Lighting practitioner knowledge and usage of fundamental concepts and accompanying metrics

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1. Introduction

When designing and conducting lighting research, the researcher must often make assumptions about the knowledge and abilities of the end user. We may not fully know if these assumptions are correct until the work is complete and digested by those end users. It is critically important that these assumptions be as accurate as possible. To the knowledge of this author, objective data about the knowledge and ability of lighting practitioners (designers, engineers, interior designers, architects, etc.), related to complex but fundamental lighting topics, does not exist or is not easily accessible.

The primary research goals of this study, therefore, were to assess the current knowledge of lighting professionals related to complex topics (i.e. color rendering, circadian lighting, dynamic lighting systems, and temporal light artefacts) and how they apply (if at all) various metrics which capture and distill these complex topics. This survey also provided a platform for lighting professionals to express particular challenges they experience in the field. With the recent release of IES TM-30-15, another particular interest was to assess awareness and use of TM-30.

Data that captures the demographics and knowledge of the lighting community is useful to more than just the researchers who perform work to support them. This information can help focus and hone educational efforts to provide the most benefit, and to use resources most efficiently. By understanding the knowledge and application gaps that exist within the professional community, we can work collectively to more easily fill them. Conference attendees can use these data to understand their peers' knowledge of various topics and how, if at all, they are applying these metrics. This baseline information can then be used for facilitating discussions on these topics during peer-to-peer exchanges.

The author hopes that the results of this study will spark a dialogue focused on improving education and establish a precedent for collecting objective data regarding the knowledge, application, and design needs of the lighting community.

2. Methodology

Participants completed a one-page paper survey (double-sided) during various networking sessions at the 2016 Annual IES Conference in Orlando, FL. The survey contains the seven following categories, listed in order of their appearance: color rendering, circadian, dynamic lighting systems, general/temporal light artefacts, and demographics. Most questions asked participants to provide a response along an 8-point disagree-agree Likert scale, with "Disagree" as the left anchor word (value of 1), and "Agree" as the right anchor word (a value of 8). Disagree 1 2 3 4 5 6 7 8 Agree Several sections have specific questions broken out to address lighting specifiers directly. To incentivize participation in the survey, participants received a raffle ticket for a chance to win a prize. The prize was announced on stage during the conference.

3. Results

3.1 Demographics

A total of 140 people completed this survey. The gender makeup of respondents was; 77 Male, 48 Female, 3 preferred not to say, and 12 did not answer. Men were more likely than women to work in professions of engineering and sales; women were more likely to work in lighting design, architecture, and research. Men and woman were equally as likely to work in manufacturing.

Most of the participants (78.4%) were between the ages of 25 and 59. Approximately 15% of participants were above the age of 60. Only eight (6.4%) of the respondents were between the ages of 18 and 24, and all eight were either students or designers; none worked in sales or manufacturing.

Several participants specified more than one profession. To simplify analysis, each participant was assigned one profession depending upon the dominant industry. For example, if a participant checked both manufacturing and lighting design, they were placed in the manufacturing category. Seventy percent (70%) of participants collectively worked in engineering (27.3%), lighting design (26.6%), and manufacturing (16.4%). See **Figure 1** for complete information.

The most common accreditation was Lighting Certified (LC), which is held by 51 respondents (36.4% of total). The LC was held by 33.3% of participants who indicated their profession as manufacturing, and 34.3% of those who indicated engineering. The LC was most common among lighting designers; 61.8% of which had this certification. The following most common accreditations after the LC were LEED (21 respondents), Professional Engineer (11), and Engineer in Training (10), respectively. Eight participants were Fellows of the IES (FIES). The Fellows have various professions and educational backgrounds, though 6 of the 8 were male. All were above the age of 40; five of the eight were above the age of 60. Four participants were fellows of the IALD (FIALD), three of which were also fellows of the IES.

3.2 Color Rendering

Participants, overall, indicated a thorough understanding of the impacts of light on color appearance and preference (86% of participant ratings ≥ 6, Average rating = 6.8), and a thorough understanding of color rendering metrics (80% of participant ratings ≥ 6, Average rating = 6.4) (**Figure 2**). Eighty-five percent (85%) of participants indicated agreeably—as indicated by a rating of 6 or above—that they used color rendering metrics as part of their work (average rating = 5.8). Lighting designers were most likely to use color rendering metrics in their work, where 76% of them reported using such metrics, followed by participants in the professions of engineering (66%), sales (60%), and manufacturing (48%).

Majority of participants (83%) indicated that "CRI" is the color rendering metric that they use most frequently, though less than a majority (47%) indicated that "CRI" satisfies their needs. Manufacturers were more likely than engineers and lighting designers to indicate that CRI does not satisfy the needs of their work (71%, 46%, and 41% of participants in respective professions). A large number of professionals working in sales (90%) indicated that they use CRI special indices (i.e. R9) to supplement their use of CRI, followed by lighting designers (68%), architects (67%), manufacturers (52%), researchers (40%), and engineers (40%).

On average, participants did not indicate that they use multi-metric color rendition systems as part of their work (average rating = 4.8). However, 80% of professionals in sales indicated using such systems. A smaller percentage of manufacturers (48%), engineers (40%), and lighting designers (38%) reported using two-metrics systems. Participants who use two-metric systems were asked to specify which system they use, of the following: CQS Q_f-Q_g [Davis and Ohno 2010], CRI/GAI [Rea and Freysinnier-Nova 2008], IES R_f-R_g [David and others 2015][1], CRI/CSI [Teunissen and others 2016], or Other. IES R_f-R_g was the most frequently selected (38 times), followed by CRI/GAI (26 times). Lighting designers reported using IES R_f-R_g at the highest percentage (38%), followed by architects (33%), researchers (30%), and manufacturers (29%). Lighting designers were more likely than manufacturers to use IES R_f-R_g, and

[1] Note that "IES R_f-R_g" was included on the survey, not the actual words "TM-30"

manufacturers more likely than lighting designers to use CRI/GAI; manufacturers were equally as likely to use IES R_f-R_g as CRI/GAI.

Sixty six percent (66%) of participants indicated minimum CRI specification criteria for *LED sources*. A minimum CRI of 90 was listed the most (27 times), followed by minimum CRI criteria of 80 (25 times), and 85 (12 times). It was indicated 14 times that the criteria varies by application. Forty six percent (46%) of participants indicated minimum CRI specification criteria for *traditional* sources. A minimum CRI of 80 was listed the most (20 times), followed by minimum CRI criteria of 85 (9 times), and 90 (6 times). A minimum criteria of 70 was listed twice. It was indicated five times that the criteria varies by application. On average, participants who specify lighting products consider color rendering *significantly* important on 70% of their projects, and use R9 to supplement CRI on 39% of their projects.

3.3 Circadian

Majority of participants indicated a thorough understanding of the *circadian impacts of light* (71% of participant ratings ≥ 6, Average rating = 6.0); many less participants indicated a thorough understanding of *circadian metrics* (36% of participant ratings ≥ 6, Average rating = 4.5). Ninety percent (90%) of researchers reported having a thorough understanding of circadian *impacts of light* (with ratings of 6 or higher), followed by lighting designers (85%), engineers (77%), architects (56%), manufacturers (52%), and sales (40%). Eighty percent (80%) of researchers reported having a thorough understanding of *circadian metrics* (with ratings of 6 or higher), followed by lighting designers (44%), engineers (37%), manufacturers (30%), sales (30%), and architects (0%). Participants with a thorough understanding of circadian metrics most frequently indicated an understanding of Circadian stimulus (CS) [Rea and Figueiro 2016] (selected 44 times), followed by Equivalent Melanopic Lux (EML) [Well Building Standard 2016] (27 times), and Melanopic Lux (ML) [Lucas and others 2014] (19 times).

When asked if they have used one or more of the above metrics, only 28% of participants rated a 6 or higher; 62% of participants rated below a value of five; 41% of participants rated a value of 1, the least agreeable choice. Despite apparent understanding of circadian concepts, and to a lesser degree an understanding of circadian metrics, the majority of participants indicated that they have not used circadian metrics. Of the 28% of participants who rated highly that they use these metrics, most were lighting designers. Fifty percent (50%) of researchers reported using such metrics, followed by lighting designers (32%), architects (22%), and engineers (20%). When asked which metrics they have used, CS was chosen 14 times, EML 11 times, and ML 5 times.

3.4 Dynamic

Majority of participants indicated familiarity with dynamic *white* systems (79% of participant ratings ≥ 6, Average rating = 6.5), and familiarity with dynamic *color* systems (73% of participant ratings ≥ 6, Average rating = 6.4). Lighting designers were most confident in their familiarity with dynamic *white* systems (97%), followed by researchers (80%), manufacturers (71%), sales (70%), engineers (69%), and architects (67%). Again, lighting designers we most confident in their familiarity with dynamic *color* systems (82%), followed by researchers (80%), manufacturers (76%), sales (70%), engineers (63%), and architects (56%). Participants were *slightly* less familiar with dynamic color systems than dynamic white systems.

Forty-five percent of respondents reported utilizing dynamic *white* systems as part of their work (45% of participant ratings ≥ 6, Average rating = 4.9), and forty percent (40%) reported utilizing dynamic *color* systems (40% of participant ratings ≥ 6, Average rating = 4.8). A high percentage of sales professionals reported using dynamic *white* systems (60%), followed by manufacturers (52%), lighting designers

(50%), researchers (50%), and architects (44%), and engineers (31%). A high percentage of lighting designers reported using dynamic *color* systems (62%), followed by sales (40%), researchers (40%), manufactures (38%), engineers (26%), and architects (22%).

Majority of participants indicated that they believe dynamic systems have the potential to enhance the quality of indoor illumination (85% of participant ratings ≥ 6, Average rating = 6.6). A large majority of lighting designers indicated this belief (91%), followed by manufacturers (81%), engineers (80%), architects (78%), and sales (70%). Researchers were least likely to hold this belief (60%). Participants were asked to list the benefits they foresee. The most frequently mentioned *words* were health, circadian, improved, mood, enhancement, healthcare, and productivity, respectively (**Figure 4**)**.** The most frequently mentioned *phrases* were health, well-being, flexibility, visual interest, mood enhancement, and circadian rhythm, respectively.

3.5 Temporal/General

About half of participants indicated that they have a thorough understanding of the *flicker* effect (53% of participant ratings ≥ 6, Average rating = 5.6), and a thorough understanding of the *stroboscopic* effect (51% of participant ratings ≥ 6, Average rating = 5.2). Lighting designers were most likely to report understanding the *flicker* effect (68%), followed by manufacturers (62%), researchers (60%), sales (50%), and engineers (37%). Manufacturers were most likely to report understanding the *stroboscopic* effect (67%), followed by lighting designers (53%), researchers (50%), engineers (49%), architects (33%), and sales (30%).

Forty-one percent (41%) of participants answered “yes” when asked if they (or their clients) depend on utility incentives to any large degree. Of those who selected yes, the majority indicated that 50% or more of their projects rely on these utility incentives. One participant commented, “Normally fight them – esp. 4000-5000 K,” which is interpreted to mean this participant is actively fighting utility companies which promote lighting with high CCT. This person was a lighting designer.

Twenty-two percent (22%) of participants utilized the open-ended section to describe particular challenges and concerns they currently face. Though responses varied widely in language, several over-arching themes were prevalent; the need for greater understanding of applicability of dynamic lighting systems, difficulty educating clients and end-users on complex topics, the need for more education/knowledge related to circadian impacts of light, more confidence when specifying lighting systems for circadian benefit, high cost and fighting value-engineering, and the lack of knowledge/information/metrics related to flicker.

4. Discussion

A large portion of lighting designers did not report using two-metrics systems of color rendition. However, lighting designers did select “IES R_f-R_g” (IES “TM-30”) at a higher rate than any of the other professions. The opposite is true for professionals in sales; a very large portion indicated using two-metric systems, but simultaneously did not select which systems they use. This may indicate a lack of understanding of what exactly constitutes a two-metric system or what specific metric abbreviations mean. Seven people indicated using “TM-30”, but did not simultaneously select the “IES R_f-R_g” checkbox; these two things are synonymous and provides further evidence for the potential lack of understanding.

The large majority of participants did not report using circadian metrics, which was somewhat surprising given the current buzz around "circadian-enhanced" lighting. This may be due to the apparent lack of understanding of circadian metrics (average participant rating of 4.5), the difficulty educating clients on circadian topics (several participant mentioned this difficulty), or because lighting professionals have not yet fully dug into specifying lighting for circadian benefit (several participants indicated a lack of confidence, lack of knowledge, or lack of research). However, of the circadian metrics listed, it is clear that the most understood and frequently used is Circadian Stimulus.

The overwhelming majority of participants believed that dynamic lighting systems have the potential to enhance the general quality of indoor illumination, with the general focus being on health, well-being, mood, and circadian rhythms. Interestingly, sales professionals reported such belief at a lower rate than most other professions. This is an interesting contrast given the strong marketing message around dynamic systems and circadian lighting, and that a large percentage of sales professionals reported utilizing dynamic systems (higher than most other professions). A large percentage of lighting designers (74%) reported using dynamic systems, but on average only reported using them 24% (dynamic white) and 21% (dynamic color) of the time. Several participants commented that their use of dynamic lighting systems is increasing or soon will increase; another said they discuss circadian impacts 90% of the time, though they act on them less than 5%. These results may suggest an uptick in the use of dynamic systems moving forward.

In the closing remarks of the survey, participants most frequently mentioned education; the need for more education, the difficulty educating the end user, the need for more research, and having the right knowledge and products to educate staff. The reader is encouraged to use the IES as a resource, and to reach out to their professional colleagues in search of information. Related to circadian impacts of light, researchers are still working toward consensus; the end user is not alone in dealing with the difficulty of attempting to understand and synthesize the information around them. This sentiment is echoed for flicker and flicker metrics. One participant comment is quoted below:

> "I am curious about how to understand the spectral effect on circadian rather than grouping the issue into a CCT problem because I don't believe this will have the impact that is being promoted right now in industry."

This participant makes a silent point that all readers should understand; CCT is a measure of the color appearance of light (an imperfect one in fact), and is not a strong predictor of the circadian impacts of light [Esposito and Houser 2016, Houser 2017]. End-users should use CCT as it was intended, to quantify the color appearance of light. The reader is encouraged to study and utilize the circadian metrics that are currently available to them. These are CS, EML[2], and ML, all of which are referenced in **Section 3.3**.

5. Conclusions

There will always be a need for *more* education. However, with the right data, we can hone our educational efforts where it matters most. According to the current results, the focus areas should be: 1. Using two metric systems of color rendition, 2. How to understand circadian metrics, and how to build a lighting spec around them, and 3. Help lighting professionals educate themselves and their clients.

[2] Note that the International Well Building Institute (IWBI), publishers of the Well Building Standard, are currently in the process of reviewing EML, and may suggest an alternate metric in a future standard.

6. Acknowledgements

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7. References

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8. Figures and Tables

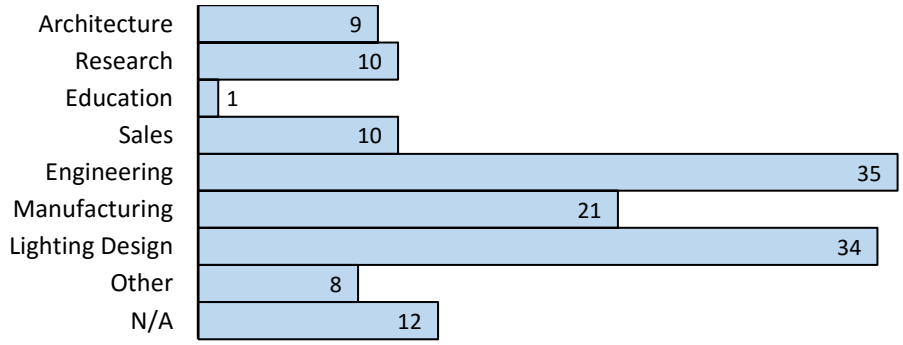

Figure 1 Participant professions. Most participants worked in the field of engineering, lighting design, and manufacturing, respectively. Twelve participants did not provide a response ("N/A").

I have a thorough understanding of the impacts of light on color appearance/preference:

Disagree								Agree
0	2	4	3	11	30	32	56	

I have a thorough understanding of color rendering metrics:

Disagree								Agree
1	3	6	3	16	30	44	37	

I use color rendering metrics as a regular part of my work:

Disagree								Agree
9	7	6	7	24	21	25	39	

"CRI" is the color rendering metric I use most frequently:

Disagree								Agree
5	2	1	6	9	25	27	61	

"CRI" satisfies the needs of my work (if applicable):

Disagree								Agree
11	12	12	16	19	31	16	15	

I used CRI special indices (e.g. R9) to supplement:

Disagree								Agree
14	11	4	10	17	29	18	30	

I use multi-metric systems as part of my work:

Disagree								Agree
19	14	6	16	20	17	20	20	

Figure 2 Participant responses for various questions related to color rendering. The number in each cell represents the number of participants that selected that cell. In the first question, for example, 56 participants selected the rightmost response (which has a value of 8), and 0 participants selected the leftmost response (a value of 1). The grey circle indicates the average response, which for the first question, is 6.8 (it falls between the 6th and 7th cell).

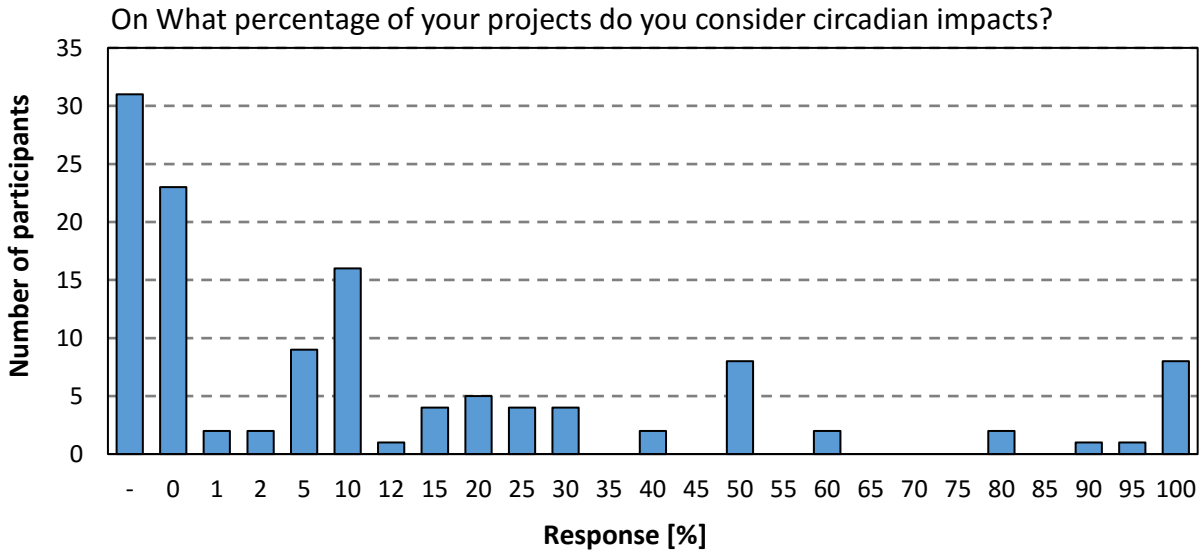

Figure 3 Participant responses to the questions "On what percentage of your projects do you consider circadian impacts?" The most frequent response was 0% (of projects), followed by 10%, and 5%. The dash (-) represents participants who did not provide a response. Two participants who wrote "100%" also wrote "if you consider daylight."

Figure 4 Word cloud for responses to the potential benefit of dynamic systems in the indoor environment. The size of the word corresponds to the number of times the word was mentioned; the larger the word, the higher the frequency of mention. Several words clearly stand out: health, circadian, productivity, healthcare, mood, and improved.