Evaluation of OLED and edge-lit LED lighting panels

Xi Mou, Nadarajah Narendran, Yiting Zhu, and Jean Paul Freyssinier

Lighting Research Center, Rensselaer Polytechnic Institute, 21 Union St., Troy, NY 12180, USA

ABSTRACT

Solid-state lighting (SSL) offers a new technology platform for lighting designers and end-users to illuminate spaces with low energy demand. Two types of SSL sources include organic light-emitting diodes (OLEDs) and light-emitting diodes (LEDs). OLED is an area light source, and its primary competing technology is the edge-lit LED panel. Generally, both of these technologies are considered similar in shape and appearance, but there is little understanding of how people perceive discomfort glare from large area light sources. The objective of this study was to evaluate discomfort glare for the two lighting technologies under similar operating conditions by gathering observers' reactions. The human factors study results showed no statistically significant difference in human response to discomfort glare between OLED and edge-lit LED panels when the two light sources produced the same lighting stimulus. This means both technologies appeared equally glary beyond a certain luminance.

Keywords: discomfort glare, edge-lit, LED, OLED, indoor lighting, background lighting

1. INTRODUCTION

Diffuse lighting panels have been used for decades for ambient illumination or where a uniform luminous appearance is desired. As lighting technologies have evolved, diffuse lighting panels have been realized in different ways but generally involve a diffuser that is either backlit or edge-lit by one or more light sources that in turn are hidden from direct view, thus creating the appearance of a large area light source that is largely uniform in luminance. Organic light-emitting diodes (OLEDs) are a new type of area light source that do not require secondary optics to produce uniform and diffuse illumination. Commercial OLED technologies have been steadily evolving and now can be used in certain niche lighting applications. Presently, OLED panels with luminances exceeding 3000 cd/m^2 and efficacies exceeding 80 lm/W are commercially available and are expected to reach 190 lm/W with correspondingly higher luminances, as well as longer rated useful lifetimes.[1] One of the most commonly quoted benefits of OLEDs is their "soft" appearance that makes them comfortable to look at because they do not produce glare.[1,2] Edge-lit LED panels are a competing technology that can offer physical, photometric, and visual properties similar to OLED panels. However, the differences and similarities between these two technologies have not been systematically compared. The goal of this study was to first measure and compare the photometric performance of the two panels and second, conduct a human factors study to gather data for the perception of discomfort glare for both OLED and edge-lit LED panels at similar luminance values.

2. BACKGROUND

2.1. What is glare?

In most applications, glare is an undesirable characteristic of the lighting system. Generally, glare is understood to be produced by excessive and uncontrolled brightness in the field of view. Glare from a light source can result in the loss of visibility (i.e., disability glare) or produce discomfort or even pain (i.e., discomfort glare).[3,4] Disability glare is primarily caused by scattered light inside the eye, resulting in reduced contrast of the retinal image, thus reducing visibility.

**Corresponding author: narenn2@rpi.edu; +1 (518) 687-7100; www.lrc.rpi.edu/programs/solidstate*

Fifteenth International Conference on Solid State Lighting and LED-based Illumination Systems,
edited by Matthew H. Kane, Nikolaus Dietz, Ian T. Ferguson, Proc. of SPIE Vol. 9954,
995403 · © 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2240465

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 09/09/2016 Terms of Use: http://spiedigitallibrary.org/ss/termsofuse.aspx

Disability glare is fairly well understood and its effects can be calculated if the photometric characteristics of the viewing conditions are known. On the other hand, discomfort glare is thought to be more subjective and can vary widely among people with different understandings of the judgment. However, there are known factors in discomfort glare such as the size and intensity of the light source, the amount of light reaching the retina, the viewing geometry, the luminance and size of the background, and to some extent, the spectral composition of the light source.[3-12] One of the most widely used rating scales of discomfort glare is the de Boer scale, which assigns word descriptors to a numerical scale ranging from 1 to 9 (Figure 1).[13] A rating of 5 is generally considered the neutral point where the source is considered just acceptable, and ratings below 5 are where the discomfort glare becomes disturbing to unbearable.

de Boer scale

1	Unbearable
2	–
3	Disturbing
4	–
5	Just acceptable
6	–
7	Satisfactory
8	–
9	Unnoticeable glare

Figure 1. De Boer rating scale used to describe subjective ratings of discomfort glare.[13]

2.2. Factors that contribute to discomfort glare

Past researchers have explored the factors that contribute to discomfort glare.[3-12] One of the primary factors contributing to discomfort glare is the amount of light that reaches the retina. Bullough et al.[6] showed that with constant source luminance, by increasing the light source size, the resulting increase in illuminance at the eye resulted in lower numerical ratings using the de Boer scale (less comfortable). Rosenhahn and Lampen[10] reported that for small sources, the human response to discomfort glare was highly dependent on illuminance, but for sources greater than 0.2 degrees in visual angle, there seemed to exist a threshold above which luminance started to have an effect on human sensations of discomfort glare. This finding was consistent with a subsequent study from Bullough and Sweater Hickcox[8], in which it was found that for a source angular size larger than 0.3 degrees, the maximum luminance of the source had a much greater effect on human perceived discomfort glare.

3. EXPERIMENT

There were two parts to this study. The first was the photometric characterizations of an edge-lit LED panel and an OLED panel of similar size that were selected for the study. The second was a human factors study to assess and compare the perception of discomfort glare from both OLED and edge-lit LED panels at similar luminance values.

3.1 Photometric evaluation

One edge-lit LED panel and one OLED panel of similar size were selected for the study. Both were commercially available products and were purchased during the end of 2015. The edge-lit LED panel (126.0 mm by 126.0 mm lit area) operates at 12 Vdc and 500 mA, and the OLED panel (102.4 mm by 102.4 mm lit area) operates at 24 Vdc and 368 mA. The luminous flux, luminous efficacy, correlated color temperature (CCT), and spectrum as a function of input current were measured in a calibrated integrating sphere. The average luminance of each panel was determined from the measurement of nine points uniformly distributed across the light-emitting area using a calibrated luminance meter (CS-100A; Konica Minolta Sensing Americas, Inc. Ramsey, NJ 07446 USA). The results of the photometric characterizations are shown in Figure 2.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 09/09/2016 Terms of Use: http://spiedigitallibrary.org/ss/termsofuse.aspx

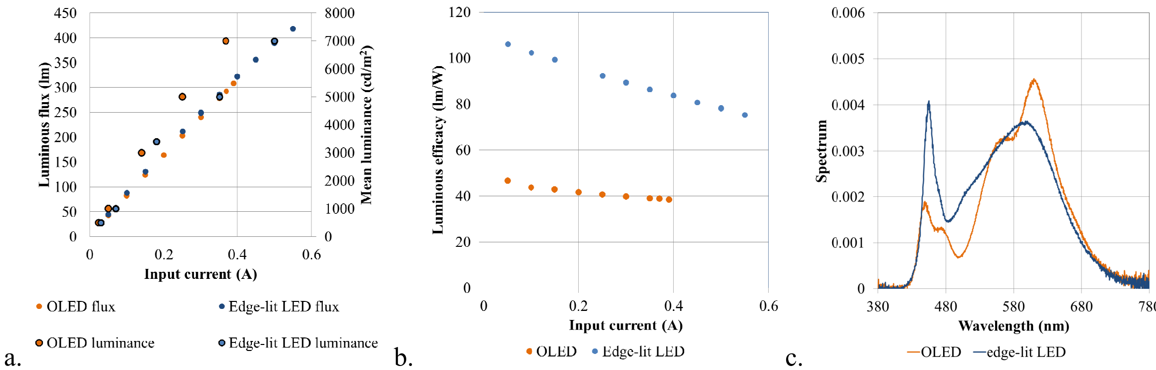

Figure 2. Photometric performance of the edge-lit LED and OLED panels used in this study, including a) luminance and luminous flux as a function of current; b) luminous efficacy as a function of current; and c) spectral power distribution.

As can be seen in Figure 2, the edge-lit LED and OLED panels selected for the study have very similar luminance and luminous flux performance as a function of input current. The measured CCTs were 3000 K for the OLED panel and 4000 K for the edge-lit LED panel. One main difference, however, is the luminous efficacy of the selected edge-lit LED panel is almost twice that of the OLED panel.

The luminance uniformity performance was carried out by using the uniformity calculation from reference[14], and 9 points were sampled over the panel as recommended in past studies.[14,15] The results are listed in Table 1. The uniformity calculation showed no difference between the two technologies with the adopted uniformity method.

Table 1. Uniformity performance of the edge-lit LED and OLED panels used in this study.

Light source	**9 points uniformity (Minimum Luminance/Maximum Luminance)**
OLED	0.9
Edge-lit LED	0.9

3.2. Human factors evaluation

A human factors study was conducted to compare the discomfort glare perception of OLED and edge-lit LED panels. The independent variables were two light sources, five light source conditions, and one background lighting condition. The five light source conditions were characterized by the luminance of the light source as well as the illuminance at the eye at each of those luminances. The dependent variable was the subjective rating of discomfort glare as measured by the de Boer scale. The experimental protocol was approved by Rensselaer Polytechnic Institute's Institutional Review Board (IRB) and explained to the observers prior to their participation.

Altogether, five volunteers (three females and two males, 19 to 40 years old) from the Rensselaer community participated in the experiment. The experiment setup consisted of one OLED lighting panel and one edge-lit LED lighting panel, a chin rest to control the subjects' viewing location, a white baffle to create a background, and an array of LED strips aimed at the white baffle for generating different background conditions. The setup is illustrated in Figure 3.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 09/09/2016 Terms of Use: http://spiedigitallibrary.org/ss/termsofuse.aspx

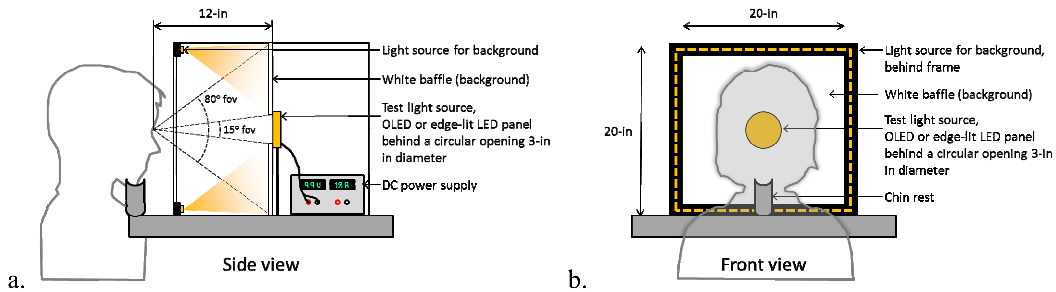

Figure 3. Illustration of the experimental setup: a) Side view; b) Front view (subject's view).

The five light source conditions were created by changing the input current of the light source to achieve a luminance of 500 cd/m^2, 1000 cd/m^2, 3000 cd/m^2, 5000 cd/m^2, or 7000 cd/m^2. The corresponding illuminances at the eye from each of the five conditions were 50 lx, 100 lx, 300 lx, 500 lx, and 700 lx, respectively. The background lighting condition was created by an array of LED strips with a CCT of 4500 K. The background luminance was 75 cd/m^2 and its corresponding illuminance at the eye was 100 lx. The distance from the chin rest to the test light source was set at 30 cm so that the light source subtended a 15° field of view. Under these conditions, the background subtended 80°.

Each subject was asked to sit and fix his/her chin at the chin rest at the beginning of the test session. Subjects were instructed to look at the test light source and background for 30 seconds before they were asked to rate the glare from the test light source using the de Boer scale. Subjects were presented with a light source luminance of 1000 cd/m^2 with a 75 cd/m^2 background luminance condition for 10 seconds in between test conditions to help cleanse their memory and avoid dark adaptation. The test conditions were counterbalanced.

4. RESULTS

4.1. Subjective ratings of discomfort glare

Figure 4 shows a comparison between the mean de Boer subjective ratings for the OLED and the edge-lit LED panels as a function of the five source luminances. As expected, the results show a clear trend of decreasing de Boer ratings (more glare) as light source luminance increases. Similarly, the de Boer ratings decrease (more glare) as the background illuminance decreases.

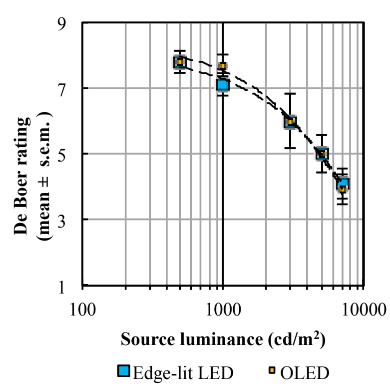

Figure 4. De Boer ratings (mean ± s.e.m.) as a function of light source luminance for background luminance of 75 cd/m^2 and its corresponding illuminance at the eye of 100 lx.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 09/09/2016 Terms of Use: http://spiedigitallibrary.org/ss/termsofuse.aspx

To further illustrate these findings, Figure 5 shows in one plot for all of the de Boer subjective ratings given to the OLED panel conditions versus the ratings of the edge-lit LED panel conditions. The ratings given to each light source showed very good agreement. The slope and the coefficient of determination of the linear correlation are both near unity. In the Student's t test[16], no statistically significant difference ($p>0.05$) was found for comparsion between OLED and edge-lit LED conditions.

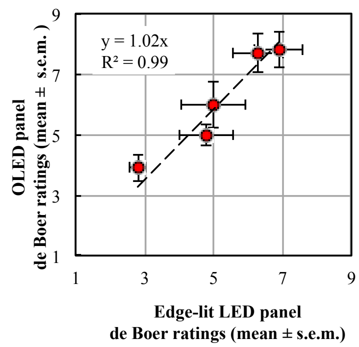

Figure 5. Correlation between the mean de Boer ratings of the tested conditions between OLED and edge-lit LED panels.

5. DISCUSSION AND CONCLUSIONS

This study evaluated perceptions of discomfort glare from two commercially available OLED and edge-lit LED panels and found no statistical difference in discomfort glare between the two sources when matched for their illuminance/luminance characteristics. The results showed discomfort glare depends on the source luminance: as source luminance increased, human perceived discomfort glare increased, independent of the technology evaluated. Further, this study showed that under realistic indoor lighting conditions, panels with a luminance of 5000 cd/m^2 or greater resulted in glare conditions that, on average, would be described as unacceptable or even disturbing according to the de Boer rating scale. This finding is consistent with the conclusion from Shin et al.'s study.[12]

ACKNOWLEDGMENTS

The authors are grateful to Dr. John Bullough and to Martin Overington of the Lighting Research Center for providing invaluable support for the experimental design, setup and analysis, to Jennifer Taylor for her support in preparing this manuscript, and to the subjects who participated in this experiment. The New York State Energy Research and Development Authority is gratefully acknowledged for sponsoring this study as part of a grant to facilitate OLED innovation in New York State (agreement number: 34929). Author X. Mou would also like to thank the Newport Spectra-Physics Research Excellence Travel Awards Program and the RPI 2016-2017 Graduate Student Professional Meeting Travel Grant Program for their support to cover travel and conference registration expenses.

REFERENCES

[1] U.S. Department of Energy, "Solid-State Lighting R&D Plan," Solid-State Lighting Program, DOE/EE-1228 120 (2015).

[2] OLED-info, "OLED introduction and basic OLED information," <https://www.oled-info.com/introduction> (22 August 2016).

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 09/09/2016 Terms of Use: http://spiedigitallibrary.org/ss/termsofuse.aspx

[3] Boyce, P., [Human Factors in Lighting 2nd ed.], Taylor & Francis, New York (2003).

[4] Rea, M.S. ed., [The IESNA lighting handbook: reference & application], Illuminating Engineering Society of North America, New York (2000).

[5] Bullough, J.D. et al., "Discomfort glare from headlamps: interactions among spectrum, control of gaze and background light level," SAE Technical Paper, No. 2003-01-0296, (2003).

[6] Bullough, J.D. et al., "Predicting discomfort glare from outdoor lighting installations," Lighting Research and Technology 40(3), 225-242, (2008).

[7] Bullough, J.D. "Luminance versus luminous intensity as a metric for discomfort glare," SAE Technical Paper, No. 2011-01-0111 (2011).

[8] Bullough, J. and Sweater Hickcox, K., "Interactions among light source luminance, illuminance and size on discomfort glare," SAE International Journal of Passenger Cars - Mechanical Systems 5.2012-01-0269, 199-202, (2012).

[9] Osterhaus, W.K.E., "Discomfort glare assessment and prevention for daylight applications in office environments," Solar Energy 79(2), 140-158 (2005).

[10] Rosenhahn, E.O. and Lampen, M., "New investigation of the subjective glare effect of projection type headlamps," SAE Technical Paper, No. 2004-01-1281, (2004).

[11] Schmidt-Clausen, H-J. and Bindels, J. Th H., "Assessment of discomfort glare in motor vehicle lighting," Lighting Research and Technology 6(2), 79-88 (1974).

[12] Shin, J.Y, Yun, G.Y. and Kim, J.T., "View types and luminance effects on discomfort glare assessment from windows," Energy and Buildings 46, 139-145 (2012).

[13] De Boer, J.B., [Public Lighting], N.V. Philips, Gloeilampenfabrieken, Eindhoven NL (1967).

[14] International Committee for Display Metrology (IDCM), Information Display Measurements Standard, Section 8.0 Uniformity Analysis, Version 1.03, June 1, (2012).

[15] Downen, P., "A closer look at flat-panel-display measurement standards and trends," Information Display 22(1), 16-21 (2006).

[16] McGuigan, F.J., [Experimental psychology: Methods of research 7th ed.], Prentice-Hall, Englewood Cliffs, NJ (1997).

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 09/09/2016 Terms of Use: http://spiedigitallibrary.org/ss/termsofuse.aspx