Bridgelux Whitepaper: Average Spectral Difference, a new method to make objective comparisons of naturalness between light sources

Abstract

The lighting market is in the early stages of adoption of human-centric lighting (HCL). HCL encompasses the effects of lighting on the physical and emotional health and well-being of people. Throughout evolution, the human visual system has evolved under the natural light of sun and fire. These light sources have standardized industry spectral power definitions that describe the state of natural light. However, conventional metrics such as CCT, CRI, and TM-30 fail to adequately quantify the naturalness, or closeness of these light sources to the standardized natural spectra. Due to a lack of an industry standard metric to quantitatively measure the naturalness of a light source, this paper presents a new method to make objective comparisons of naturalness between two sources.

The evolution of artificial light

The 21st century has seen a decisive shift globally to solid-state LED light sources. LEDs have won the day most of all because of their greatly superior lifetime and efficacy. A LED lamp typically uses around 10% of the energy consumed by a familiar incandescent light source, such as a halogen lamp, while lasting at least ten times as long. Motivated both by overall energy cost savings and reducing carbon emissions, consumers, commercial entities, and governments have embraced LED technology for almost all indoor and outdoor lighting applications.

For most of the history of electrical lighting, the traditional, yet inefficient, tungsten filament bulb dominated. The introduction of the fluorescent tube was an early attempt in the 20th century to dramatically improve the energy efficiency, or luminous efficacy, measured in lumens per Watt (lm/W). However, while fluorescent lighting was inexpensive to install and operate, it was never truly liked due to poor quality of light, as it has a spiky and unbalanced spectral power distribution (SPD). To many observers, fluorescent lighting creates a harsh blue-white effect and renders colors poorly.

Incandescent halogen lighting technology was also developed in the 20th century to provide an improvement in efficacy over tungsten filament bulbs without sacrificing light quality. But since halogen sources provided only a marginal gain in efficacy over other incandescent lights, they were soon supplanted by solid state lighting as efficacy and cost-competitiveness matured.

Every stage in this evolution has been driven by a push for lower total cost of ownership. In many cases, however, technology advancements caused the unfortunate side effect of reduced light quality. The tungsten filament incandescent bulb is often considered a perfect light source, in both human evolutionary and spectral terms, as its color point sits on the blackbody curve and it has an ideally smooth SPD over the visible light spectrum.

LED Lighting market in mature phase

Professional lighting designers have worried about the impact of LED lighting on the aesthetics of indoor and outdoor spaces ever since LED adoption began at the turn of the 21st century. In fact, the lighting industry has made considerable progress in addressing light-quality issues, notably by introducing LED products which have improved color fidelity, as traditionally measured by the Color Rendering Index (CRI).

For many years, however, work to improve light quality had a much lower priority than developments intended to increase efficacy. LED manufacturers have been in an arms race in which they are constantly competing to announce the next new product boasting the highest ever efficacy in its class. So successful has this engineering effort been that future incremental energy and cost savings are projected to be rather limited. In this sense, the LED lighting industry has considerably matured.

This has allowed the industry to turn its attention to quality, rather than quantity, of light. More broadly, lighting designers, specifiers, and users are exploring the concept of human-centric lighting (HCL). HCL has many definitions, but it is broadly agreed that it encompasses the effects of lighting on the physical and emotional health and well-being of people.

Naturally, as part of the HCL initiative, there is a drive to develop “natural” sources of lighting. The evolution of the human species in the past 200,000 years has conditioned the body to function in daylight hours by the light of the sun, and after dusk, in the warm glow of fire. Thus, we define natural light sources as those which match the SPDs of sunlight and firelight.

Similar to how a blacksmith can make a metal rod glow by leaving it in a hot fire, an incandescent light bulb produces light by heating a tiny metal element at its core to a specified temperature. The temperature of the metal filament, when measured in Kelvins, corresponds to the Correlated Color Temperature (CCT) of light. Thus, an incandescent bulb is inherently a type of firelight, with a smooth SPD and color point on the CIE color space blackbody curve. Therefore, it is only in the past several decades, the blink of an eye in evolutionary terms, that humans have subjected themselves to non-natural light, such as fluorescent or LED lighting, for extended periods of time.

There is a strong presumption among most lighting experts and HCL advocates that the more natural a light source is, the better for the observer. When consumers who are not deeply steeped in LED technology are presented with the question of preference of natural vs. non-natural light, preference is shown toward natural light. Lighting specifiers for both residential and commercial spaces such as offices, schools, elder care homes, and hospitals may also presume that the safest option is to avoid exposing people to non-natural lighting, moving toward the replication of natural light consistent with the conditions under which humans have developed and evolved.

This raises the question; how do we measure the “naturalness” of artificial light?

Established methods for measuring quality of light

The concept of quality of light includes many characteristics. The lighting industry has developed methods for quantifying light quality, developing new metrics in response to changing demands from specifiers and consumers and to changes in the underlying lighting technology.

One important parameter of light quality is color fidelity: rendering the color of an object so that its color appears the same to the average human observer as when illuminated by a reference light source. The historical measure of color fidelity is CRI, which in its Ra form averages the color rendering performance of a light source across a palette of eight color samples (R1-R8). A standard incandescent bulb has a CRI of 100, denoting perfect color fidelity, whereas most LED products have typical CRIs of 80 or 90.

For some applications, the user might be particularly sensitive to the rendering of a specific color or range of colors. For example, in apparel shops the rendering of red hues is often considered important, and the CRI R9 value represents this saturated red color point.

In fact, a high average CRI Ra value can mask a weakness in rendering some hues even while color fidelity is strong for all other hues. For applications which require a uniform quality of color rendering across all hues, the specifier might choose to evaluate a light source's extended CRI rating, evaluating an expanded color palette, denoted R1-R15, which measures color rendering individually for each of the CRI's 15 standardized color samples.

For the two decades during which LED light sources have been commercially available, the CRI rating has been the main metric for light quality supported by the industry. In recent years, concerns about this reliance on CRI have grown. The metric itself is valid, but it only offers a partial measure of one aspect of quality of light.

To address this shortcoming, the industry has recently introduced IES TM-30, a new metric which expands the definition of color fidelity and adds another key quality aspect: color saturation. That is, does a color appear washed-out, stronger and more vibrant, or equivalent when compared to its appearance when illuminated by the reference light source? And as with CRI, does it render the color faithfully?

TM-30 measures a light source's performance on average across 99 color samples, providing an R_f score for color fidelity and an R_g score for color gamut, or saturation. Additionally, individual color fidelity scores for each of the 99 standardized samples may be reported.

Both CRI and TM-30 provide important information to the lighting designer or specifier about the extent to which a light source matches the lighting effect of a natural reference source such as daylight (at cooler color temperatures of ≥5000K) or of firelight (at warmer color temperatures of <5000K) in terms of color rendering. However, two different light sources with the same CRI, R_f, and R_g values may appear differently when viewed side by side, thus these metrics alone are insufficient to wholly define the quality, or naturalness, of light. To understand why, it is important to study the SPDs of different light sources.

Understanding the shape of the natural light spectrum

What humans perceive as visible light is in physical terms an effect of electromagnetic radiation. A photonic generator such as the sun produces electromagnetic radiation across a broad spectrum of wavelengths. Short wavelength radiation from the sun is in the ultraviolet band, which is invisible to the human eye. Much of the sun's ultraviolet radiation is blocked by the earth's atmosphere, but some passes through to reach the earth's surface, where it can cause sunburn in unprotected humans.

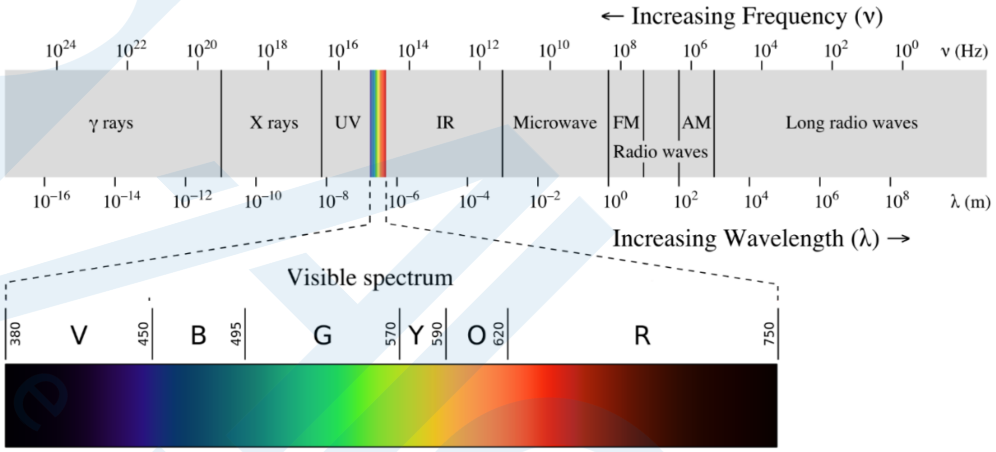


Figure 1: The spectrum of electromagnetic radiation, showing the small portion which is visible. (Image credit: Philip Ronan, Gringer under Creative Commons 3.0 license.)

The middle wavelengths of the sun's radiation, between 380nm and 780nm, are visible to the human eye. At the long wavelength end of the sunlight spectrum is infrared light, which is also invisible to the human eye, but to which human skin is sensitive – it is felt as warmth.

The change in the color of sunlight during the course of the day, from warm yellow at dawn to cool blue at noon to golden yellow at dusk, is reflected in the changing balance of intensity in each part of the visible spectrum shown in Figure 1, as more or less of the blue, red, and green wavelengths are absorbed in the light's passage through the earth's atmosphere.

This effect is mapped by diagrams showing the spectral power distribution of sunlight at different times of day as is shown in Figure 2. It should also be noted that the spectral power distribution varies by location and atmospheric conditions, as well as by time.

The spectral power distributions shown in Figure 2 are natural; these represent the exact balance of wavelengths to which evolution has conditioned the human body to respond, and under which humans have evolved and thrived. This balance of spectral power also conditions the way in which color is rendered. For example, in late afternoon when the SPD in Figure 2 shows relatively high intensity at red wavelengths above 600nm, red, yellow, and orange hues will appear stronger to the human eye, while under a noon time blue sky with no clouds, the same source will appear to have a bluer quality.

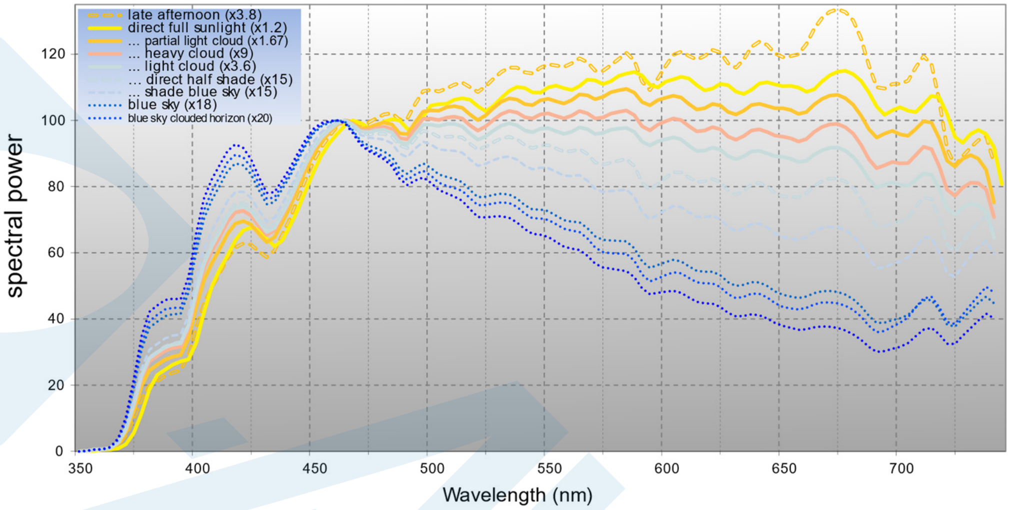


Figure 2: The changing spectral power distribution of sunlight at various times of day and weather conditions. (Image credit: Txbangert under Creative Commons 4.0 license.)

SPD plots, like those shown in Figure 2, can be plotted for any visible light source. If an artificial light source with a color temperature of 6500K has a spectral power distribution with peaks close to those of the ‘Blue Sky’ curve in Figure 2, its CRI value will be high, since at 6500K noon daylight is the reference light source. On this basic measure of quality of light, it will rank highly. But as Figure 3 shows, this does not mean that it is necessarily a good source of natural light.

Figure 3 displays the typical SPD of a fluorescent light source, and Figure 4 of a typical white LED light source. It is obvious how different the profiles of these spectra are from any of the sunlight curves shown in Figure 2. In recent years, LED manufacturers have put considerable development efforts into optimizing the composition and application of phosphor coatings on the LED semiconductor dice (or chips) to damp the blue peak shown in Figure 4, and to boost the red/green portion of the spectrum in order to achieve a better average CRI value. Tradeoffs often sacrifice light quality for the sake of increased efficacy, favoring the green portion of the visible light spectrum to which the human eye is most responsive with the effect of boosting luminous intensity and therefore efficacy.

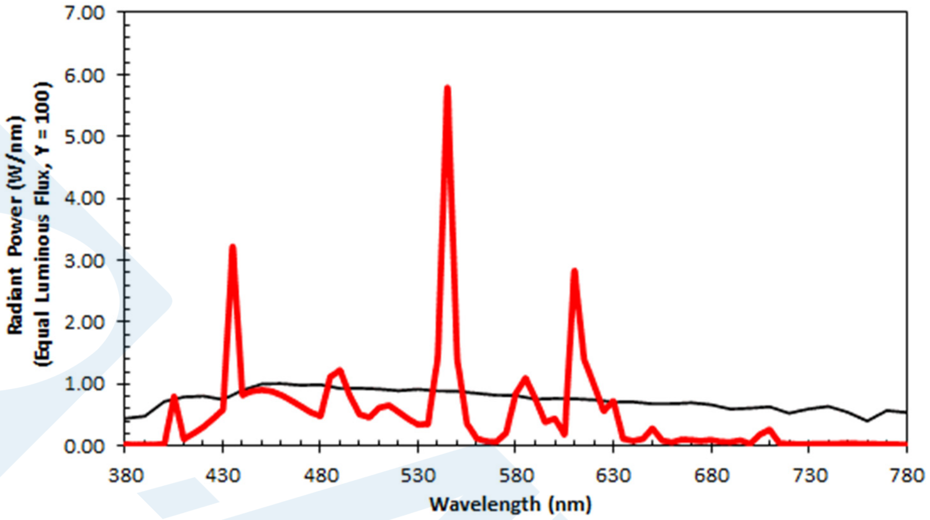


Figure 3: Spectral power distribution of a typical fluorescent light source at 6500K against the D65 standard illuminant.

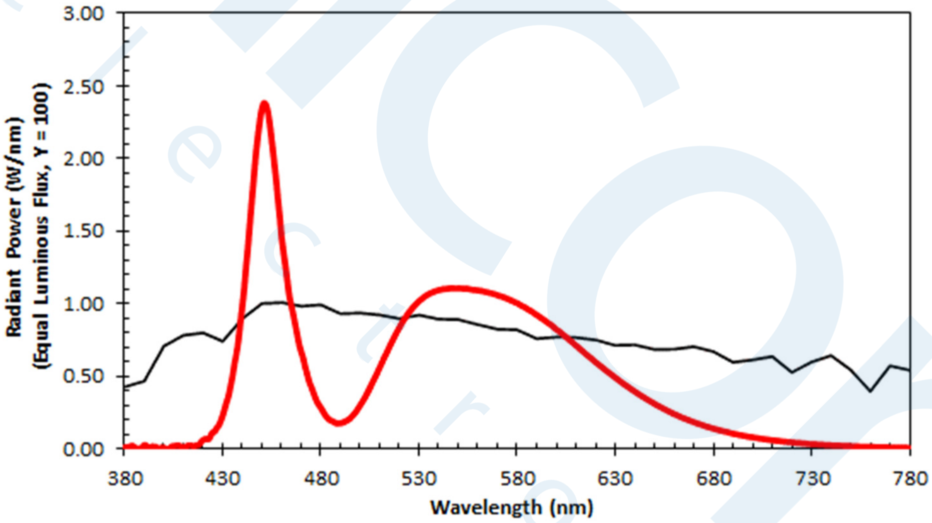


Figure 4: Spectral power distribution of a typical 6500K white LED, showing the peak power produced by the LED and the effect of YAG phosphor converting blue to other wavelengths against the D65 standard illuminant.

For LED light sources at a CCT of 4000K (typical for interior lighting in commercial, office, and education settings), the effect of these design optimization efforts is shown in Figure 5. The reference light source at this color temperature is firelight, represented diagrammatically as the blackbody curve (BBC) and referenced in Figure 5 as natural light. LEDs offering a CRI of 90 or 98 have a closer match to the blackbody curve than the 80 CRI light source. Nevertheless, across the entire visual spectrum, both light sources show a substantial deviation from the natural light BBC. This is shown in the spectral spikes (deviations above the blackbody curve) and valleys (deviations below the blackbody curve).

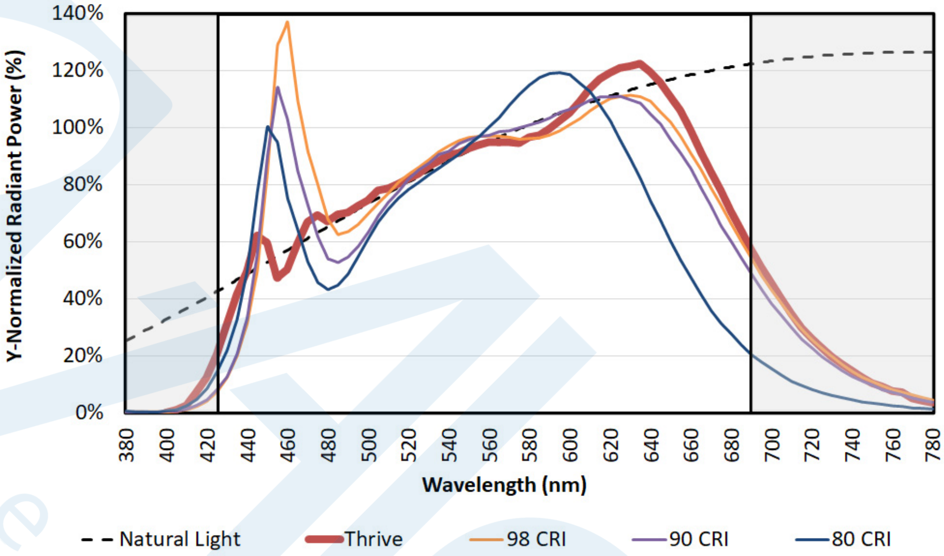


Figure 5: SPDs of LED light sources at 4000K against the blackbody curve.

The sharp spectral peak at around 440-460nm in a typical blue pump phosphor converted LED is clear in Figures 4 and 5. This characteristic of LED light is particularly concerning to some since the blue emission is clearly a large deviation from natural light and thus may instigate a disruption to human circadian rhythm, the pattern which regulates the body's cycle of activity, rest, and sleep. One of the benefits that users of natural, human-centric lighting should gain is harmonization of lighting with the circadian rhythm.

In this regard, the practice maintained by some LED manufacturers of artificially boosting emissions in the blue or violet portions of the spectrum in order to produce an artificial energizing effect is regarded by many HCL advocates as potentially fraught with risk.

Bridgelux, on the other hand, advocates that in the absence of substantial evidence that exposure to manipulated spectra with higher intensities of blue or violet light has no harmful long-term effects, why take the risk? Human evolution instructs that the spectrum of natural light is the safest and best for human physiology. Thus, in developing the series of Thrive™ natural LED light sources, Bridgelux has engineered the spectra to align as closely as possible with that of natural light.

Due to a lack of a good industry standard metric to quantitatively measure the naturalness of a light source, this paper presents a new method to make objective comparisons of naturalness between two light sources.

Bridgelux Thrive: The best natural LED light source

The natural light that Thrive produces is the result of proprietary chip, phosphor, and packaging technologies developed exclusively by Bridgelux. It is the combination of these three elements, optimized to interoperate effectively, which produces the natural spectral characteristics. Figure 5 shows the spectral power distribution of the Bridgelux Thrive 4000K LED alongside Bridgelux 80, 90, and 98 CRI products.

In order to quantify the relative naturalness between each SPD in Figure 5, a simple calculation can be performed. Although the visible wavelength range stretches from 380nm to 780nm, Bridgelux recommends a wavelength range of 425nm to 690nm for this calculation. This range is based on the photopic response curve, or V(λ); a luminous efficiency function describing the average spectral sensitivity of human visual perception of brightness, shown in Figure 6. The wavelength range of 425nm to 690nm was chosen to remove the tails of the V(λ) gaussian distribution below 1% of the peak value at 555nm. Indicated by the area between the shaded boxes on Figures 5 and 6, this range covers 99.9% of the total area under the photopic response curve.

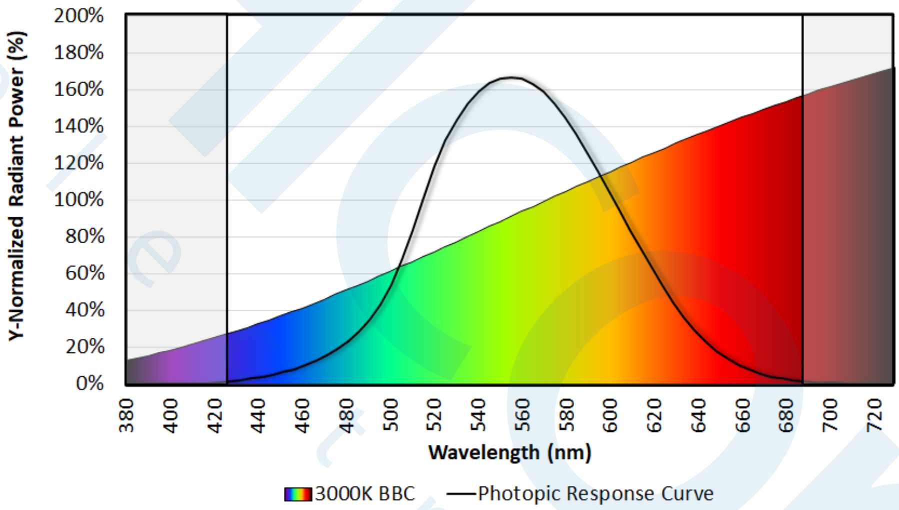


Figure 6: Photopic response curve, V(λ), against the 3000K blackbody curve with shaded boxes indicating the cut off range for ASD calculations.

To arrive at a quantitative value for depicting the naturalness of the light source, the SPDs of each source must be Y-normalized so that they are comparable in the visible spectrum. The spectrum is then divided into 266 segments, each 1nm wide, between the visible light wavelengths of 425nm and 690nm. The difference in radiometric power between the artificial light source and its reference light at each segment is measured and expressed as a percentage deviation. The absolute value of all 266 values is then averaged to produce a single value. This calculation can be expressed as an Average Spectral Difference, or ASD. Lighting designers, buyers, and specifiers can compare this single value to assess the relative naturalness of different light sources under consideration. The equation for calculating the ASD value is shown below.

$$ASD = \frac{\sum_{\lambda=425}^{690} \left|\frac{\phi_{ref} - \phi}{\phi_{ref}}\right|_{\lambda}}{266}$$

The ASD value, expressed as a percentage, always compares a test source to a reference source at the same CCT. The reference source used by Bridgelux is the blackbody curve (BBC) for light sources of 4000K and below, and the daylight spectrum (i.e. standard illuminants such as D50, D57, and D65) for light sources of 5000K and above.

Bridgelux has selected these natural light reference spectrums based on existing color quality metric calculation methods. CRI is calculated using the BBC as the reference for sources below 5000K and standard illuminants for sources ≥ 5000K. TM-30 use the BBC as a reference for sources of 4000K and below and then a blend of both the 4000K BBC and D50 illuminant for sources between 4000K and 5000K at which point the metric transitions to standard illuminants only for sources ≥ 5000K. ASD is calculated by using the more recent TM-30 methodology for determining the reference source.

A comparison of the SPDs in Figure 7 at 3000K, a typical color point for interior residential, hospitality and retail lighting, qualitatively shows the superior naturalness of the Thrive LED. By using the newly defined ASD metric, the quantitative difference is stark. While the best of the three standard LEDs is the 98 CRI product, with an ASD of 18%, the Thrive LED has an ASD of just 9%, cutting the variation from natural light by half by comparison. It may seem counterintuitive that the 98 CRI product would have a similar, and not significantly lower ASD vale in comparison to the 90 CRI product, however the 98 CRI product has been spectrally engineered to deliver a high CRI, not to deliver a closer match to natural light. This validates the premise that CRI alone is not an accurate measurement for naturalness.

As previously mentioned, the ASD can be calculated over any specified wavelength range with simple modifications to the equation above. However, if the wavelength range specified is significantly broader than the emission range of the evaluated light source, the results are less meaningful as they are washed out by the high concentration of deviations at the short and long wavelength tails of the spectra. Bridgelux uses the wavelength range corresponding to the luminosity function as described above, which, based in human evolution, describes the average spectral sensitivity of human visual perception of brightness.

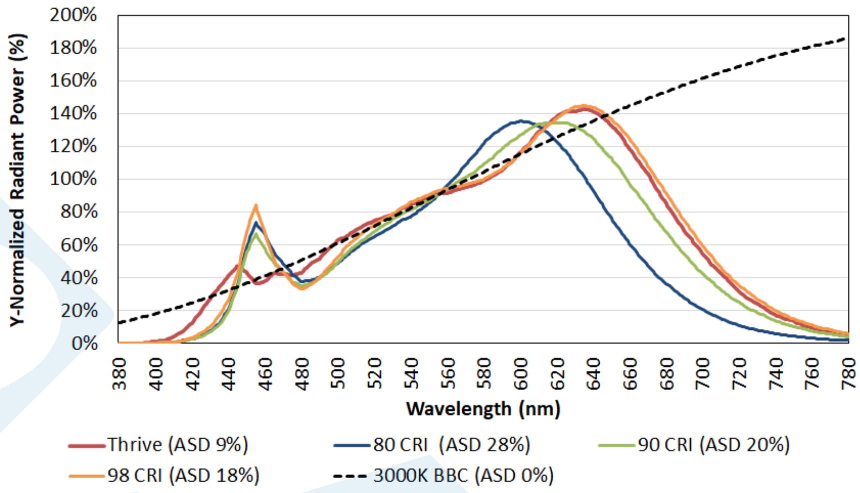


Figure 7: SPDs of 80 CRI, 90 CRI, 98 CRI, and Thrive in comparison with the blackbody curve.

ASD can be used to compare Thrive with any light source. Figure 8 compares the SPDs of 6500K Thrive with a competitive 6500K LED in the human-centric lighting market. It is notable that the Bridgelux product shows a particularly effective damping of the LED light source's inherent blue peak. This enables it to match the shape of the natural light curve much more closely than the competitor product. This is reflected in their ASD values: for the competitor, 27%; for Thrive, 8%.

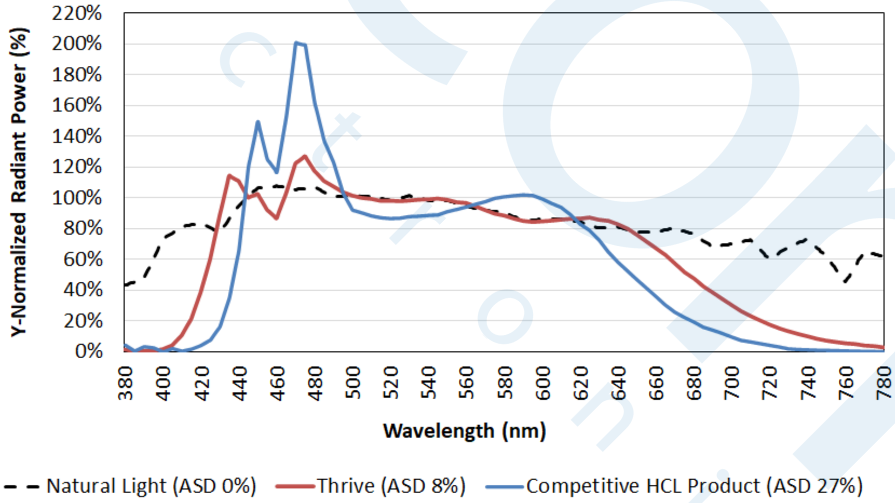


Figure 8: Comparison of Thrive and a competing product at 6500K in comparison with the standard illuminant D65 referenced as natural light.

Augmenting or suppressing blue light emission regulates melatonin secretion, and this can affect personal feelings of alertness or restfulness. But the long-term effects of this unnatural light emission created by a manipulated SPD on humans are unknown and will remain unknown until long-term studies are conducted. The philosophy of Bridgelux is that replicating natural light is safe and beneficial to human well-being. Exaggerating or suppressing blue light emission to affect human physiology has unknown and untested long-term effects on human well-being.

While high CRI and TM-30 values can be produced by a light source that has a poor (high) ASD value, a light source with a good (low) ASD value will always correspond to high CRI and TM-30 ratings due to the naturalness of the light. Table 1 exemplifies this by showing that the two sources the lowest ASD values (natural light and Thrive) have near perfect CRI, where the 98 CRI product also has a near perfect CRI but a much worse (higher) ASD.

Evaluation Metric		**Natural Light**	**Thrive**	**80 CRI**	**90 CRI**	**98 CRI**
ASD		0%	9%	28%	20%	18%
CRI	Ra	100	98	83	92	98
TM-30	R_f	100	98	84	91	94
	R_g	100	101	93	97	102

Table 1: Typical ASD, CRI, and TM-30 values for 3000K light sources.

The Thrive series of light sources from Bridgelux have been engineered to produce natural light across a broad range of CCTs. Table 2 includes both ASD values as well as standard TM-30 and CRI color quality metrics for range of available product options.

CCT	**ASD**	**TM-30**		**Typical CRI and CRI R Values**															
		R_f	**R_g**	**Ra**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**	**R14**	**R15**
2700K	10%	97	100	98	98	99	95	94	97	99	98	98	93	97	92	92	99	96	98
3000K	9%	98	101	98	98	99	95	93	97	99	96	97	97	98	92	93	98	96	97
3500K	8%	97	100	98	98	98	97	98	98	98	98	97	93	97	97	95	98	97	98
4000K	8%	96	99	98	99	98	96	98	99	98	98	98	95	95	97	94	99	97	99
5000K	9%	96	99	98	99	98	96	97	98	96	97	97	92	94	97	92	98	98	99
5700K	9%	96	99	98	98	98	97	95	98	97	96	95	92	97	96	96	98	98	97
6500K	8%	96	99	98	98	98	98	98	97	96	99	99	96	98	98	91	98	99	97

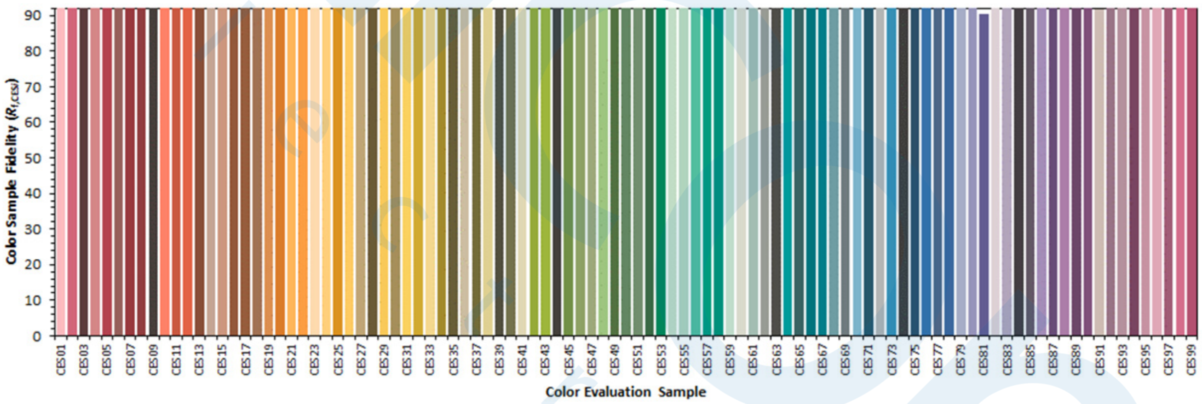
Table 2: Typical ASD, TM-30, and CRI values for Thrive light sources.

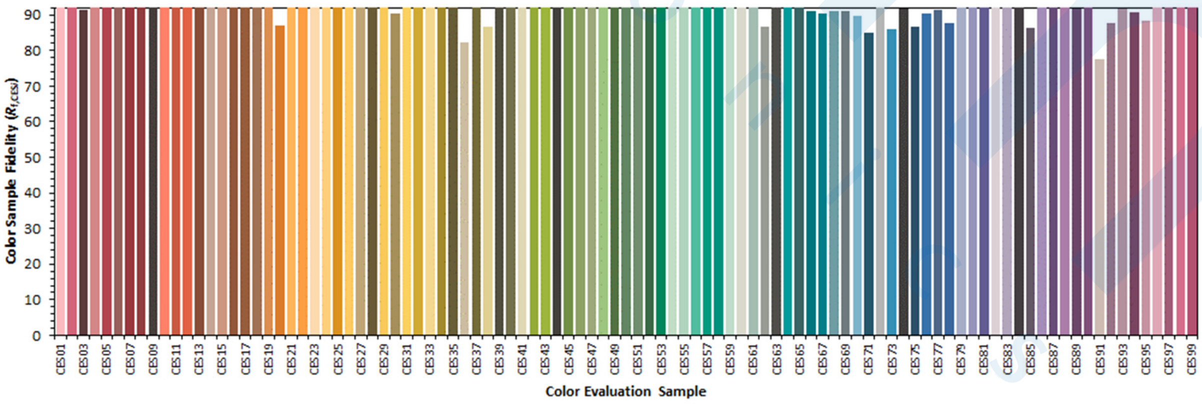
When comparing the quality of light between two sources, it is important to understand the limits of human vision. The limit of perceptible distinction between two sources can be specified and is typically referred to as the just-noticeable difference.

Research conducted at the California Lighting Technology Center (CLTC) at the University of California at Davis produced an interesting finding about human perception of artificial light sources using the TM-30 framework. The CLTC research concluded that if an illuminated reference color sample has R_f ≥92, the average observer is not able to distinguish between that source and the reference source, natural light. Thus, for a human observer, light sources with TM-30 R_f values ≥92 are essentially equivalent to reference natural light sources with R_f of 100.

Figure 9 compares three artificial light sources: a 3000K Thrive LED, a 3000K 98 CRI LED, and a competitive 3000K HCL full spectrum light source. For the 3000K Thrive LED, 97 of the 99 TM-30 color sample fidelity values are ≥92 with the two values below 92 still greater than 90. For the 3000K 98 CRI LED, only 74 of the 99 color sample fidelity values are ≥92, with 13 of the 25 values below 92 also below 90. For the competitive 3000K full spectrum light source, only 69 of the 99 color sample fidelity values are higher than 92, with 16 of the 30 values below 92 also below 90.

This supports the argument that Thrive is a much closer match to natural light, virtually indistinguishable across 98% of the color samples used in TM-30 measurements.





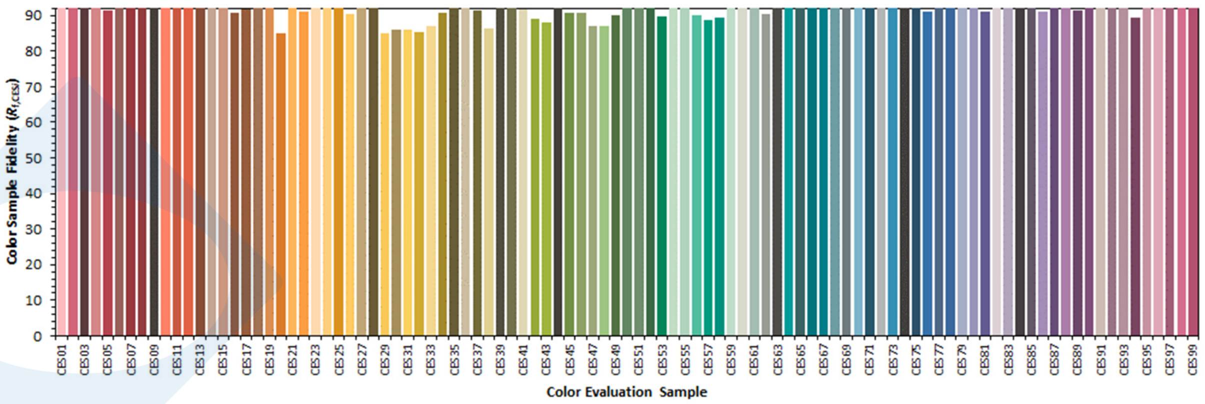


Figure 9: TM-30 Individual sample fidelity score, 3000K Thrive LED (top) compared to a 3000K 98 CRI LED (middle) and competitive 3000K full spectrum LED (bottom).

The uniform high color rendering and color saturation performance across the visible light spectrum is a unique achievement of Thrive technology. It is particularly difficult to cap the blue spike and to fill the cyan valley, but Figures 5, 7, and 8 show that even at this portion of the spectrum, Thrive maintains a tight relationship with the spectrum of the reference light source.

Light impacts humans in more ways than just our visual perception. There are several metrics currently used in the lighting industry to describe the impact of a light source on human circadian rhythm. A few of these metrics include the Melanopic Ratio (MR), Circadian Action Factor (CAF), and Circadian Stimulus (CS). While these metrics are important to consider, they do not present an adequate method of quantifying naturalness of the light source since they are derived from the melanopic response and circadian action factor curves, rather than the visual response curve, as shown in Figure 10. Therefore, while worthy to consider as part of understanding the impact on human circadian rhythm, having CAF, MR, or CS values equivalent to natural light presents only part of the overall picture and does not help quantify the naturalness of light.

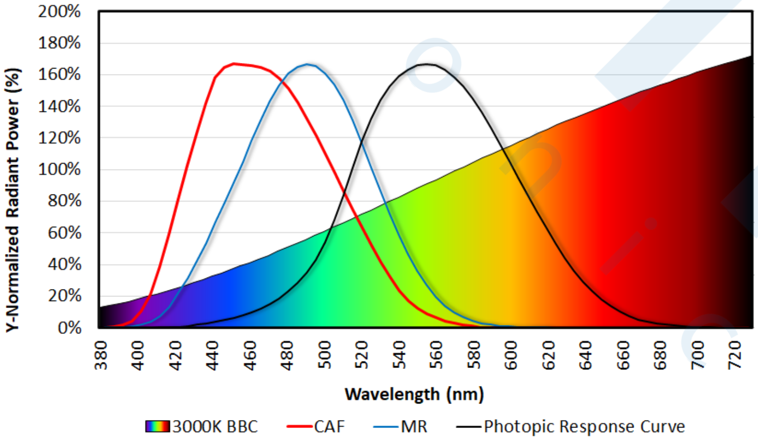


Figure 10: CAF and MR calculation curves and their overlap with the photopic response curve at 3000K.

Table 3 compares the MR, CAF, and CS values of Thrive to that of natural light sources. It can be observed that the circadian metrics of the Thrive light sources are very similar to that of natural light, with most differences within the tolerance of measurement error. This is yet another indication of how closely Thrive mimics the properties of natural light sources, both in visual and non-visual responses, and is an ideal solution for human-centric lighting applications.

CCT	MR Value			CAF Value			CS Value 300 LUX Eye Illuminance		
	Thrive	Natural Light	Difference	Thrive	Natural Light	Difference	Thrive	Natural Light	Difference
2700K	0.515	0.522	-1.3%	0.337	0.353	-4.5%	0.297	0.302	-1.7%
3000K	0.598	0.603	-0.8%	0.419	0.428	-2.1%	0.328	0.331	-0.9%
3500K	0.669	0.679	-1.5%	0.486	0.501	-3.0%	0.358	0.360	-0.6%
4000K	0.739	0.734	0.7%	0.536	0.557	-3.8%	0.249	0.256	-2.7%
5000K	0.945	0.934	1.2%	0.744	0.759	-2.0%	0.341	0.337	1.2%
5700K	1.024	1.016	0.8%	0.828	0.840	-1.4%	0.361	0.366	-1.4%
6500K	1.093	1.079	1.3%	0.898	0.912	-1.5%	0.385	0.391	-1.5%

Table 3: Comparison of MR, CAF, and CS values of Thrive vs. natural light.

Table 4 presents the CAF, MR, and CS values of 80, 90, and 98 CRI light sources at 3000K in comparison to both Thrive and a competitive 3000K HCL light source. While many of these sources are close to that of natural light in these three circadian rhythm metrics, Thrive delivers the closest match to natural light.

Product	MR Value			CAF Value			CS Value 300 LUX Eye Illuminance		
	Value	Natural Light	Difference	Value	Natural Light	Difference	Value	Natural Light	Difference
3000K Thrive	0.598	0.603	-0.8%	0.419	0.428	-2.1%	0.328	0.331	-0.9%
3000K 80 CRI	0.560	0.603	-7.1%	0.395	0.428	-7.7%	0.323	0.331	-2.4%
3000K 90 CRI	0.548	0.603	-9.1%	0.377	0.428	-11.9%	0.318	0.331	-3.9%
3000K 98 CRI	0.585	0.603	-3.0%	0.420	0.428	-1.9%	0.331	0.331	0.0%
Competitive 3000K HCL Product	0.553	0.603	-8.3%	0.404	0.428	-5.6%	0.321	0.331	-3.0%

Table 4: Comparison of MR, CAF, and CS values of 3000K light sources vs. natural light.

Where Thrive natural lighting may be used

Emerging research is likely to continue to build lighting industry knowledge about the associations between natural light sources and health and well-being, but lighting designers and specifiers are increasingly drawn to natural lighting as the safest and most comfortable light for any space in which friends, family, or colleagues spend time. Applications for Thrive natural lighting can be found in retail, residential, commercial, educational, and medical settings. Arts and cultural organizations may also want to explore the naturalness of Thrive in order to ensure the faithful rendering of the colors that the artist intended the viewer to see.

Lighting designers and luminaire manufacturers are also able to implement advanced forms of human-centric lighting by combining Thrive natural light sources of different CCT values with tunable lighting controls such as with the Bridgelux Vesta® Flex driver and controls platform. Tunable white lighting gives the user flexibility and control over the color temperature of their light. It gives them the choice to align the CCT of artificial light sources with their individual circadian rhythm, to choose function-oriented lighting, or to further personalize their environment beyond the historical ability to only adjust intensity through dimming.

The full scope for implementing HCL with low ASD light sources is beyond the scope of this white paper but is a topic which Bridgelux is uniquely well-qualified to analyze because of its advanced Thrive and Vesta tunable lighting product ranges.

Conclusions

Lighting designers and specifiers are ready to move on from comparisons of raw lumen output and power consumption to consider the profound differences in the naturalness of light between multiple sources.

To date, measures of quality of light have been narrowly confined to color fidelity, comparing the rendering and saturation of color by comparison with a reference light source. Users are becoming increasingly mindful of the effect of LED light on human health and well-being, driving the demand for natural lighting products mimicking the spectral power distribution of natural light sources such as sunlight or blackbody emitters such as firelight.

Existing quality metrics do not address the naturalness of light sources. Bridgelux has introduced ASD to provide a single metric to quantify the closeness of a light source's match to a natural reference light source. Table 5 summarizes key values from the various lighting metrics discussed in this white paper for 3000K light sources including a competitive HCL product compared to the spectra of natural light. It can be observed that even when CRI or TM-30 metrics such as R_f or R_g are similar, the ASD metric depicts a clearer differentiation to better quantify the naturalness of the light. The just noticeable difference proposal of ≥ 92 for TM-30 fidelity values shows a similar differentiation for products with a closer match to natural light, however the ASD metric takes into account all wavelengths across the indicated range (266 values compared to 99), presenting a more comprehensive and scientifically credible metric independent of human observation variables.

Evaluation Metric		Natural Light	Thrive	80 CRI	90 CRI	98 CRI	Competitive HCL Product
Average Spectral Difference (ASD)		0%	9%	28%	20%	18%	14%
CRI	Ra	100	98	83	92	98	96
	Minimum R1-R15 Value	100	92	7	79	83	84
TM-30	R_f	100	98	84	91	94	93
	R_g	100	101	93	97	102	103
	TM30 Fidelity Samples ≥ 92	99	97	17	46	74	69
	TM30 Fidelity Samples < 90	0	0	70	41	13	16
Circadian Rhythem Metrics	MR Δ Natural Light	0.0%	-0.8%	-7.1%	-9.1%	-3.0%	-8.3%
	CAF Δ Natural Light	0.0%	-2.1%	-7.7%	-11.9%	-1.9%	-5.6%
	CS Δ Natural Light	0.0%	-0.9%	-2.4%	-3.9%	0.0%	-3.0%

Table 5: Comparison of various color quality and human-centric lighting metrics for 3000K sources vs. natural light.

Through comparisons of this objective score, users can evaluate Bridgelux Thrive, which offers a superior match to natural SPDs across the visible light spectrum, free of violet light augmentation effects found in some competing products.