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Spectral Effects of Lighting on Visual Performance at Mesopic Lighting Levels

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1.0 INTRODUCTION

This technical memorandum examines the spectral effects of lighting at low luminances typically found in nighttime conditions, focusing on visual performance, with brief discussions of roadway visual tasks, glare, chromatic effects, environmental effects, and others. Spectral effects that are known to occur primarily at higher levels (e.g., >5 cd/m^2) are not addressed, and in most night-time environments there is enough ambient light to prevent true scotopic vision.

In recent years a number of studies have been done on lighting under mesopic conditions. However, much of this work has simply highlighted the need for more research, as the complexity of the problems of reconciling vision and photometry becomes evident. As knowledge and technology evolve, this document will be revised.

Lighting design normally uses rated lamp lumens, based on the photopic (2º) spectral sensitivity curve V(λ), as the basis for the design. Recommended light levels almost always refer to photopic light levels. However, there are limitations to the applicability of the V(λ) function. This technical memorandum formally acknowledges the existence of problems with an assumption that photometric quantities based on V(λ), or any other function, exhibit linear proportionality to visual performance as conditions change into the mesopic range, and provides information for challenging and overcoming this assumption.

A method of modifying photometric values for mesopic conditions has been developed for application and design procedures, based on the recent system of mesopic photometry developed by the Commission Internationale de l'Eclairage (CIE) in Report 191.[1] Details of this method are used and outlined in **Section 2** later in this document. Use of this methodology is recommended, as it allows photometric quantities to take into account the extent to which spectral effects at mesopic light levels influence visual performance.

Evidence has accumulated showing a relationship that in some cases may be significant between lamp spectral power distribution (SPD) and visual performance. Under reduced adaptation luminances, two lamps with identical lumen output, but with different SPDs, may produce different levels of visual performance. The significant question is what *visual performance* will be produced using the different sources? A key related question is, "what level of lighting from the different sources is needed in order to provide equivalent visual performance or equivalent appearance of brightness?" Note that equivalent brightness does not necessarily produce equal visual performance. This technical memorandum discusses these issues and provides guidance for lighting practice based more closely on visual performance at mesopic light levels

2.0 KNOWN FACTORS IN DETERMINING SPECTRAL EFFECTS

Despite there being little direct empirical evidence, it is often accepted that adequate visibility at night is a significant factor in accident reduction, the facilitation of traffic flow, and providing security. It is therefore highly relevant to determine what aspects of outdoor lighting design affect visual performance and how visual performance may be improved, within budgetary and technical constraints. Current practices rely on several simplifying assumptions, which do not always hold true.

2.1 Limitations of the V(λ) Curve

Visual performance, especially under mesopic conditions, is not a simple matter. Illuminating engineers and vision scientists have known for over a hundred years that the way in which the visual system responds to different light source spectral distributions depends on the lighting and viewing conditions.[2,3,4] Equivalent lumen output of different lamps may be perceived differently. Lamps, however, are given a rated lumen output as if the human sensitivity to the light output of any particular lamp is always identical.

The definitions of photometric quantities have been standardized by the CIE.[2,3] CIE states that "Light is radiant power weighted according to the spectral sensitivity of the human visual system". To obtain a lumen value, the spectral power distribution (SPD) of the light source is integrated with the relative spectral luminous sensitivity of the human visual system, specifically the photopic (2º) luminous efficacy function. The spectral sensitivity curve that is used to define V(λ) applies only to on-axis viewing under high light levels. V(λ), shown in **Figure 1**, is the sensitivity curve of the visual system that is used most often to relate visual response to the wavelength of the light source.

To the extent that V(λ) approximates the spectral sensitivity of the human visual system to light for a given visual response, the lumens determined in the photometric laboratory, and ultimately used by the designer, will have predictive value in characterizing expected visual responses. Similarly derived quantities such as illuminance (lux and footcandles), inten-