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Why CCT Tuning in the Work Environment is not Enough

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There is a great deal of marketing noise professing the use of CCT white light tuning to enhance circadian function in work environments. The real question is whether this approach actually has any real-world effect on human response to light in the spaces it is being applied to.

Theoretically, the proposition is that by changing the CCT of light, one can effect circadian reaction – specifically increase or decrease melatonin suppression. The proponents of CCT tuning profess that, with no consideration of illuminance levels, cooler CCT's will produce greater melatonin suppression, resulting in a more wakeful state, while warmer CCT's will produce significantly less melatonin suppression, creating a more restful state that does not disrupt sleep cycles. The assumption is that illuminance levels required for proper task performance can be maintained, relying solely on a CCT change alone to impart the desired "Human Centric" benefit.

To test this, I created a test box (https://tascalight.com/New%20Tasca/Detail%20Pages/TascaColorViewer.htm) that houses 5 different high CRI LEDs, with a dimmer. The CCT's I chose are the popular 2700, 3000, 3500, 4000, and 5000K. All had >88CRI and >90Rf/94Rg (using TM30). The first test was to set illuminance at 50Fc, and measure the difference in Circadian Stimulus (RPI method), and Melanopic Lux (Well Buildings Standard). The assumption is that illuminance >200 Mlux, with a CS >.30 produces what is considered a solid baseline for waking state environments, such as offices and classrooms. Once these thresholds are met, benefits of exceeding them produce a diminishing return (no significant gain).

Here are the results:

High Circadian Effect - Normalized to 50Fc Target Illuminance

CCT Ref	CCT Meas	Lux	Fc	CS	Mlux	CRI	TM30	
				Goal >.30	Goal >200		Rf	Rg
2700	2646	538	50	0.38	255	98	91	98
3000	2926			0.37	238	92	90	99
3500	3343			0.40	270	92	90	98
4000	3785			0.28	367	92	88	97
5000	4672			0.34	347	91	86	94

(https://solidstatelighting.files.wordpress.com/2018/11/high-cs.gif)

Based on this, it would appear that there is little or no real effect from changing CCT alone, assuming that the illuminance level is maintained. In fact, the "warmer is better" for reducing melatonin suppression is not necessarily true. In this test, the 4000K CCT produced a lower CS than the 2700K. However, if Melanopic Lux alone is used, the 4000K is higher than the 5000K, while the 3000K is higher in Mlux than 2700K. The reason for this is that the SPD produced by the LEDs employed effect the two metrics differently – which is why simple characterizations based on raw CCT values is not an appropriate approach – you must test light sources to understand their actual performance characteristics.

Regardless of the discrepancies between the CCTs mentioned, it should be noted that all of these sources produce ~.30CS or greater, at 50Fc, and >200CS. That means shifting from one CCT to another (cooler to warmer or warmer to cooler), with no change in illuminance level, will have no difference in effect on circadian response.

To get below the .30 CS recommended by the RPI method, and 50 Melanopic Lux recommended by the Well standard, requires a significant reduction in illuminance level. For example, reducing illuminance levels by 25%, will reduce CS levels below .30, at any CCT. However, the Melanopic values will remain at or near the 200 Mlux shown, even when dimmed to 70% of full light output – again regardless of CCT. This means that even with the combination of dimming and CCT tuning, the end result is nominal, with the effect on circadian response being small.

To realize a significant change to both CS and Mlux values demands a far greater reduction in illuminance than would be found acceptable for commercial task environments. To demonstrate this, below are results of testing the sources at 10Fc:

Low Circadian Effect - Normalized to 10Fc Target Illuminance								
CCT Ref	CCT Meas	Lux	Fc	CS	Mlux	CRI	TM30	
				Goal <.30	Goal <50		Rf	Rg
2700	2638	108	10	0.13	39	95	91	97
3000	2919			0.14	56	92	90	98
3500	3340			0.16	65	92	90	98
4000	3748			0.08	74	92	88	96
5000	4614			0.12	91	91	85	94

Even at 10Fc, while the CS value is <.30, the Mealopic Lux value remains too high, with the exception of the 2700K CCT source. Reducing the Mlux target value to a goal of 40, as an example, requires even further reductions in illuminance levels, as follows:

Low Circadian Effect - Normalized to 40 Mlux								
CCT Ref	CCT Meas	Lux	Fc	CS	Mlux	CRI	TM30	
				Goal <.30	Set @ 40		Rf	Rg
2700	2638	111	10	0.14	40	95	91	97
3000	2919	77	7	0.10		92	90	98
3500	3340	67	6	0.10		92	90	98
4000	3748	58	5	0.04		92	88	96
5000	4614	48	4	0.05		91	85	94

(https://solidstatelighting.files.wordpress.com/2018/11/40-mlux.gif)

Discussion

While the concept of tuning white light using CCT alone is a common basis for "Human Centric" effect – the application of the approach produces a nominal real result at illuminance levels experienced in commercial or task environments. Regardless of the CCT, at 50Fc or greater, melatonin suppression will be a factor, regardless of claims otherwise. This means that, while there may be anecdotal proclamations otherwise, changing of CCTs, without also significantly reducing illuminance levels, will have no effect on feelings of restfulness.

This does not mean that there is no psychological effect from changing CCTs to suit occupant preference, mood of the setting, fit to coloration of the environment illuminated, or daylight tracking. The preference for warmer white light is well established at lower illumination levels, so that is a given. Whether having multiple CCTs present or available to occupants, or changing to match daylight contribution to the space, or to provide a visual reference to time of day – is another topic not related to the metrics of CS and Mlux. Evidence suggests that when occupants like the color of light in a space, they like the space itself better, which will make them “feel” better about working or living in it. This may indeed have a positive effect on well being and productivity. However, these effects are subjective, and highly changeable based on numerous other factors involved in the design and presence of the subject environment. This makes the concept of CCT tuning alone as a significant factor unsupportable.

Another interesting dynamic to consider here is that their exists no direct correlation with “feeling better” or “well” and visual performance of tasks. It is entirely possible to have a space illuminated in such a way that occupants feel great, but perform visual tasks poorly. Conversely, it is also very possible to illuminate spaces for maximum visual performance, that make people feel less well as a generality. Light must serve both to be considered truly human-centered.

At low illuminance levels, like that one might experience at home within the one to two hours prior to sleeping, the effect of CCT is somewhat more significant. This is particularly true when following the Well Buildings standard, which lowers the maximum Melanopic Lux from >200 to <50 between working and pre-rest exposure. Even at illumination levels as low as 10Fc, all but the 2700K source generates a too-high Melanopic Lux value.

Interestingly, the correlation between illumination levels and CCT preference are aligned well with the CS and Mlux values observed here. Several studies have indicated that observers prefer lower CCTs in low light conditions, and somewhat higher CCTs as illumination levels are increased. At very high illumination levels, CCT presents very little preferential response, including preference for the highest CCT of daylight conditions. However, both of these statements are drawing a fallacious connection between feeling of well-being, and task performance, and applied CCTs to spaces we occupy. The assumption is that we accept higher CCT sources at work because we prefer higher CCTs at higher illuminance levels, and that we choose lower CCTs at home where we rest, because illumination levels are lower. There is more to it all than this, which has not yet been fully explored.

Some may point to this as supporting the warm preference for street lighting, and the argument that too high CCT street lights are disturbing sleep cycles. In the table above, however, the applied illuminance levels of all CCTs, with the Mlux value at 40, are significantly higher than one might experience from street lighting, which generally applies very low illuminance levels, below the 4Fc even the 5000K CCT source would require. In other words, at illumination levels <2Fc, there is no real difference in CS or Mlux between any of the CCT sources tested in this article. The objection to 4000K and 5000K street lights is far more about subjective light color preference than it is about actual human impact factors.

More odd is the surprised reaction of utilities and LED product producers to the high CCT products applied in the low illumination environments of outdoor lighting. With the well established preference for warmer CCTs at low illuminance levels, it seems most obvious that their would be a wide spread objection to LED area and street lighting systems producing 4000K or 5000K light. Had the industry utilized known data and applied the preferred 3000K or 2700K CCT sources in outdoor applications, one has to wonder whether most of the hysterics, blue light panic, and outrage over

LED street lighting could have been avoided altogether. Since the greatest benefit of LED street lighting is in reducing maintenance costs, sacrificing some of the energy savings in order to more closely align product visual performance with well known CCT preference in the applied environments, seems a serious industry-wide miss that is being paid for in the form of community outrage and resistance to the technology. My own attempts to bring this to the attention of the leading producers (and DOE) of street lighting products dating back to 2008, fell on deaf ears.

Add to all of this the fact that the illuminance levels indicated here are at the eye, not on horizontal surfaces of spaces around occupants. In most every case, the vertical illuminance of an observers eye are a fraction of what will be present on the surfaces of the surrounding environment. This means that the results of this summary at 50Fc are actually inadequate at all illuminance levels, producing even less positive impact on melatonin suppression than desired. To realize a very real circadian response will require changes in approach to illumination to increase vertical illuminance at the eye, which will have a knock-on demand for higher surface illuminance everywhere than is considered normal in conventional lighting design practice. In other words, much of the trimming of illuminance levels we have done over the last 30 years to reduce energy consumption, is in need of being un-done to improve illumination qualities and human factor effects. Thankfully, this can be done with modern solid-state light sources, where we can utilize the bonus improvement in efficacy – not to cut energy consumption, but to re-establish appropriate illumination conditions to support human health and well-being.

Coupled to this is the parallel preference for daylight contribution in work environments. This carries a two-fold benefit of higher CCT and higher illumination levels, which will bring with it higher CS and Mlux values. Again, it is not about CCT tinkering, it is about the composite effect of delivering to observers illumination levels they need to see, that support physical health, with spectral values (color and content) they prefer. Put these together and people will not only think they feel better, they are likely to actually be physically better – which is the real motivation for including human factors in design consideration.

Conclusion

The effect of CCT white light tuning alone may produce subjective results manifest in observers and occupants expressing feeling's of improved comfort and well being. However, at commercial task environmental levels, CCT tuning alone is unlikely to produce a significant physiological effect that can be objectively proven to effect circadian response.

Most interesting in the exploration of illumination as it pertains to human effects, is the realization that new information, fresh research, and current knowledge all point to our having got it wrong for the last 30+ years. The simultaneous introduction of light sources with truncated spectral content (fluorescent, HID, and now LED), coupled to lower and lower illuminance levels have created lighted environments that make use feel tired and un-well. Contrary to the belief of some that excessive melatonin suppression from artificial light is the cause of our feeling less well, the opposite is actually the case. The decreasing illumination level recommendations, which have dropped from 70Fc – 100Fc in the 1970's, to 30's and 50's in the modern era, are simply delivering too little CS and Mlux light to the eye, to suppress melatonin sufficiently to produce a feeling of energy and vitality. Couple this to spectral content that challenges proper visual performance, glare from efficient but otherwise glare bomb luminaires, and lack of sensitivity to humans over dollars, and we have an ugly soup of expensive lighting under-performing across every measure, to serve energy efficiency metrics that are disconnected from the human experience.

The next step in connecting circadian supportive lighting, is through the development of a new generation of light sources that include the SPD content necessary to support human circadian performance, without the need to increase illumination levels to compensate for shortcomings. Whether or not this is particularly energy efficient may need to be set aside for now as a secondary component of modern lighting system design. Otherwise, solid-state lighting is just another in a long train of light sources delivering disappointing results, creating feelings of negative health impact, pushed by marketers making unsupportable claims to support sales campaigns and revenue growth over human health and well-being.