the white LED sources. (Luginbuhl, 2012; Aube. 2013)

The blue-rich LED's are detrimental to road safety and contribute to undesirable sky glow, due to excessive glare caused by the 'Rayleigh Scattering Effect'. (Ashdown, 2015). There is also a considerable negative aesthetic impact, particularly in areas with heritage lighting. Light affects our health and well-being in more ways than one, not to mention the aesthetic component. The health hazards from lighting are not exclusive to LEDs.

Blue-rich LEDs have been shown to double drivers' peripheral vision and increase brake reaction time by 25%. (Mokoff, 2015) 'Modern' headlights (without automatic adjustment systems) and street lamps are causing glare and prolonged retinal recovery following light 'stress'. (NHTCA, 2007)

NIGHT-TIME CRIME

Many believe improving visibility will reduce nighttime crime, including sexual assault. When there is no outdoor lighting, pedestrians may genuinely feel fear. Simply being able to see makes us feel safer. However, feeling safe and being safe are not the same. There is no clear scientific evidence that increased outdoor lighting deters crimes. It may satisfy the 'feeling of safety', but has not been shown to make us safer. This has been confirmed in Chicago (Parks, 2014) and other cities. (Steinbach, 2015) One of the largest, most scientific studies of outdoor crime and lighting at night was the 1998–99 Chicago Alley Study. (Morrow, 2000)

Feedback from Chicago residents was mostly positive; the only problem was that the residential-light replacement program did not reduce crime. To the contrary, in the areas where 'enhanced lighting' was installed, the incidence of crime increased. Studies in the UK comparing communities with similar demographics in which the only difference was the introduction of street lighting have found no significant variation in the rates of crime. (Parks, 2014)

HEATH AND WELL-BEING

Peter Boyce, professor of lighting and human factors, wrote that there were three kinds of lighting: bad lighting, nondescript lighting and good lighting. Bad lighting, which has identifiable faults, should be avoided, and the new LED lamps have faults: glare, light

trespass and colour temperature. (Boyce, 2014)

Light affects our health and well-being in more ways than one. LED-based streetlights are whiter than traditional ones and contain more blue light, which can disrupt people's circadian rhythms.
Studies recognized by the World Heath Organization (WHO) show that white LED lights emit a form of blue light that suppresses the production of melatonin, which is responsible for regulation of the body's biological clock. Interference with the body's internal clock has been associated with health problems including sleep disruption, depression, diabetes, obesity and cancer. (Stevens, 2016)

The American Medical Association (AMA), at its annual meeting on 14th June, adopted an official policy statement about street lighting: "Cool it and dim it." This was in response to the rise of new LED street lighting sweeping the country. An AMA committee issued guidelines on how to choose LED streetlights to minimize harmful human health and environmental effects. Although the streetlights deliver energy-saving benefits, the AMA's stance reflects the importance of proper design of new technologies and the connection between light and human health. (AMA, 2016)

CORRELATED COLOR TEMPERATURE of 2,700K VS CCT 400K-4,800K

It is now widely accepted that lighting on streets, roads and other outdoor public places should have correlated colour temperature (CCT) of 2,700K – but, in any event, must not exceed a CCT of 3,000K. (Bunya, 2015)

The City of Davis, California replaced newly installed 4,800K lighting with 2,700K at a cost of $350,000 in 2015, following surveys that showed residents' complaints about what they called 'prison-white lighting'. (Ashdown, 2015) The US Department of Energy published a Gateway report on pedestrian lighting and, had city officials acted on the report, they might have saved $350,000 and the wrath of the citizenry. (DOE, 2014)The results of the surveys also revealed that pedestrians might have different criteria for lighting than those of drivers, especially in areas in Davis where cars are subordinate to bicycles and foot traffic. In addition, the city of Montreal suspended its $110 million project to replace 110,000 standard streetlights with LED lighting until the health risks and potential for light pollution is better documented. (Bruemmer, 2016)

Yet, in contrast, Sheffield City Council (SCC) is installing 4,000K-plus LEDs. The SCC seems to have taken no notice of the US Department of Energy's Gateway report on pedestrian lighting and other research. Neither is the SCC taking the advice of the AMA (American Medical Association), IDA (International Dark Sky Association), CPRE (Campaign for Rural England) and PHE (Public Health England), which all recommend using warm-white CCT – ideally 2,700K lights – to minimize glare and discomfort. (Stevens, 2016)

PHOTOPERIODISM – THE CIRCADIUM RHYTHM

Trees have to sleep at night. "Research shows that trees near street lights die earlier. Like burning a lamp in your bedroom at night, it is not good for you." (Wohlleben, 2016) Sensitivity to day length, known as photoperiodism, determines when a plant bolts, fruits or produces storage organs (as potatoes do). It occurs in plants and animals. It can also be defined as the developmental responses of plants to the relative lengths of light and dark periods.

Scientific research has confirmed it is the length of the dark periods that controls plant growth. Almost all living things have internal circadian clocks that control many of life's processes. According to University of Washington researcher Takato Imaizumi, whose Imaizumi Laboratory studies seasonal response and circadian rhythms in plants, "The circadian clock is not constantly sensitive to light. It has a light-sensitive window at the end of the day that acts as a gating mechanism. (Imaizuni *et al.*, 2006)

The specific band of wave lengths of light tells a tree or shrub to grow, while, through shorter days and cooler nights, mother nature tells it to get ready for winter. Trees prepare for winter by becoming dormant. Come a cold snap, a young tree still growing could be killed.

Red light from streetlights are the problem. This can have harmful effects on both wild and domesticated plants. Horticulturalists became aware of the problem as a result of research by Cathey and Campbell in 1975 using 40 ornamental trees. When compared, the five light sources used promoted vegetative growth and delayed dormancy of woody trees in the order from most to least effective. The sensitivity of the 40 trees to security lighting was then placed into three groups, i.e., High, Intermediate and Low. For example, Betula papyrifera (Paper birch) was in the high group. (Cathey *et al*, 1975). Birch were placed in the high-sensitivity group (Fig. 2: Birch near HPS lamp with dead crown), while Oak species were placed in the low-sensitivity group.

Figure 2 Paper Birch near HPS lamp with dead crown

LED streetlights, likewise, emit more red light on a per-lumen basis than HPS lamps. For example, "It is the specific band of wave lengths at the red end of the spectrum that were the controlling factor in preventing morning glory buds from opening normally". (Ott, 1958)

The LEDs will affect the short-day/long-night plants, which flower in spring or autumn. A plant that requires a long period of darkness is termed a "short-day" ("long-night") plant. Short-day plants form flowers only when day length is less than about 12 hours. Many spring and autumn flowering plants are short-day plants, including tomatoes, roses, nasturtiums, chrysanthemums, poinsettias and Christmas cacti.

Street lighting is causing spring to come at least a week early in the UK. Researchers from the University of Exeter, in collaboration with independent environmental consultants Spalding Associates in Truro, have found that buds were bursting by up to 7.5 days earlier in brighter areas, and that the effect was larger in later-budding trees.(Richard H. ffrench-Constant *et al*, 2016). The research was led by a team of biologists based at the Penryn campus. It highlighted for the first time,

and on a national scale, the relationship between the amount of artificial nighttime light and the date of budburst in woodland trees.

The study was of data collected by citizen scientists from across the UK – part of a phenology network of The Royal Society and the Woodland Trust. The data provided evidence to scientists that phenology of woodland tree species (i.e., advanced in budburst) may be affected by light pollution. The data also suggested that smaller plants growing below the height of streetlights were even more likely to be affected. This advance of budburst illustrated the need for further experimental investigation into the impact of artificial night-time lighting on plant phenology and subsequent species interactions. As light pollution is a growing global phenomenon, the findings of this study are likely to be applicable to a wide range of species interactions across the world.(Richard H. ffrench-Constant *et al.*, 2016)

The night-time illumination can also reduce crop yield by 20–40%. As a result, soybean farmers learned not to plant in a field adjacent to HPS roadway lighting. (Chen *et al.*, 2009)

Long-day/short-night plants flower in summer: hollyhocks, irises, sweet clover, barley, and wheat. (The cessation of growth us usually induced by long nights.) Many summer-blooming flowers and garden vegetables are long-day plants, such as asters, coneflowers, California poppies, lettuce, spinach and potatoes.

Depending on the species and various environmental factors, even low levels of light trespass from roadway and outdoor luminaires can have harmful effects on both wild and domesticated plants. LED streetlights likewise emit more red light on a per lumen basis than HPS street lights. Sensitivity of trees, distance from lamp standard, season, temperature and age are factors that need to be considered.

According to research (Cathey *et al.*, 1975) conducted at the US Agriculture department centre, in Beltsville, Maryland, the lights are injurious to most trees and can be fatal to young ones. Low vigor is due to a number of causes: limited sunlight, carbon monoxide, little water, sulfur dioxide, ozone, fine particulate matter from smoke stacks, interference with transpiration and respiration, and lack of humus in soil.

Finally, excessive outdoor lighting disrupts many species that need dark environments. Poorly designed LED lighting disorients some bird, insect, turtle and fish species. Knowing this, US national parks have adopted optimal lighting designs and practices that minimize the effects of light pollution on the environment. (AMA, 2016)

DISCUSSION

Trees can significantly influence the urban environment. Further research is needed to quantify and monetize the environmental benefits of urban forest ecosystems, and to measure their effects on our health and wellbeing.

The results of The Royal Society and the Woodland Trust study in 2016 highlight the need to carry out experimental investigation into the impact of artificial night-time lighting on phenology and species interactions. It also suggests that looking at other aspects of phenology, such as leaf senescence, would be highly worthwhile. Importantly, further studies should also consider differences in light quality, such as the specific wavelengths of light generated by different lighting types. (Richard H. ffrench-Constant *et al.*, 2016)

I urge city officials to carefully select such trees that are day neutral and hence unaffected by the blue-rich LED's. Day-neutral plants form flowers independent of day length. However, as a result, there is concern over creating a monoculture on the urban streets.

We need to create responsible standards to guide urban- and outdoor-lighting design and not continue to allow uncontrolled lighting. The rush to replace roadway lighting systems with blue rich LEDs could degrade our quality of life and have a negative impact on human health and ecology.

A better understanding of how and to what degree urban trees influence the environment will lead to better management of urban trees, significant monetary savings for urban residents and a more pleasant and healthy urban environment.

The wavelength, angle and intensity of new or replacement lighting intended to save energy should be tested in situ before a scheme is implemented. This will ensure that it is the minimum required and does not cause harm to human well-being, trees and wildlife, and be preceded by thorough health and environmental impact assessments.

As there are various factors in selecting urban tree sizes Municipal Authorities should Survey their residents to find out how much they are willing to pay to preserve and improve urban environments. (Sanchez-Medina A. et al, 2017). It is imperative for local communities be listened to and involved in deciding how streetscapes including trees and lighting are planned, managed and maintained to ensure that citizen concerns and complaints about excessive lighting are taken seriously and demand action.

REFERENCES

American Medical Association [AMA] Press (2016). **AMA Adopts Guidance to Reduce Harm from High Intensity Street Lights**. Available from: http://www.ama-assn.org/ama/pub/news/news/2016/2016-06-14-community-guidance-street-lighting.page

Ashdown, Ian. (2015) **Light pollution depends on the light source CCT**.

Ashdown, Ian. (2016) **Botanical light Pollution, Red is the New Blue**. All Things Lighting**.**

Aubé, M, Roby, J, Kocifaj, Miroslav (2013) **Evaluating Potential Spectral Impacts of Various Artificial Lights on Melatonin Suppression, Photosynthesis, and Star Visibility**. Available from: https://doi.org/10.1371/journal.pone.0067798

Benya, Jim. (2015) **City's LED retrofit shows need for careful lighting**.

Boyce, P. R. (2014) **Human Factors in Lighting**. CRC Press Book.
Bruemmer R. (2016). **Opposition calls for suspension of Montreal's LED street-lights project**. Montreal Gazette.

Cathey, H. M., and L. E. Campbell. (1975) **Security Lighting and its Impact on the Landscape.** Journal of Arboriculture 1(10): 181-187.

Chen, C. L, Y. H. Su, C. J. Liu, and Y.C Lee. (2009) **Effect of Night Illumination**

on Growth and Yield of Soybean. Journal of Taiwan Agricultural Research 58(2): 146-154.

Gewirth, W. (1973) **Another view of the sodium vapour lamps**. The Herald, p22.

Imaizumi, T. and Kay, S.A. (2006) **Photoperiodic control of flowering: not only by coincidence**. Trends Plant Sci 11,550-558.

LighTimes (2014) **DOE Publishes Gateway Report about LED Lighting for Pedestrians**. US Department of Energy.

Luginbuhl CB, Boley PA, Davis DR, Duriscoe DM. (2014) **The effects of lamp spectral distribution on sky glow over observatories**. Highlights of Astronomy vol. 16, 2014, as presented at the XXVIII General Assembly of the International Astronomical Union, Beijing, China, August 20–31, 2012.

Matzke, E. B. (1936) **The Effect of Street Lights in Delaying Leaf-fall in Certain Trees**. Journal of Botany 23(6): 446-452

Mokhoff, N. (2015) **LEDs Address Concerns of Efficient Street Lighting**. Electronics 360.

Morrow E, Shawn A. Hutton N. (2000) **The Chicago Alley Lighting Project: Final Evaluation Report**. Research and Analysis Unit Illinois Criminal Justice Information Authority.

NHTCA. (2007) **Nighttime Glare and Driving Performance**. National Highway Traffic Safety Administration Report to Congress

Ott, J. (1958) **My Ivory Cellar**. Literary Licensing, LLC.

Parks, B. (2014) **The Future of Outdoor Lighting**. PAS Memo.

Richard H. ffrench-Constant, Robin Somers-Yeates, Jonathan Bennie, Theodoros Economou, David Hodgson, Adrian Spalding, Peter K. McGregor. (2016) **Light pollution is associated with earlier tree budburst across the United Kingdom**. DOI: 10.1098/rspb.2016.0813

Ruddat, M. (1975) **Evaluation of Report on High Pressure Sodium Lighting by Dr. John W Andresen**.

Ruddat, M. (1975) **Critique Of Anderson Report, Detailed Commentary**.

Sanchez-Medina, A. Alvaro Sánchez-Medina, Esperanza Ayuga-Téllez, Lucrecia Contato-Carol, M. Ángeles Grande-Ortiz, and Concepción González-García, (2017) **Selection of Tree-Size Variables for Appraisal Methods for Urban Trees According to Their Collinearity**. Arbourculture & Urban Forestry scientific journal.

Seong-Rin Lim, Daniel Kang, Oladele A. Ogunseitan, and Julie M. Schoenung (2013) **Potential Environmental Impacts from the Metals in Incandescent, Compact Fluorescent Lamp (CFL), and Light-Emitting Diode LED) Bulbs.** Environ. Sci. Technology, *47* (2), pp.1040–1047

Steinbach R, Perkins C, Tompson L, Johnson S, Armstrong B, Green C, Grundy J, Wilkinson P, Edwards P. (2015) **The effect of reduced street lighting on road ca-**

sualties and crime in England and Wales: controlled interrupted time series analysis.

Stevens, R. (2016). **American Medical Association warns of health and safety problems from 'white' LED streetlights**.

Technology Strategy Board (TSB). (2014) Available from: http://futurecity.glasgow.gov.uk/

Wohlleben, Peter (2016) **The Hidden Life of Trees: What They Feel, How They Communicate – Discoveries from a Secret World. Penguin Press Science** (ISBN: 9781771642484). Quoted statement made at the Hay Festival of Literature in Wales, 2017.