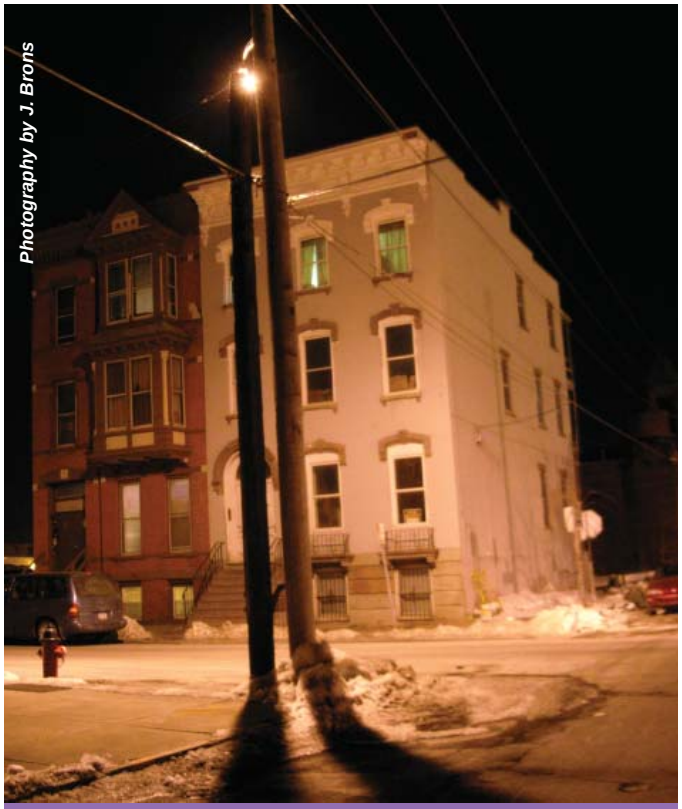
Thinking *Inside* the Box

Jennifer Brons, John Bullough and Mark Rea of the Lighting Research Center, Rensselaer Polytechnic Institute in Troy, New York, USA, report on a simple, yet comprehensive method of calculating light pollution and its effects, which could have widespread application

Light pollution encompasses many types of nuisance light leaving the boundaries of a property[1]. Lights from a city may prevent a view of the stars; street lights may cause light trespass by illuminating a bedroom window; a neighbours' luminaires may cause uncomfortable glare. These main effects are illustrated in ***photos 1-4.*** A group of lighting manufacturers[2] have joined with the Lighting Research Center to develop a comprehensive system for addressing these three key aspects of nuisance light. Entitled 'Outdoor Site (Lighting) Performance' (OSP), this evaluation system helps individuals meet their lighting needs, while protecting the interests of neighbours and society as a whole.

OSP starts with the fundamental assumption that a property owner needs the flexibility to use light as desired inside the boundaries of the property – but what matters from a societal perspective is the light leaving the property. OSP establishes a notional 'box' as the dividing boundaries between personal interests and public interests. The OSP 'box' follows the property



1. Light tresspass from a streetlight

2. 'Sky glow' over a city centre

3. Glare from poorly controlled floodlights

4. Another example of light trespass into windows

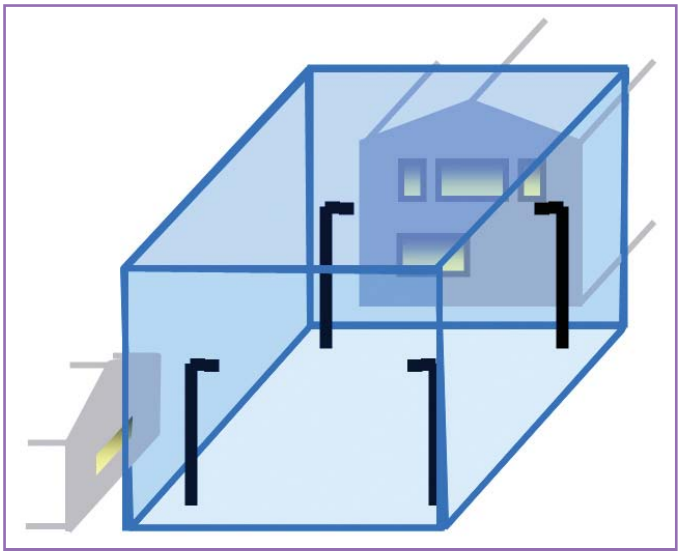


Figure 1: Calculation 'box' surrounding an outdoor lighting installation

line. Property lines (and set-backs) are a commonly established and well-understood foundation for legal considerations around the world. OSP calculations based on this 'box' provide a useful insight into the different aspects of light leaving the boundaries of a property.

As shown in Figure 1, OSP uses a hypothetical calculation 'box' surrounding a site. OSP calculates the light crossing the planes of the box in every direction. The calculation box is composed of calculation planes that can be generated by any commercial lighting software capable of calculating inter-reflections (OSP is based on both direct and inter-reflected light). The top of the calculation box is located a fixed but arbitrary distance (10m) above the highest architectural element on the property, such as the highest luminaire or the top of the building. Along a roadway, luminaires typically have regular spacing and therefore the process can be simplified by creating a box over just the repeated road segment ***(Figure 2).***

OSP is designed to be comprehensive, yet simple to understand, provide accurate predictions – and be field verifiable. OSP addresses sky glow by measuring all light leaving the property; this is termed glow. OSP addresses light trespass by measuring peak illuminances crossing the property boundaries; this is simply termed trespass. Although not discussed here, due to ongoing research, OSP will also include a measure of discomfort glare from luminaires; this will be termed glare.

OSP calculations rely primarily on illuminance (lux, or foot-candles in the USA) – probably the most widely-used photometric unit. Illuminance (rather than flux or intensity) is used because it is simple to understand, allows field-verification with standard instrumentation, and is the standard output of lighting calculation software. Field verification for OSP does not require extensive technical expertise, other than an illuminance meter and, in some cases perhaps, a bucket truck. Importantly, using illuminance as a unit of measurement does not place greater restrictions on large sites than small sites (calculations of glare will include geometric factors to supplement illuminance values).

Glow is the overall average illuminance combining side planes and top plane. Trespass in the OSP system employs maximum illuminances on any calculation plane. It is necessary to have separate OSP measures for glow and trespass because they are not necessarily correlated for a given property; for instance, a site may have

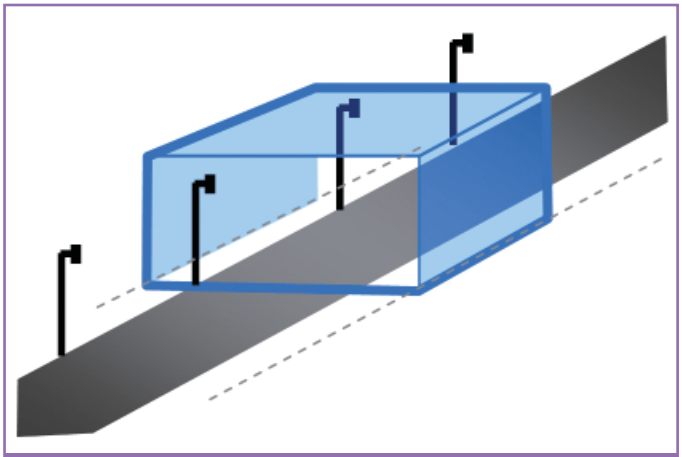


Figure 2: Calculation 'box' simplified for a roadway installation

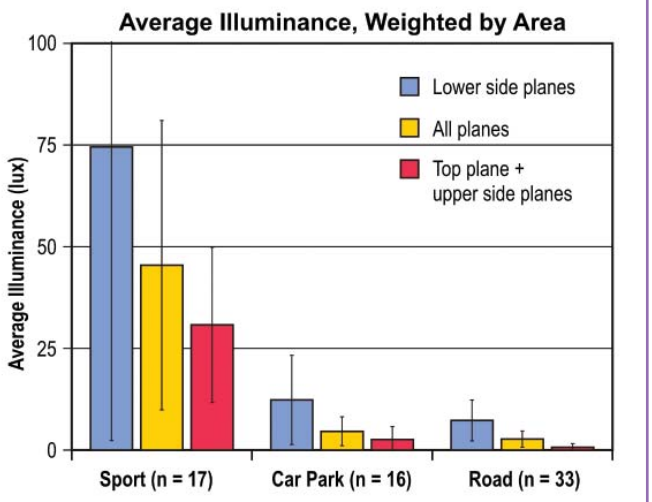


Figure 3: The amount of light leaving the properties is not negligible

low average illuminance but a few points with high illuminance.

Test Runs

The project sponsors collaborated with the Lighting Research Center to generate OSP calculations for common outdoor lighting applications, including car parks, roadways, and sports fields. Test runs were performed for 66 sites, many of which were actual, installed lighting designs. Each participant used their preferred lighting calculation software. The evaluated projects represented common practice, but not necessarily industry recommended practice. Most sites used pole-mounted luminaires that directed light only downward.

These OSP test runs showed a number of interesting results with regard to glow. When ground reflectance is included, the amount of light leaving outdoor lighting installations is not negligible ***(Figure 3)*** and is typically 20% of ground illuminance ***(Figure 4)***. This was true despite the fact that few luminaires in these test runs emitted light above 90 degrees. Present industry recommendations on light pollution limit direct upwards light from luminaires, ignoring the impact of inter-reflection on the amount of light leaving the property. Inter-reflections are a significant contributor to sky glow [3, 4]. The OSP test runs also showed that the amount of light leaving the property is highly correlated with the amount of light delivered to the ground plane ***(Figure 4).***

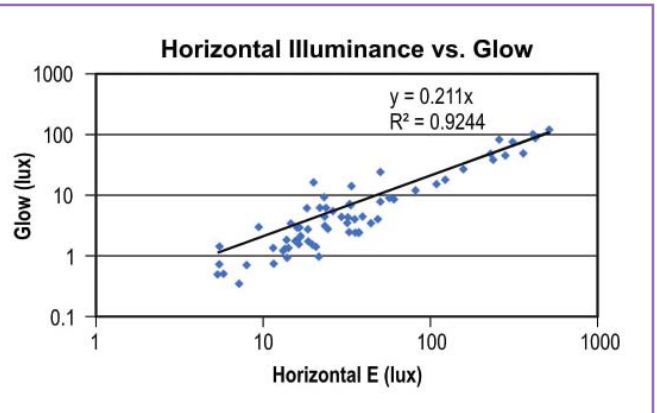


Figure 4: Glow increases as horizontal illuminance increases

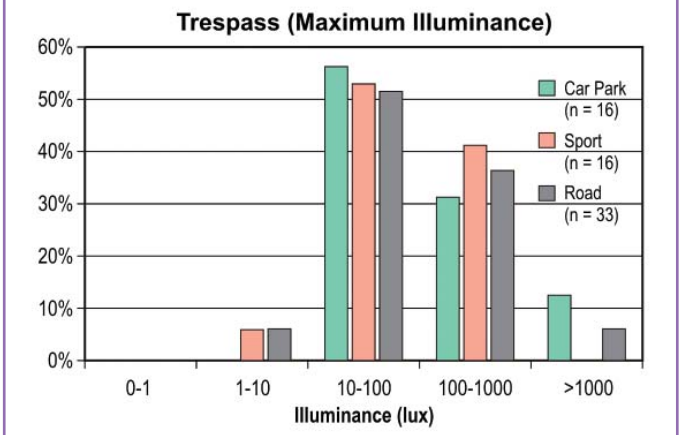


Figure 5: Maximum illuminance at property line often exceeds that allowed at a neighbour's window

The OSP test runs also provided insight into trespass. Maximum illuminances measured at the property lines (10-1000 lx) often exceed current illuminance recommendations[5,6] for those permitted on a neighbour's window (1-25 lx) ***(Figure 5).*** This difference is a natural consequence of the inverse square law; properties further away from the property boundary will have significantly lower illuminance levels than those on the property boundary. Of special interest, maximum illuminances at the property line were, in general, caused not by poor luminaire optics but simply by close proximity of the luminaries to the property lines.

These test runs showed that OSP is simple enough to work with real sites, yet refined enough to quantitatively evaluate potential light pollution caused by common lighting designs. Furthermore, the results of these initial test runs provide, for the first time, a platform for discussions about how much light should be allowed to leave properties.

Implications

Glow, that is, how much light leaves the site to contribute to sky glow, is affected by many features of a site.

- Illuminance levels: reducing light levels within the property boundaries will reduce glow.
- Ground reflectance: concrete will, for example, cause more light to leave the property than black tarmac, for the same design illuminance.
- Trees, roofs, and other structures: plantings and other light-absorbing materials will reduce glow.
- Small changes in luminaire optics will not significantly affect glow

as long as the luminaire is aimed toward the object being illuminated.

Trespass, that is the amount of light falling on adjacent properties, probably needs to be considered in new ways:

- Neither glow nor glare is well correlated with the maximum illuminance on the property line. For example, a single luminaire could be perceived as glaring, even if does not produce a high illuminance at a property boundary.
- Pole location plays a major part in determining illuminance on adjacent properties. Control of trespass is much more than controlling the luminaire optics.
- Trespass should not consider illuminance on planes outside the property boundaries because it is often impossible to know at the design stage where someone has, or will, locate an architectural feature, such as a bedroom window.

Present industry recommendations often focus on the optical distribution characteristics of a luminaire, rather than how the site is actually used. OSP test runs showed that seemingly innocuous pole lights can create trespass when mounted near a property boundary. By extension, a luminaire that is otherwise restricted by a luminaire standard (e.g. one with a curved bowl diffuser) could be allowed if the owner installs the pole some distance away from the property boundary or installs shielding. Since OSP is

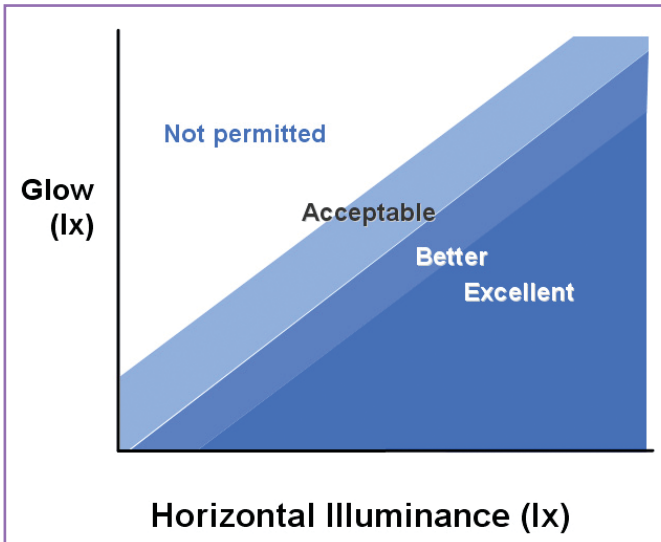


Figure 6: Diagram (not to scale) showing an example of how OSP could be used as a basis for an outdoor site rating system

performance-based, property owners are even free to use non-lighting techniques such as plantings to limit the amount of light leaving a property.

What makes OSP different than other methods of characterizing light pollution?

- OSP is fundamentally based on the property boundaries, the division between private and public interests.
- OSP is comprehensive in addressing all of the main issues associated with light pollution, glow, trespass and, although not discussed here, glare.
- OSP was developed from data generated from actual sites, so that stakeholders can begin meaningful and realistic discussions of recommended levels.
- OSP uses common calculation software, so implementation will not be hindered.
- OSP is flexible, so that individual needs can be addressed. For example, it is trivial to calculate total flux from glow. Further, as more research is acquired, different spatial, temporal or spectral weighting factors can be included in the calculation software.
- OSP calculations can be verified in the field using measurement equipment that is commonly available and inexpensive.
- Perhaps most importantly, OSP allows creative design solutions. The system is not dictatorial with regard to how a professional might meet the lighting design criteria; moreover, OSP respects the rights of property owners while ensuring social justice with regard to light pollution.

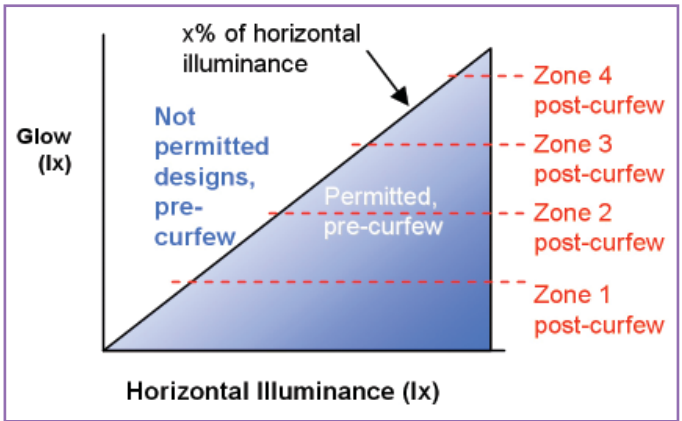


Figure 7: Diagram (not to scale) showing an example of how OSP could form the basis for community regulations for glow

Next Steps

OSP could form the basis of a rational, quantitative discussion among stakeholders interested in limiting light pollution. Using results like those shown in Figure 4 above, a light pollution rating system could be established. Those sites producing glow values closest to the regression line could be rated as 'acceptable'. Those with minimal glow values for equivalent horizontal illuminance levels could be rated 'excellent' ***(Figure 6).***

OSP can also be used to shape a community's lighting restrictions. For instance, a community could permit a sports field with high horizontal illuminance, and thus high glow, as long as operation is limited to certain hours. Then, the community could superimpose stricter limits on glow after curfew hours ***(Figure 7).***

Groups concerned with trespass could also use OSP

in their efforts. Maximum illuminance (i.e., trespass) values could be set by a community, based on their environmental zone, the type of facility, special animal habitats or other community needs.

It should be noted that maximum illuminance leaving the sides of a property will, naturally, often be higher than the limits set by other bodies based upon illuminance on a neighbours' window[7]. It is usually impractical and even unreasonable to consider the location of windows on adjacent properties. Still, the goal is to establish limits on maximum illuminance on the property lines, such that trespass will be minimised. Research is ongoing to translate existing recommendations into maximum illuminance levels on property boundaries.

Conclusions

Light pollution is a general term that has been used in many different ways for many different purposes. OSP allows engineers, manufacturers and regulators to perform and quantitatively compare lighting designs with regard to light leaving the property (glow), obtrusive light on neighbour's property (trespass) and discomfort from a luminaire (glare, which will be subsequently presented). The OSP system is simple to understand, the measures are easy to calculate, they can be field verified – and OSP takes advantage of the commonly available lighting calculation software.

OSP is, we believe, the first comprehensive, quantitative system of assessing light pollution based upon the simple concept that property owners should have the personal freedom to meet their lighting design objectives, while simultaneously being required to meet the nuisance lighting limits set by their community.

References

1. McColgan, M, et al, 2003: Lighting Answers: Light Pollution, National Lighting Product Information Program, Troy, New York, USA.

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3. McColgan, M, et al. 2003: Lighting Answers: Light Pollution, National Lighting Product Information Program, Troy, New York, USA.

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5. International Commission for Illumination. 2003: 'Guide on the limitation of the effects of light trespass from outdoor lighting installations', CIE 150: 2003.

6. Standards Australia Committee, 1997: 'Control of the obtrusive effects of outdoor lighting', Australian Standard AS 4282-1997.

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