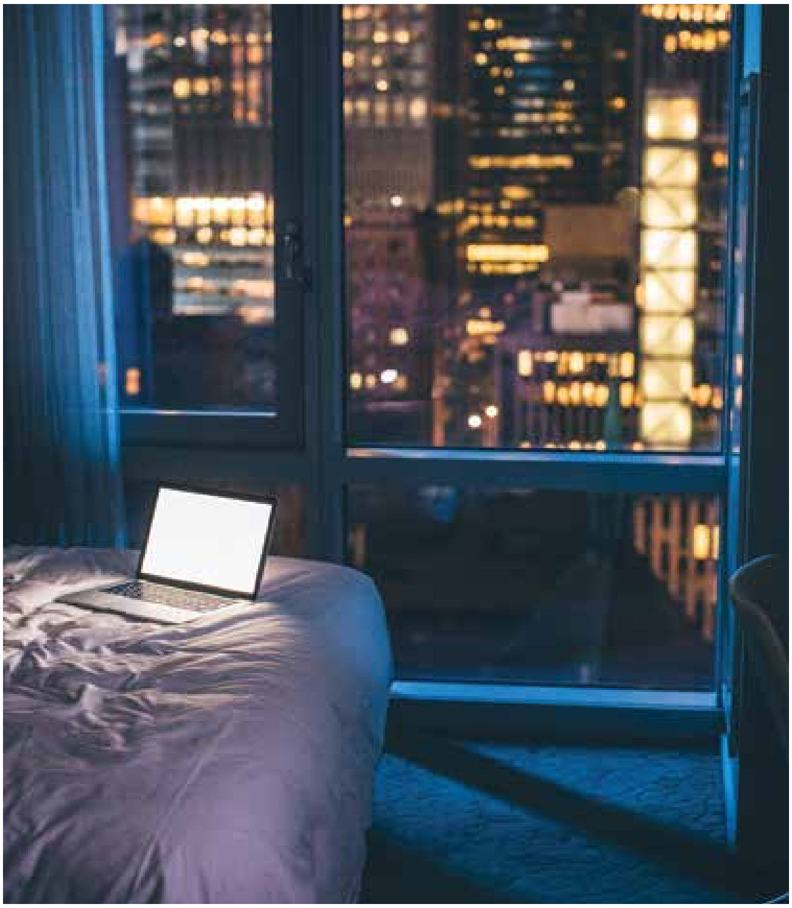

Home Nighttime Light Exposures

How much are we really getting in our residences?

BY NAOMI J. MILLER AND BRUCE R. KINZEY

An investigation into residential light exposure at night was prompted by the publication of an American Medical Association (AMA) report on LED street lighting in June 2016[i], and subsequent citations and responses by both the professional and mainstream press. The report raised fears that exposure to light at night from LED streetlights may contribute to a variety of potential health concerns, such as circadian disruption and insomnia, and possibly related issues like increased obesity and even cancer. Both the DOE and the IES published statements challenging the AMA's statements concerning the impact of LED streetlights on human circadian systems, and their recommended guidance[ii],[iii],[iv].

While the AMA document mentions various sources of light at night, from street lighting that filters through bedroom windows, to household interior lighting, to nightlights, to electronics such as TVs, tablets and cell phones, the recommendations are directed solely at street lighting. Nighttime light level and spectral exposure data are scarce[v], hindering clear understanding of the relative risks presented by different light sources. The authors undertook this project in order to pursue additional information about the amount of light people receive from street lighting entering their homes relative to typical light exposure inside residences during the evening and nighttime hours.

Pacific Northwest National Laboratory (PNNL), through the U.S. Department of Energy's Solid-State Lighting program, explored this issue with a small pilot study to measure light reaching the eye in various residential locations, enlisting the help of people who already own light meters and the knowledge to use them: lighting professionals. This group is also able to identify the types of light sources found in and around their own homes, to adequately measure the illuminance they provide, and to characterize their basic color qualities. IALD and IES Members were contacted and invited to participate in collecting lighting data.

The questions are listed in **Table 1**. Twenty-three IALD Members completed measurements; these results were further supplemented through an invitation to IES Members in the Portland, OR, and San Francisco Bay area. In all, data were received from 30 individuals: 25 from the U.S., three from Canada and two from the European Union. Of the participants, 11 described their neighborhood as urban, 17 as suburban and two as rural. Characterizing their living environments, 19 reported living in detached houses, six in apartments, two in high-rise apartments and three in condominiums. Several participants provided photos to illustrate the general space in which the measurements were recorded.

Participants measured illuminance at the eye as they looked through their living room or bedroom windows toward the nearest and brightest streetlight or other outdoor light, as well as from evening interior lighting in the kitchen, living room and bedroom. Illuminance at the eye was also measured from television, electronic tablet and phone sources, as well as from reading a book or magazine using a bedside reading light. It was important to measure illuminance at the eye rather than horizontal illuminance, because light entering the eye is the source of any biological effect. The illuminances and correlated color temperatures (CCT) reported by participants are summarized in **Table 2**.

Although this pilot study involved a relatively small number of participants, and participants were self-selected from a lighting-savvy population, the study gleaned information that may be useful for a more extensive study of this topic. **Figure 1** illustrates the resulting data grouped by area in each residence.

Table 1. Home Lighting Measurements Table

HOME ILLUMINANCE TABLE FOR IALD AND IES MEMBERS: LIGHT METER TEST

Residential Area	Target Measurement	Lux measured perpendicular to line of sight (e.g., 24.4)	Dominant light source (e.g., LED, CFL). Attach measured SPD if avail.	Dominant light source CCT (e.g., 5000K)	Dominant light source CRI (e.g. 80-90)	Notes or Comments
Kitchen	Kitchen, with all normal evening electric lights on. Standing at counters, looking in variety of directions. Maximum illuminance measured at the eye, with realistic viewing angles. Measurements in multiple directions optional.					
Living room or family room	Typical measurement of illuminance at eye using all normal evening electric lights. Drapes/blinds **closed**.					
Living room or family room TV watching	Drapes **closed**. Room lighting off. Measure illuminance at eye watching TV.					
Living room or dining room, looking outside	Looking out window toward brightest streetlight. Room lights **off**. Describe other visible outdoor lighting. See sketch B. **Please provide photo looking outside.**					
Bedroom interior	In bed at night reading book or magazine with normal pre-bedtime task and room lighting **on**, drapes/blinds **closed**. See sketch A.					
	In bed at night reading electronic tablet or cell phone screen with normal pre-bedtime task and room lighting **on**, drapes/blinds **closed**. See sketch A.		N/A	N/A	N/A	
	In bed at night with all lights, electronic displays and nightlights **off**, blinds or drapes **closed**		N/A	N/A	N/A	
	In bed at night reading tablet or cell phone screen set to normal evening brightness. Blinds or drapes **closed**, no electric lighting. Measure light from screen only.		N/A	N/A	N/A	
Bedroom, looking outside	At window facing nearest streetlight, vertical illuminance at eye looking outside toward streetlight, drapes/blinds open. No interior lighting. See sketch B. **Please provide photo looking outside.**					

Table 2. Summary of illuminances measured at the eye, CCT and light source types in the homes of 30 lighting professionals. INC = incandescent; HAL = halogen; CFL = compact fluorescent; HPS = high pressure sodium; LED = light emitting diode.

Space or task	Illuminance at eye (lux) reported by 30 participants			Light source CCTs and type, as reported by participants	
	Minimum	Median	Maximum	Minimum	Maximum
Kitchen – all normal evening electric lights on	6	104	485	1900 K LED	4000 K CFL
Living/Family room – normal evening lighting	3	23	410	1900 K LED	3000 K HAL or LED
Living/Family room - contribution from TV only	0	2	139	not recorded	not recorded
Living or Dining Room, looking outside through street side window at brightest light. No interior lighting	0	0.5	20	1800 K HPS	4600 K LED
Bedroom – in bed reading book or magazine with normal pre-bedtime room lighting and task light	1	15	347	2100 K INC	3000 K HAL or LED
Bedroom – in bed reading cell phone or tablet with normal pre-bedtime room lighting	1	14	86	not recorded	not recorded
Bedroom - in bed with light from reading cell phone or tablet ONLY	0	0.6	13	not recorded	not recorded
Bedroom – in bed with all lights off, drapes/blinds closed	0	0	2	not recorded	not recorded
No interior lighting	0	0.1	5	2100 HPS	4600 LED

Figure 2 shows a subset of these results, but on a smaller scale to show detail on lower-illuminance spaces or tasks.

OBSERVATIONS

Several observations are possible from the results:

1. **Wide variations across residences.** A considerable amount of variation is to be expected among individual residences. The sample sizes were too small to draw definitive conclusions, but homes in rural areas generally had lower illuminances from street lighting entering windows than in urban or suburban locations, as would be expected. Otherwise, there were no discernable trends among interior lighting or outdoor lighting exposure levels by dwelling type.

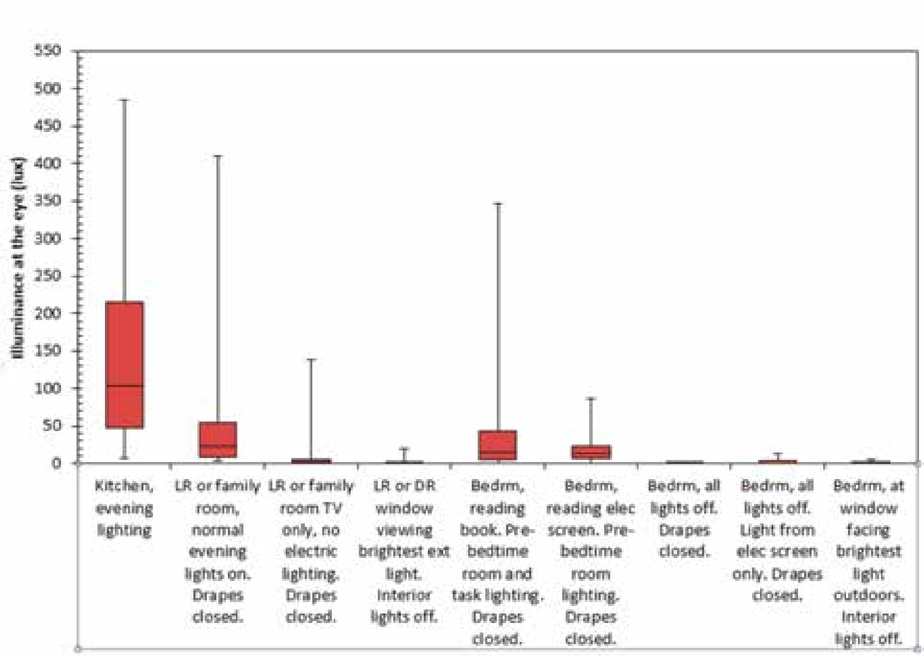

Figure 1. Range of measured eye illuminance values, by space. The top of the upper vertical line represents the maximum value; the top of the red bar, the 75th percentile; the horizontal line in the red bar, the median; the bottom of the red bar, the 25th percentile; and the bottom of the lower line represents the minimum value.

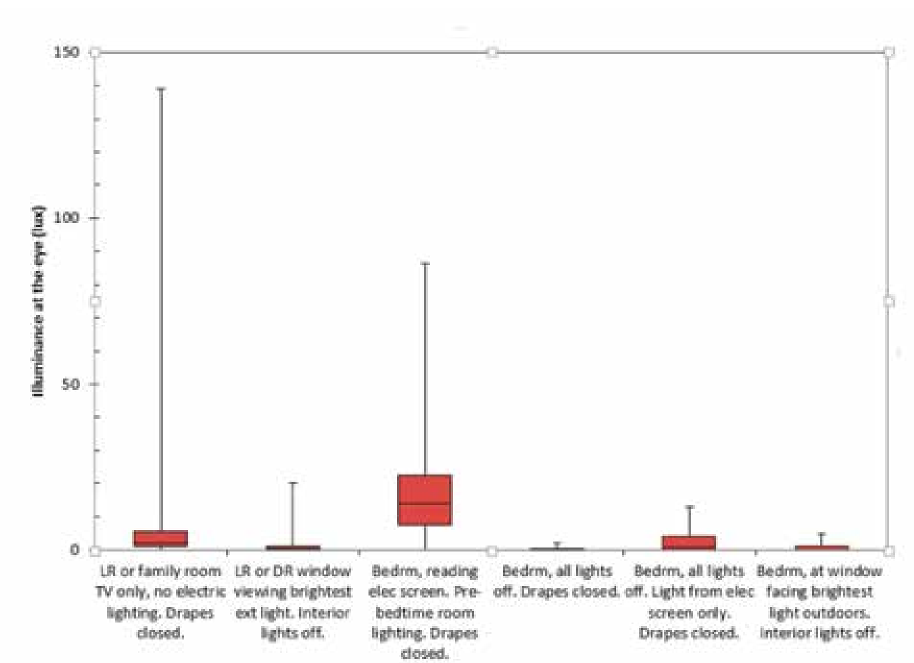

Figure 2. Range of measured eye illuminance for the six lower-illuminance measurements. See Figure 1 for key to plotted values represented in bar. In the case of the bedroom with all lights switched off, the median and minimum values are almost identical.

Table 3. Selection of light sources used for indoor and outdoor lighting, and their relative melanopic content compared to an incandescent baseline. This is an approximation, since SPDs for a given CCT can vary widely. In the case of phosphor coated LEDs (PC White), a range is shown, based on PNNL's 2017 database of tested outdoor commercial products.

Row	Light source	Luminous Flux (lm)	CCT (K) Content*	Relative Melanopic
A	PC White LED	1000	2700	0.67 - 0.95
B	PC White LED	1000	3000	0.74 - 1.06
C	PC White LED	1000	3500	0.83 - 1.26
D	PC White LED	1000	4000	0.83 - 1.20
E	PC White LED	1000	4500	0.97 - 1.35
F	PC White LED	1000	5000	1.13 - 1.32
G	PC White LED	1000	5700	1.22 - 1.60
H	PC White LED	1000	6500	1.55 - 2.07
I	Narrowband Amber LED	1000	1606	0.04
J	Low Pressure Sodium	1000	1718	0.03
K	PC Amber LED	1000	1872	0.15
L	High Pressure Sodium	1000	1959	0.30
M	High Pressure Sodium	1000	2041	0.35
N	Mercury Vapor	1000	6924	0.87
O	Mercury Vapor	1000	4037	0.89
P	Metal Halide	1000	3145	0.90
Q	Metal Halide	1000	4002	1.12
R	Metal Halide	1000	4041	1.33
S	Moonlight	1000	4681	1.61
T	Incandescent	1000	2836	1.00
U	Halogen	1000	2934	0.99
V	F32T8/830 Fluorescent	1000	2940	0.81
W	F32T8/835 Fluorescent	1000	3480	1.01
X	F32T8/841 Fluorescent	1000	3969	1.12

* Melanopic content calculated according to CIE Irradiance Toolbox, http://files.cie.co.at/784_TN003_Toolbox.xls, 2015

2. **Color and melanopic content of light.** 100% of participants responding to the questions on CCT indicated 2700K or 3000K interior light sources in their living rooms and bedrooms, comprising either halogen, compact fluorescent or LED sources. In kitchens, one respondent reported a CCT as high as 3500K (linear fluorescent) and another 4000K CFL. One participant reported LED sources as low as 1900K used in the home at night, using a dim-to-warm lamp product. The streetlight sources contributing light through residential windows were almost entirely either high-pressure sodium (HPS, 1800K–2100K) or LED in 4000K. Two participants reported higher LED streetlight CCTs, one at 4600K and one at 5000K.

Because only a few lighting professionals were able to capture light source spectra, the authors estimated the relative amount of blue-cyan rich light for a selection of common sources, according to the known response of the intrinsically-photosensitive retinal ganglion cells (ipRGCs)[vi]. The last column of numbers in **Table 3**, termed "melanopic content," roughly indicates the relative effect the light source could have on the human circadian system at night, compared to an incandescent lamp at the same lumen output. The ipRGC response is only one input to the alerting and circadian systems in the body, and is subsequently combined with input from rods and cones (and possibly other yet-unidentified inputs), the effects varying with intensity, duration and other factors. Nonetheless, melanopic content continues to be considered a prominent indicator of the biological impact of a light source on the human body at night.

3. **Moderate illuminance values.** Although each of the compiled illuminance readings in **Figure 2** contains maximum values that exceed IES recommendations, the medians are much nearer the minimum values in each set, suggesting that high light levels in residential applications are likely more the exception than the rule. For example, eye illuminance values in the kitchen varied widely by participant, with a high of 485 lx, a median of 104 lx and minimum of only 6 lx.
4. **Bedroom lighting.** Illuminances at the eye were measured by participants in multiple ways. They were measured with normal pre-bedtime room lighting and task lighting, with blinds or drapes drawn and the participant sitting in bed reading either an electronic screen or a paper book or magazine (**Figure 3**). Measurements were also taken to represent the "worst case" of light trespass from outdoor lighting, with the blinds open and looking out of the window towards the brightest exterior light source. The values are summarized in Table 2, with the interesting result that electronic display screens contributed considerably less light to the eye than the room lighting and task lighting for bedtime reading.

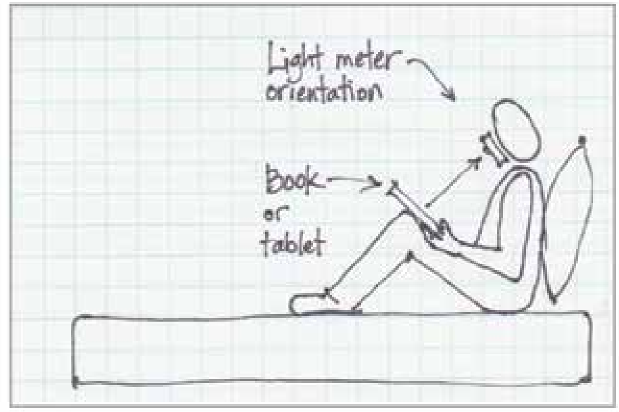

Figure 3. Illustration of bedroom area measurement orientation.

5. **Light from electronic screens.** Table 2 shows that television screens delivered a maximum of 139 lx, and a median of 2 lx to the eye of the occupant in the living room in addition to standard room lighting. Tablet or cell-phone screens delivered a maximum of 13 lx and median of 0.6 lx to the eye in the bedroom. Table 1 lists the total eye exposure when combined with normal pre-bedtime room lighting. These numbers are somewhat lower than studied in two recent research papers looking at cellphone and tablet use [vii],[viii]. Wood et al 2013, examined melatonin suppression from exposure to an Apple iPad screen at full output for one to two hours, delivering approximately 18 lx to the eye—with the accompanying finding of melatonin suppression averaging 7% after one hour of exposure, and 23% after two hours of exposure. In the Gringras et al 2015 paper, photopic illuminances at the eye ranged between 39 and 319 lx, recorded in a dark room from text displayed on an Apple iPhone 5S cellphone, Kindle Paperwhite or Apple iPad screen. The screens in that study were allowed to self-adjust according to ambient light level, except for the Kindle Paperwhite, which was set to a 50% brightness setting. Likely the lower eye

illuminances recorded in the PNNL study occurred because the screen images could be adjusted to the participants' preferred luminance setting, and the software displays were not unified to a specific screen image, such as a text mode with white background that would maximize illuminance to the eye.

6. **Comparatively low exterior light trespass.** The outdoor lighting contribution to the eye measured through interior windows was low overall: 20 lx maximum and 0.5 lx median. [Note that the 20 lx value was unusual, given that the next highest recorded value from outdoor lighting was only 5 lx and the median only 0.5 lx, but it does demonstrate the importance of blocking exterior light from windows.] The color of light ranged from 1800K-2100K high pressure sodium, to 4000K metal halide, and LEDs that ranged from 3500K up to 4600K.

Overall, the findings suggest that general interior and task lighting is most likely delivering far greater evening illuminance to residents than light trespass from street lighting. This interior light exposure, with its possible influence on alertness, sleep quality and circadian health, may in fact be of primary concern in nighttime environments for populations with diurnal schedules. The lighting industry should be communicating ways to minimize such interior light exposure in homes and residential facilities, perhaps even more so than outdoor lighting.

CONCLUSION

All outdoor lighting, including street lighting, can affect nocturnal conditions for plants and animals, and therefore cannot be ignored. But it appears that outdoor lighting may not be the top priority for our daily light exposures and related consequences to health. The findings of this small pilot study suggest that residential interior lighting may have considerably greater impact on our evening light exposure than outdoor lighting; however, a more rigorous study is needed to further explore this topic.

At present there are no firm guidelines for healthful illuminance levels, duration and spectral choices for light at night. All we can do in the meantime is follow common sense rules for minimizing unnecessary exposure to all types of light at night, balanced against the many benefits that lighting enables. ☐

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