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TECHNICAL NOTES

Human Health: LED Lighting, Insects, and Wavelength

This article examines the issue of insects attracted to lights in the nighttime environment and the risk to people from insects carrying diseases. A review of the current understanding is given, along with possible ways to reduce attraction, in the context of LEDs used in off-grid lighting products.

Introduction

Everyone knows that certain flying insects are attracted to artificial lights in the evening. This can be seen at countless outdoor fixtures every night as swarms of bugs fly around the glow of the lamp. Aside from being a potential nuisance, this could have consequences in terms of human health when insects that carry human diseases are included in that swarm.

New research has tested a variety of lighting technologies, including light emitting diode (LED) sources, and how these may differ in their attraction to flying insects. More research is needed to better understand this phenomenon, but some elements are understood and offer ways in which off-grid LED products might be configured to reduce insect attraction.

Flying Insect Disease Vectors

Insects that help spread and transmit diseases are called vectors. The types of insect vectors and the diseases they spread vary greatly by geographic region, season, and local conditions. Many are bloodsucking and spread infection between animal and human hosts through blood borne transmission, biting an infected individual and then transmitting the disease through subsequent bites. Some vector-borne diseases are spread by mechanical transmission (where the disease is transported by the insect but does not undergo development on or in the insect host), while others require their insect host as an essential step in the disease organism life cycle. Some examples of flying vectors and the diseases they spread are:

Mosquitos

Mosquito species (Figure 1) represent the greatest insect health hazard to large populations of people. Malaria and Dengue fever, both spread by mosquitos, affect hundreds of millions of people every year. Most species of mosquito are crepuscular, meaning that they are most active in the low light environment during dusk and dawn. Three species of mosquitos are responsible for the following diseases:

- *Aedes* – Chikungunya, Dengue fever, Rift Valley fever, Yellow fever, Zika
- *Anopheles* – Malaria, Lymphatic filaiasis
- *Culex* – Japanese encephalitis, Lymphatic filariasis, West Nile fever

FIGURE 1.
Anopheles Gambiae, primary malaria vector

The movement of insects towards a source of light radiation is referred to as positive phototaxis. The reasons for this behavior are not thoroughly understood and may or may not serve an evolutionary function in different species. Celestial navigation in nocturnal insects, where an individual uses a fixed point of light for orientation so it can fly in a straight line, results in a decreasing spiral for terrestrial light sources. It has also been postulated that artificial light may appear to insects as an area of open sky, which may be either attractive or repellant depending on the behavioral goal of the insect at the time (when diurnal insects are disturbed at night, for example, they may seek areas of open sky as a means of escape).

Wavelength

Of particular interest is the influence of wavelength on positive phototaxis. Spectral (colour) vision is dictated by the structure of the eye and the presence of certain pigments in the cell structures, and these vary by species. Many have peak visual sensitivity in the ultraviolet (UV) and blue portions of the spectrum, while some are also capable of seeing red and infrared (IR, or heat) wavelengths emitted by warm blooded animals. Research and anecdotal experience suggests that flying insects have a strong phototaxis response to UV wavelengths. This has led to the development of UV 'bug zappers', which attract and kill flying insects, and also yellow incandescent 'bug lights', which (purportedly) do not attract as many insects because of the lack of blue light emitted by the source.

Bug Zappers and Yellow Bug Lights

Bug zappers typically use a UV emitting source and an electric grid to attract and kill insects. They can be very effective in killing many insects a night, though they are indiscriminant and potentially kill more beneficial insect species than pests. One study looked at the variety of insects killed and found a low number of mosquitos in the total population of kills[1]. Bug zappers do, however, provide anecdotal evidence that UV light is a strong insect attractant.

Yellow incandescent bug lights have been available for many years. The yellow filter on the bulb wall reduces the blue light component of the output but does not eliminate the infrared (IR) output. The efficacy of these lamps in reducing phototaxis is unproven and likely dependent on insect species. Some insects may be less attracted because of the lack of blue light, while others may still respond to the heat output (one researcher suggests that flies in particular seem attracted to the heat[3]).

Most commercially available white LEDs do not emit any UV radiation (< 400 nm) and very little IR radiation (>700 nm) but do emit blue wavelengths with an emission spike centered around 440-460 nm. As explained in the following section, the proportion of blue light relative to the rest of the visible light spectrum (generally considered to be 380-780 nm) will determine how 'cool' or 'warm' the light appears, with lower blue emission giving a warmer, redder light.

Colour Temperature, Correlated Colour Temperature, and Wavelength

An understanding of the spectral power distribution (SPD) of a light source and how this relates to colour temperature and correlated colour temperature (CCT) is helpful when assessing the influence of wavelength on the phototaxis behavior of insects. SPD is a measurement of the emitted wavelengths of electromagnetic radiation and is frequently represented graphically (Figure 2). The relative balance between the blue spike and the broader green/yellow/red emission results in white light of different hues, with a larger blue spike resulting in a bluish-white light and a smaller blue spike resulting in a reddish, or warmer, white light.

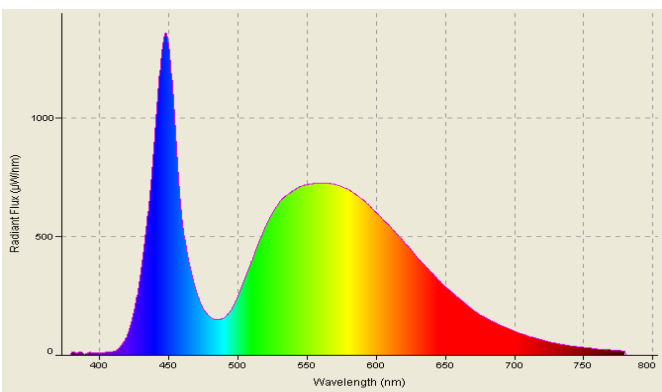

FIGURE 2.
A graph showing the spectral output of a white LED within the visible spectrum. The LED emits light at different wavelengths including a sharp blue spike at 460 nanometers.

Colour temperature is used to describe the spectral composition of a black body radiator. Sunlight and light from filament (incandescent) bulbs will exhibit black-body radiation emission according to the temperature of the emitter (i.e. the Sun or the bulb filament), with hotter temperatures increasing the blue content of the light (described as bluish, or cooler colour temperature) and lower temperatures increasing the red content (warmer colour temperature). The colour of the white light can be charted on a chromaticity diagram (Figure 3), with black-body radiation from a thermal emitter falling on a locus (called the Planckian locus). This method of describing white light stems naturally from the light emitted by the Sun as well as the light from a filament bulb.

Light from LEDs and electric discharge lamps generally does not fall on the Planckian locus on a chromaticity diagram but still has the necessary wavelengths for us to perceive it as white. Correlated Colour Temperature (CCT) is then used to describe this light. CCT can be thought of as "similar to" colour temperature in the sense that a 2700K fluorescent lamp has a similar colour appearance as a 2700K incandescent (filament) lamp and a 2700K LED lamp. All three sources will have different SPD's, the LED and fluorescent lamps will have a 2700K *CCT*, and the incandescent filament lamp will have a 2700K colour temperature. When viewed side-by-side, however, the lights will look somewhat different and may render different hues of greens, blues, or reds.

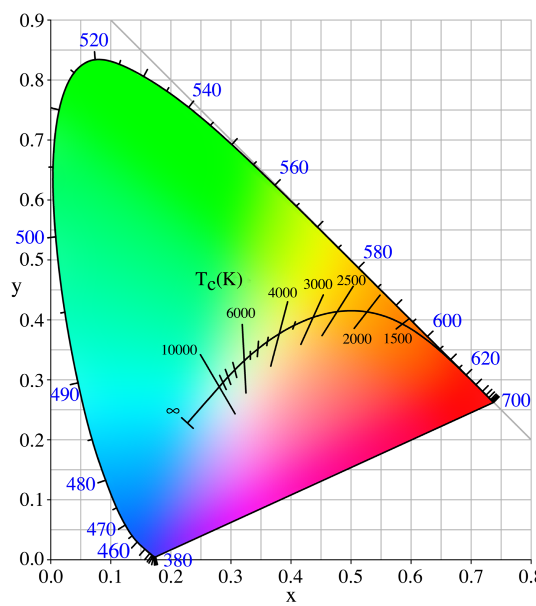

FIGURE 3.
CIE 1931 xy chromaticity diagram w/ Plankian locus[2]

These relationships must be considered when assessing the spectral content of different lighting technologies.

The 2700K fluorescent and LED lamps in the previous example will look very different in terms of their SPD's, and the fluorescent lamp will have UV emissions that are absent in the LED lamp. Indeed, two different LED lamps with the same CCT can also have different SPD content (though in general the emission will be substantially similar).

This leads to the conclusion that CCT alone cannot be used to assess the wavelength content of a light source. When considering how this affects insect phototaxis, a more detailed SPD review will often be necessary.

Phototaxis Research

Insect phototaxis research is difficult to perform. There are a large number of variables that must be considered, and many of these variables cannot be readily controlled during the experiment. Outdoor environments contain a great variety of possible factors that may influence outcomes, and the heavy amount of work involved in setting traps and collecting/counting different trapped insect species makes it exceedingly difficult to amass large sample sizes over many evenings.

Experiments reviewed for this article3,4,5 are based on light trap collections at night. The light traps are set up with controls for total illumination, placement geometry, lunar illumination, temperature, season, and other miscellaneous factors that could affect collection efficiency. Researchers attempt to control for these variables in different ways and this will contribute to the types of conclusions that may be drawn.

When two different lighting technologies are placed near each other, research supports the conclusion that some technologies attract a particular insect species more than others. This preferential phototactic response appears related to the spectral content of the different lights. UV radiation has been shown to be a preferential attractant, with blue and infrared wavelengths following second in terms of likely contributor wavelengths. The overall results suggest that LED lights are less attractive to insects overall than those emitting UV or IR radiation – this includes fluorescent, compact fluorescent, discharge, or incandescent lamps. This places LED illumination as a potentially good choice in terms of reducing positive insect phototaxis.

Studies looking at the differences between 'cool' LED lights (high CCT) and 'warm' LED lights (low CCT) are less conclusive. For two lights with the same overall light output, the cooler of the two will typically have a higher blue output and the research suggests it will be somewhat more attractive to many insects. This is a relative response, however, and while warm white LED lamps may reduce phototactic response in relation to other white lights, they are unlikely to eliminate positive insect phototaxis entirely. A reduction, however, may still have value.

One study5 followed this line of thought by tuning an LED lamp output to specifically decrease insect attraction. The details of the output were not provided but an overview of the study suggests the LED lamp was based on a red/green/blue (RGB) combination of individual LEDs. RGB LED lamps are a known and available technology but are less common than phosphor converted white LEDs. Colour tuning approaches like this have been in use for several years in the general LED lighting industry, in both commercial and residential settings, and could offer promise in the off-grid space.

Relative vs. Absolute Phototactic Response

One important aspect of the available research concerns the basic way the studies are conducted. If multiple lighting technologies (and insect traps) are employed at the same time, the results point to relative differences between phototactic insect behavior. Given a choice between two lights, insects may prefer one over the other and this becomes a relative measure of response.

If, however, only a single technology is used during a single evening, this can point to the absolute phototactic response of those individuals caught in the traps. Controlling for differences between consecutive evenings becomes more challenging, however, and introduces additional variables related to nightly changes in the local conditions during the experiment.

Invisible Bug Lights?

The ultimate goal of research in this field would be to produce a lighting technology that would be either invisible or repulsive to insect species AND visible to humans as bright white light. Thus far this has not been demonstrated as possible. The next best outcome is a reduction in insect attraction, and unlike the ideal case this goal may be achievable through selective design and novel approaches.

As an example, filters have been used with white LEDs to reduce or eliminate wavelengths below a target value, typically below 500 nm. Directing light from a fixture downward by using cutoff optics might be another approach. This can reduce the lateral brightness of the light, reducing glare and lowering the long-distance visibility of the light.

Yellow (Amber) LED Lights

The yellow region of the visible spectrum is the most promising wavelength range that is least attractive to insects. LEDs are capable of producing these wavelengths without producing UV, blue, or IR wavelengths.

There are two amber led technologies currently in use. (Figure 4). One is based on an LED chip that directly produces single colour (narrow band) light with a peak wavelength near 585-590 nm. Another uses a blue LED chip, as with white LEDs, and an amber phosphor that converts the majority of the blue light to a wide band amber light. These are called PC (phosphor converted) amber LEDs. They were originally developed to address the lower efficiency of chip based amber technologies.

As LEDs are increasingly used in outdoor nighttime environments, it has been suggested that amber and PC amber LEDs could be used to instead of white to reduce the environmental impact of artificial outdoor lighting. Light pollution is driven in large part by blue wavelengths scattering in the atmosphere, and is increasing as white LED lamps are replacing traditional high pressure sodium lamps. Sea turtle nesting grounds are disturbed by white light but can be safely illuminated by amber LED light.

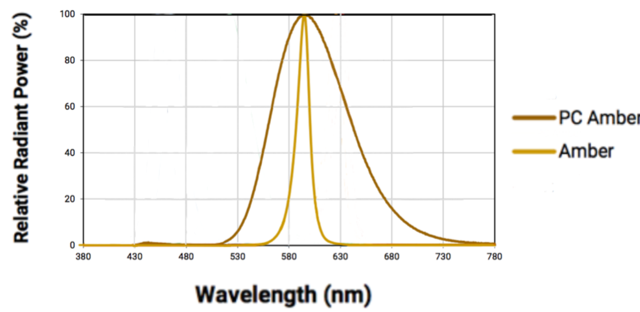

FIGURE 4.
Amber and PC Amber LED wavelengths

Conclusion

Opportunities may exist to design off-grid LED products that reduce insect attraction. The absence of UV and IR wavelengths in the LED emission is helpful, and design considerations to further reduce the blue component of light may decrease attraction even more. Warm white (low CCT) LEDs have lower blue content and would seem to offer a benefit, but research is still inconclusive regarding any insect phototactic benefits of warm white LEDs over cool white versions.

More research needs to be done to investigate the complex relationship of insects and nighttime lighting. If mechanisms can be found to reduce insect attraction, many people in areas afflicted by vector borne diseases stand to benefit.

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