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A pilot daylighting field study: Testing the usefulness of laboratory-derived luminance-based metrics for building design and control

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ABSTRACT

This paper documents a field study that collected visual comfort feedback and High Dynamic Range (HDR) luminance maps to test the validity of laboratory-derived metrics in field settings. This study included 13 subjects for 149 daylighting evaluations. Similar to previous laboratory-based research, simple luminance-based metrics outperformed complex glare indicators in their predictive ability in this pilot field study. Also similar to lab studies, metrics derived using luminance data within the horizontal 40° band of human vision and a mask of just the window represented the majority of the top 20 squared correlation coefficients, considering all questionnaire items. While standard deviation of window luminance, a highly predictive metric derived in a laboratory setting, did not maintain similar predictive ability in these field studies, the field study supported previous laboratory findings that this metric may be useful in discerning visual discomfort in spaces that are very dim. Two new metrics, the ratio of the 98th percentile to mean window luminance and the coefficient of variation (COV) of luminance in the horizontal 40° band, yielded the strongest squared coefficients in field studies ($_{adj}r^2 = 0.35$ and $_{adj}r^2 = 0.32$ respectively). The COV 40° band was more stable across multiple positions within a scene than other luminance-based methods. These findings suggest that some metrics are better suited for use within a single room over time (for purposes of dynamic daylighting scene control), whereas other metrics are better suited for evaluation between spaces and from alternate positions within a room (for purposes of design guidance).

1. Introduction

Daylighting strategies remain the most frequent design approach employed in aggressively energy efficient buildings, and in nearly 90% of zero net energy buildings [19]. However, challenges in maintaining visual comfort and achieving anticipated energy savings in these buildings persist. Therefore, there is a need to continue to improve daylighting design analysis metrics. These metrics, and their associated criteria can be prioritized, and therefore evaluated, around three spheres of influence. The first is the pursuit of developing fundamental knowledge about what humans find preferable and acceptable regarding their visual environment in spaces with daylight, such as offices and classrooms. Another is for application during design stages to inform and improve design choices. A third application is during building operation and control of dynamic visual comfort systems. Most studies to date have focused on discomfort glare in settings with daylight. While additional research in this area is needed, even fewer studies have been conducted to address the human visual preference to acceptance spectrum or a particular metrics' usefulness during building systems control. Furthermore, many studies available [20,26–28,31] have examined these phenomena in a single scene with multiple subjects. Relatively few [8,9,15] have employed field testing post-occupancy techniques to provide insight regarding the usefulness and applicability of these metrics in occupied spaces. Finally, even results from field-studies often do not consider the strengths or limits to their usefulness during the building design process or during building systems control. In order to help address these barriers we implemented a visual preference field study. We began with several candidate luminance-based metrics that were derived in laboratory settings. We also examined metrics that emerged as strong predictors from the field study directly in order to better understand the relationship between laboratory and field derived luminance metrics.

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While recognizing the shortcomings of existing illuminance-based lighting and daylighting design metrics [7,18,22,23,28], integrated lighting and daylighting control technologies [1,5,6], and simulation methods [11] and given the recent development of more sophisticated luminance-based lighting metrics [9,26,31], this paper aims to validate and provide critique of established and emerging luminance-based lighting design recommendations, reflect on how these can or cannot translate to computational methods for design process analysis, and suggest ways that these metrics can support future integrated lighting control technologies. It is also important to discern which metrics are most useful at explaining various aspects of the visual comfort preference to acceptance spectrum. There are multiple scenarios that would be useful for metrics to attempt to characterize including disability glare [29], discomfort glare [2], brightness characterization [17], a range of satisfaction and acceptance, and a range of low light levels that make spaces feel too dim or degrade visual performance [21]. To support this aim, a pilot field study with 13 subjects was conducted using a repeated measures design that is similar to the laboratory research methods published to date. However, we brought these 13 subjects to an array of regularly occupied locations under random daylighting and electric lighting conditions.

2. Methodology

2.1. Field study research procedures

This study used data collected from four (4) separate field sites (Table 1) during winter 2016 in Eugene, Oregon. During each field site visit luminance data were recorded using High Dynamic Range (HDR) photography techniques [3,12] and corresponding subjective evaluations were captured under a variety of daylighting and lighting conditions. Four cameras were used to collect luminance data from multiple positions and view directions concurrently within each room. Specifically, three Canon EOS 5D cameras and one Canon EOS 5D Mark III were used, and each had their own Sigma 8 mm fisheye lens. During each field study, bracketed image capture sequences were taken simultaneously with multiple cameras in various positions set up in a single room in order to test spatial stability and variability of luminance metrics. The HDR luminance acquisition process filtered for usable exposures from within the bracketed capture sequence (from 1/8000–30 s), combined these into a single HDR image, and applied vignetting correction and spot calibration to maintain per-pixel luminance accuracy of approximately 10% [12]. Fisheye lenses have substantial luminance falloff at the edge of the lens and this vignetting effect was corrected using mathematical techniques during post-processing. A grey card was placed near the center of each room and spot luminance values were captured with a Minolta LS-160 for absolute calibration. Vertical illuminance values were also recorded during the HDR capture sequence as a backup absolute calibration data source.

In addition to the research aims outlined in the introduction, this pilot field study was conducted to test and improve HDR luminance-mapping procedures developed in laboratory environments to support for future large-scale field studies. It was completed during winter and produced a wide range of observed lighting conditions from very dim to very bright. However, there are more dim scenes in the study due to the predominance of overcast weather patterns in Eugene, OR, as illustrated by the vertical illuminance measurements in Fig. 1. It should be noted that this study identified a maximum luminance value of 534,500 cd/m^2 and did not apply luminous overflow methods [13,14] as these are still undergoing validation. These post process steps utilize several Radiance [16,30] functions including the following:

i. *hdrgen*

To process a series of low dynamic range images into a single HDR image.

ii. *rcalc*

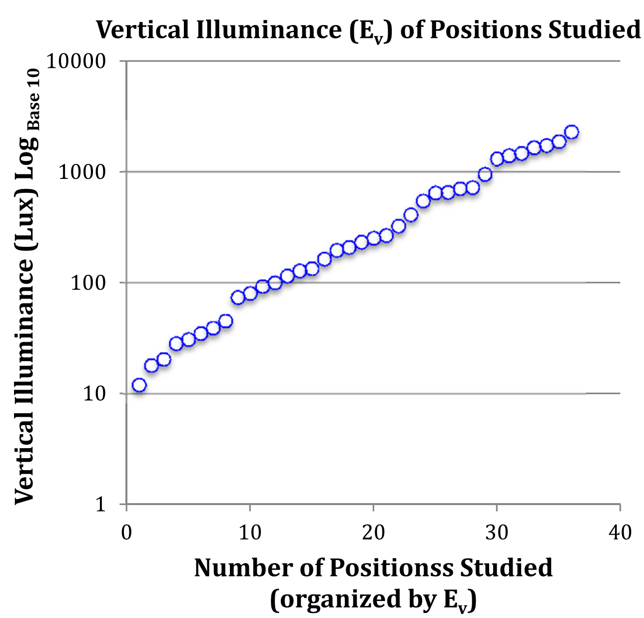

Fig. 1. Vertical Illuminance of positions studied using Log$_{(base\ 10)}$ scale.

Table 1
Field site locations, camera positions, scene captures and evaluations.

Field Site	Room	Time span	Station	Orientation	Participants	HDR captures
Field Site 1	Room 279	11:12:26 a.m. -	1_A	Facing Northwest	13	3
Lawrence Hall		11:33:00 a.m.	1_B	Facing North	13	3
			1_C	Facing East	13	3
Field Site 2	Room 402	10:56:07 a.m. -	2_A	Facing East	12	3
Ford Alumni Center		11:12:27 a.m.	2_B	Facing Northwest	12	3
			2_C	Facing North	12	3
Field Site 3	3rd Floor Atrium	10:46:40 a.m. -	3_A	Facing Southwest	11	5
Lillis Business Complex	4th Floor Atrium	11:27:36 a.m.	3_B	Facing Southeast	11	5
Field Site 4	Room 316	10:51:43 a.m. -	4_316_A	Facing East	14	2
Lane Community College Downtown		11:03:30 a.m.	4_316_B	Facing East	12	2
	Room 409	11:18:53 a.m. -	4_409_A	Facing East	12	2
		11:26:37 a.m.	4_409_B	Facing East	14	2
Total					**149**	**36**