**3. Outdoor Lighting Visibility and Brightness**

The resources listed below discuss how pedestrians see under nighttime conditions and how the visual system responds to different light levels and light source spectra (color). All links below are up-to-date as of January 2020.

ASSIST. (2009). ASSIST recommends... Outdoor Lighting: Visual Efficacy. Troy, NY. Retrieved from <http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-VisualEfficacy-Jan2009.pdf> This report describes how to apply the unified system of photometry (sometimes referred to as mesopic vision) developed at Rensselaer's Lighting Research Center. Using this system, outdoor lighting can be designed that reduces energy use but maintains visual performance.

Bullough, J. D., & Rea, M. S. (2008). Innovative, Energy-Efficient Lighting for New York State Roadways: Opportunities for Incorporating Mesopic Visibility Considerations Into Roadway Lighting Practice (p. 55). Retrieved from <https://rosap.ntl.bts.gov/view/dot/16440> This report discusses the potential to use the unified system of photometry (also called mesopic vision) developed at Rensselaer's Lighting Research Center to outdoor lighting practices for roundabouts, mid-block crossings, and work-zone lighting as well as new opportunities for better lighting practices to reduce operating cost and improve energy efficiency at roadways in urban and rural communities.

Bullough, J. D., Radetsky, L., & Besenecker, U. (2013). Leveraging Brightness from Transportation Lighting Systems through Light Source Color: Implications for Energy Use and Safety for Traffic and Pedestrians (p. 30). Retrieved from <http://www.utrc2.org/sites/default/files/pubs/Final-LRC-Light-Source-Color_1.pdf> This report presents the findings of a laboratory study that explored brightness perception using various color light sources. This has implications for using "yellowish" high-pressure sodium lamps vs. "white" light sources such as LED in areas where brightness perception is important, such for perceptions of safety and security by pedestrians.

Fotios, S., Unwin, J., & Farrall, S. (2014). Road lighting and pedestrian reassurance after dark: A review. Lighting Research and Technology. Retrieved from <http://lrt.sagepub.com/cgi/doi/10.1177/1477153514524587> This article looks into road lighting for pedestrian reassurance and safety. A more thorough and focused research approach is proposed to validate the 10 lux suggested optimum illuminance level as well as desirable spectral power distributions.

Fotios, S., Uttley, J., Cheal, C., & Hara, N. (2014). Using eye-tracking to identify pedestrians’ critical visual tasks, Part 1. Dual task approach. Lighting Research and Technology. Retrieved from <https://doi.org/10.1177/1477153514524587> The visual fixations and critical visual tasks of pedestrians were examined using eye-tracking technology. It was found that under daylight conditions and for long distance visual tasks, other pedestrians were the most frequent point of fixation, while for close distances, the pathway itself was the most frequent visual fixation. At night, the pathway was the most frequent visual fixation for any relative distance.

Rea, M. S. (2001). The road not taken. The Lighting Journal, 66(1), 18. This paper discusses the importance of peripheral vision when designing roadway lighting. Topics include the background physiology and considerations for intensity and spectral power distributions of light sources. This paper is currently not available online.

Rea, M. S. (2001). The road to Hell is illuminated with good intentions. The Lighting Journal, February, 12-14. Retrieved from <https://issuu.com/matrixprint/docs/lj_feb_2019_issuu> The author described the relative importance of light level and spatial distribution in a driver’s ability to see pedestrians within crosswalks. The distribution of light is more critical than the overall light level.

Rea, M. S., Radetsky, L. C., & Bullough, J. D. (2011). Toward a model of outdoor lighting scene brightness. Lighting Research and Technology, 43(1), 7–30. Retrieved from <https://doi.org/10.1177%2F1477153510370821> A series of experiments was used to create a model of brightness perception of outdoor scenes. Brightness perception is important for pedestrians' sense of safety and security.

Rea, M., Bullough, J., & Akashi, Y. (2009). Several views of metal halide and high-pressure sodium lighting for outdoor applications. Lighting Research & Technology, 41(4), 297–320. Retrieved from <https://doi.org/10.1177/1477153509102342> Quality comparisons were performed to better understand the differences between metal halide and high-pressure sodium light sources for nighttime outdoor lighting applications. In general, at equal illuminance levels, metal halide sources were viewed as brighter than the high-pressure sodium sources, however, differences between the lighting systems for facial recognition, eyewitness identification and acceptability for social interaction were not as clear.

Rea, M., Bullough, J., & Zhou, Y. (2010). A method for assessing the visibility benefits of roadway lighting. Lighting Research and Technology, 42(2), 215–241. Retrieved from <https://doi.org/10.1177/1477153509360855> This study used photometrically accurate lighting software and a mathematical model of visual performance to evaluate roadway lighting, a methodology that can be duplicated by others. Three conclusions were reached: That low-speed and high-speed intersections should be illuminated; older drivers particularly benefit from high illumination levels on high-speed roadways; and lighting from sources other than fixed roadway lighting systems are important for driving, implying photosensors might be more strategically used to save public funds.

Rea, M., Bullough, J., Freyssinier-Nova, J., & Bierman, A. (2004). A proposed unified system of photometry. Lighting Research & Technology, 36(2), 85. Retrieved from <https://doi.org/10.1191/1365782804li114oa> This paper describes a unified system of photometry that predicts visual performance (reaction times) at all light levels. This model incorporates what is sometimes called "mesopic vision." Predicted visual performance is based on both photopic luminance and the ratio of scotopic to photopic lumens for a particular light source.

U.S. Department of Transportation, University Transportation Centers Program (2014). Maximizing Pedestrians’ Perceptions of Safety Using Light Source Spectrum. UTC Spotlight. Retrieved from <https://www.transportation.gov/sites/dot.gov/files/docs/spotlight_0714.pdf> This brief synopsis summarizes the results of experiments that found that the spectrum of outdoor lighting influences perceptions of brightness, safety, and security.

Washington State University Extension Energy Program. Mesopic Lighting for Street Lighting. Energy Efficiency Emerging Technology Program Database. Retrieved from <http://e3tnw.org/ItemDetail.aspx?id=25> This technology summary discusses the benefits and uses of tuning outdoor lighting for the best visibility under moderately low (mesopic) light levels. Energy savings potential and costs are discussed.