PHILIPS

Mr. Andrew McAllister
Commissioner
California Energy Commission
Dockets Office, MS-4
Re: Docket # 14-AAER-1
1516 Ninth Street
Sacramento, CA 95814-5512

Philips Lighting Comments on Small Diameter Directional Lamp and Light Emitting Diode (LED) Lamps

Date: 2014-11-14

Dear Commissioner McAllister,

Philips Lighting appreciates the opportunity to provide the attached comments on the California Energy Commission Proposed Lighting Efficiency Measures for Residential and Nonresidential Buildings.

As you may know, Philips North America is headquartered in Andover, Massachusetts. The U.S. Philips companies are affiliates of the Netherlands-based Royal Philips N.V., a diversified health and well-being company, focused on improving people's lives through meaningful innovations. Our long history in North America began in 1933, and today, it is the company's largest single market in the world, with approximately 22,000 employees and operations at 55 major facilities in 25 states and across 3 Canadian provinces. Sales for the region in 2013 was more than $9.5 billion*, which accounts for more than 30% of Philips global revenue.

Philips is a diversified technology company, focused on improving people's lives through meaningful innovation in the areas of Healthcare, Consumer Lifestyle and Lighting. Innovation has been a cornerstone of the company's strategy for over 120 years, creating a strong and trusted Philips brand with market access all over the world. Philips is a leader in cardiac care, acute care and home healthcare, energy efficient lighting solutions and new lighting applications, as well as male shaving/grooming and oral healthcare. Philips lights 65% of the world's top airports, 30% of offices and hospitals and landmarks such as the Empire State Building, the Sydney Opera House, the New Year's Eve Times Square Ball and the Great Pyramids. Philips owns more than 64,000 patent rights, is one of the world's top-50 most valuable brands, one of the world's top-50 most innovative companies, and ranked as one of the Best Global Green Brands by Interbrand.

Please find our detailed comments below. We look forward to working with you further on this important effort. If you have any questions on these comments, please contact me.

Sincerely,

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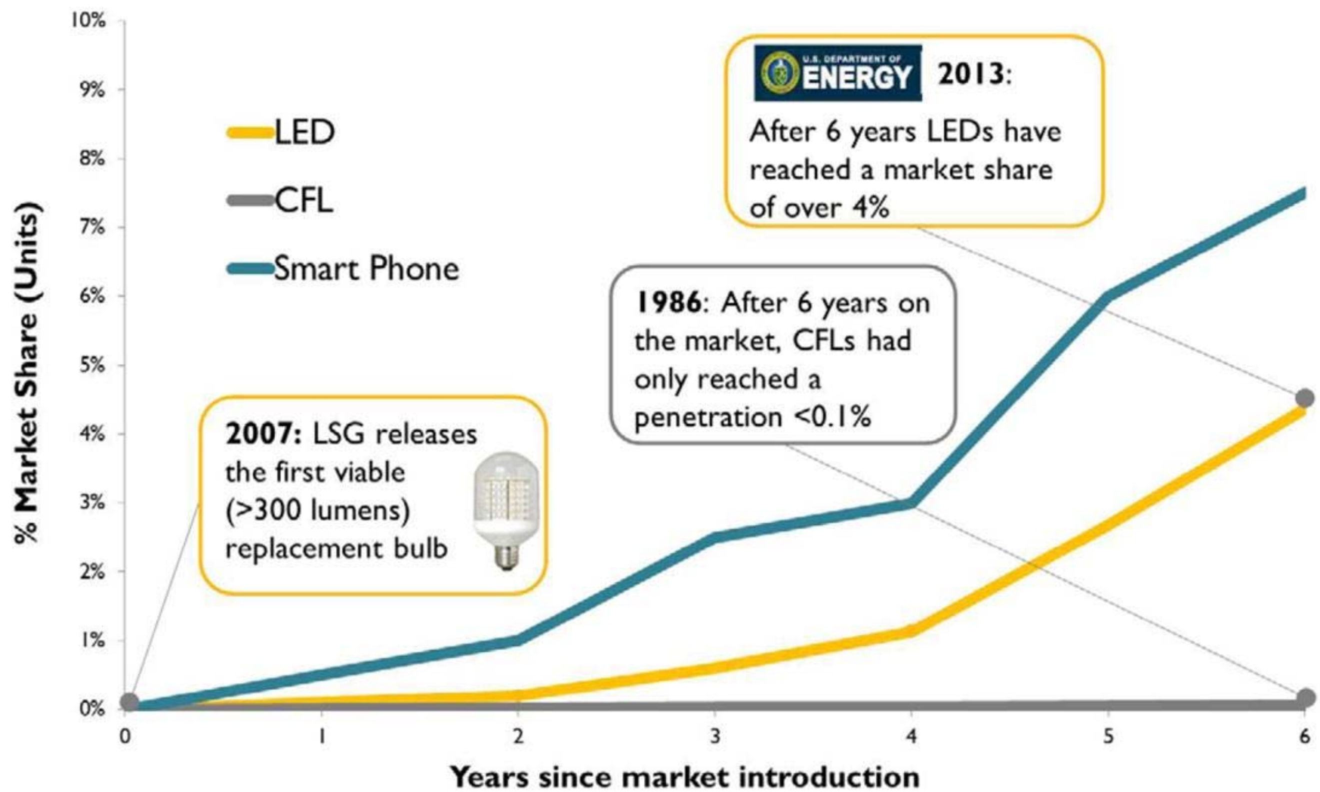
CA Title 20 inputs (Omnidirectional Lamps)

Title 20 is intended to provide minimum specifications for products to be sold in California. California seems to be consistently marching unreasonably high color quality metrics into its standards and requirements, starting with the requirement for CRI 90 in residential luminaires, which was inserted in appendix JA-8 of the 2013 version of Title 24. It continued with CRI 90 requirements in the CA LED Quality Lamp Specification. Now high CRI is proposed for Title 20 (notwithstanding the stated minimum of 82, which is only obtainable with unreasonably high efficacy!) Michael Siminovitch, in the Staff Workshop on 29 September, stated that the next version of Title 24 will have even more emphasis on performance parameters, making it clear that the march will continue. This march is founded on vague, unsupported statements that higher CRI is “better” and that reproducing incandescent light quality (high color fidelity) is essential for adoption of SSL. It is based on the unsuccessful adoption of CFL and a fear of repeating that failure with LED. (CFL’s have completely different spectra and other performance parameters than LED, so focus on CRI is misleading.) It is readily demonstrated that people prefer, depending on the application, different CRI’s. In some instances, depending on saturation of the light, low CRI (70-80) is preferred over higher CRI. Forcing high CRI removes the option to alter the light to increase customer preference.

DOE has demonstrated that SSL is being adopted radically faster than CFL was (see figure below). There is simply no comparison between the two adoption rates. Why does CEC, in light of this high adoption rate, persist in thinking that they need to put in strict CRI standards based on old arguments that the CFL story will repeat itself? Does anyone think that the adoption of LED will suddenly reverse itself? We believe that CRI 90 has its place in certain applications, but is not reasonable as a minimum acceptable REQUIREMENT in state codes.



DOE report: "Solid-State Lighting: Early Lessons Learned on the Way to the Market" Published January 2014
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_lessons-learned_2014.pdf

Manufacturers, with a few exceptions, oppose mandatory requirements for CRI above 80, because it increases cost with little to no benefit to the user. Even CREE, who supports the CRI 90 requirement in Title 20 states, in their documentation:

> **3. Isn't 80 CRI good enough?**
>
> Yes it is - but good enough for what? For general illumination it is fine. But there are certain applications where a higher CRI light might be preferred. In places where you want to accurately display the colors of fabrics, woods, food, skin, you may want a high CRI light source to see the true and natural colors.

This statement clearly acknowledges the role of the application in color quality decisions. The main effect of over specifying will limit the size of the CA market, and decrease the adoption rate, because of the higher cost of high CRI LEDs.

CLTC representatives have made statements that fewer lumens are required with a high CRI source than with a low CRI source. This is used as an argument that cost will not go up as much as expected, because fewer lumens are needed. These statements are made with no supporting evidence. It may be true when comparing a sodium lamp, with CRI near 0, to an LED light source. People do perceive an area lit by LEDs as being brighter than an area lit by sodium lamps. But we do not believe this is true when comparing a CRI 80 LED source with a CRI 90 LED source. In fact, the perception of higher brightness seems to be connected to increased blue content in the light.

Requiring 4 McAdam steps as the minimum is unnecessarily strict and will increase lamp cost. As with CRI, there are some applications where tight color consistency is needed, but many do not need it.

With typical LED formulations of today, R8 will only reach 75 when the overall CRI is at or near 90.

Detailed questions:

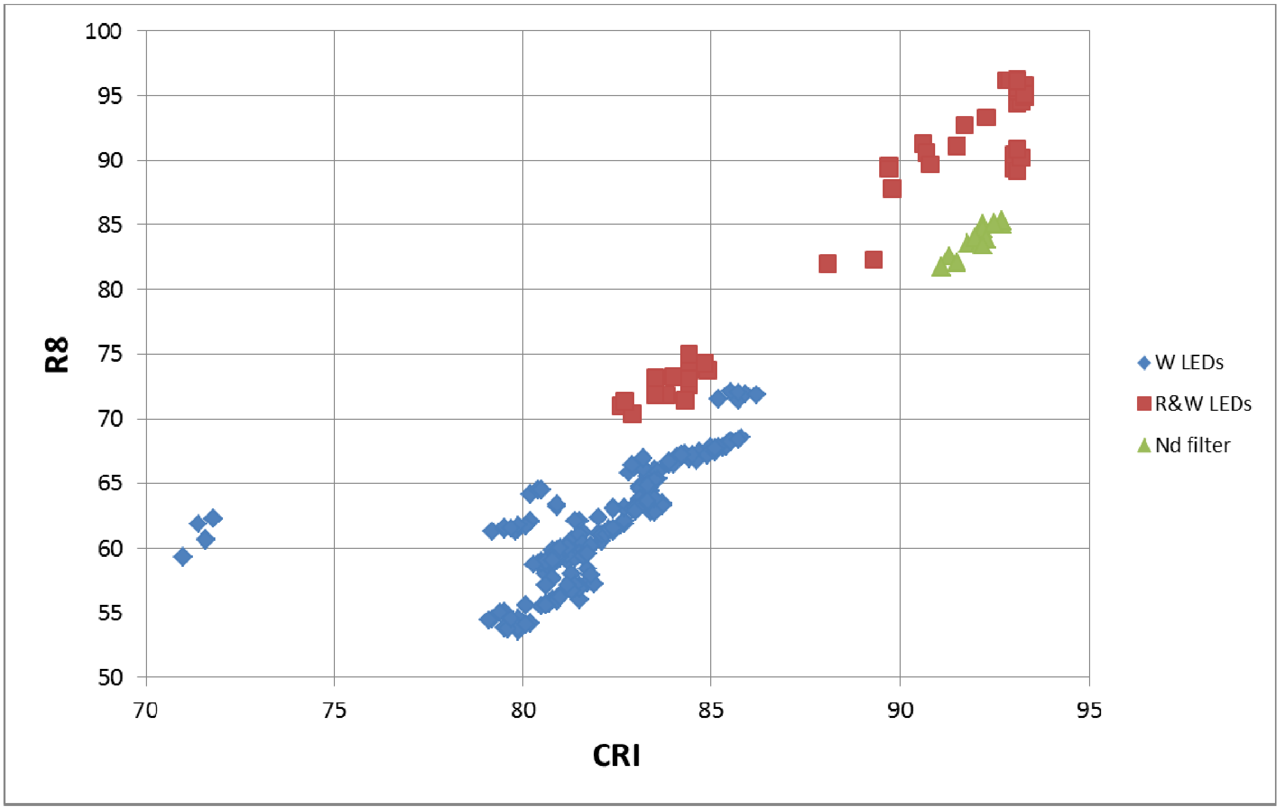
1. *For the R1-R8 values, how much variation is there from lot to lot of LEDs?* The Nichia, Lumileds, CREE, and LG specification is +/- 2 in CRI. Osram specifies +/-3 in CRI for LED package itself. The variations in a single Ri may be considerably larger, because 8 values are averaged to get the CRI.
2. *How much measurement variation due to operator and equipment is there?* From CIE 13.3, which is referenced by Energy Star Lamps V1.1:

   > *7.2 Uncertainties in the determination of R*
   >
   > Experience has shown that *Colour Rendering Indices* depend on the choice of reference illuminants and therefore, on the value of the correlated colour temperature, T_c (to calculate correlated colour temperature see [20 ... 33]), of the reference illuminant. The corrected value of *R* should be regarded as that obtained when this value of T_c is made equal to the correlated colour temperature of the lamp to be tested.
   >
   > Experience has shown that differences in spectral power distribution due to present methods of measurement (see section 5.5) may cause uncertainties of the order of 1 to 3 units in *Ra*.
   >
   > Particular attention should, therefore, be paid to the precise determination of the spectral power distribution of the light source to be tested.
   >
   > It has been found that the value of *R* may be influenced by the spectrum range taken to represent the visual spectrum (e.g. 400 ... 700 nm, 380 ... 830 nm), and also by the spectral intervals employed in the computation.

   Again, this is for the total CRI, which is the average of the 8 individual R's. No specification is placed on the individual R's, but a variation of 1-3 can be reached with larger variation in the individual R's.
3. *If we were to propose a minimum CRI of 80, what should the R numbers be? What should they be if we are stuck with a CRI over 84?* The value of R8 with typical LED

products now depends on the CCT. R8 tends to be the lowest of the 8 Ri's at common CCTs, because it contains the greatest amount of red. CCTs on the black body line contain different amounts of red, however, so R8 tends to be low for low CCTs (2700K), if CRI is kept constant. For example, R8 is 58-59 for two Philips 2700K lamps with CRI 80.5. A 3000K lamp with CRI 83 has an R8 of 65, and a 4000K lamp with CRI 83 has R8 70. An unintended consequence of specifying that all R's be 75 or above is that manufacturers may tend to make higher CCT lamps to more readily meet the specification. Philips' Crisp White lamp, with CRI 92.9 and CCT 3000K has an R8 of 84.

The figure below plots R8 vs. CRI for all of the lamps in CLTC's report, "OMNI-DIRECTIONAL LED REPLACEMENT LAMP PERFORMANCE TESTING" (http://cltc.ucdavis.edu/sites/default/files/files/publication/140609-report-omni-directional-led-replacement-lamps_rev140807.pdf) This plot shows data from lamps of three different types. The results labelled "R&W" are for lamps that contain both Red and White LEDs. The results labelled "Nd filter" are for lamps that contain white LEDs and a filter that removes part of the spectrum from the white LEDs to yield > 90 CRI. The results labelled "W LEDs" are for lamps that contain white LEDs only. In principal, all of the "R&W LEDs" are capable of CRI > 90. Some of the tested "R&W LEDs" lamps are clearly poorly designed and not realizing their CRI potential, despite the complication of adding R LEDs. The "W LEDs" data is for the most practical approach, as explained in the appendix. Projecting the "W LEDs" data to an R8 of 75 yields a CRI in the high 80's. For a CRI of 80, R8 averages about 60. Therefore, a requirement that all Ri's be greater than 75, is effectively a requirement that CRI be greater than ~88.



4. *If we were to design a product as close as possible to the 75 minimum R values, what would the actual value be for CRI allowing for manufacturing tolerances?* If one allows for both the tolerance in the LED manufacturing process (2-3 units) and the measurement error (1-3 units), one would need to design for 3-6 extra units in CRI to be certain of meeting a specified minimum level. This would mean designing for 85-88 CRI, in order to get 82.
5. *What value do we recommend for a minimum R9? Why?* Use the Energy Star minimum, R9 ≥ 0, or less stringent. We see no reason to make the specification stricter than Energy Star, particularly for a minimum mandatory specification. As stated above, acceptance of SSL is going very well, without stricter requirements.
6. *By 2017 for omnidirectional lamps, where do we expect the efficacy to be?* From "SSL Pricing and Efficacy Trend Analysis for Utility Program Planning", October 2013, PNNL publication, the predictions are shown below, for various lamp categories. Note that the MR lamps are in the 70s lm/W, and not 80 in 2017. For omnidirectional lamps, the predicted average is between 70 and 90 lm/W in 2017. (The average omnidirectional efficacy for Lighting Facts is considerably higher than Energy Star.)

Table 5.1 Projected efficacy for key LED lamp categories

Product category	Dataset	Curve	Projected efficacy at start of year (lm/W)			
			2014	2015	2016	2017
LED omnidirectional lamps	LF	Upper 95% confidence band	78	84	89	95
		Modeled average	76	81	86	90
		Lower 95% confidence band	74	78	82	85
	ES	Upper 95% confidence band	71	74	77	80
		Modeled average	67	68	69	70
		Lower 95% confidence band	63	62	60	59
LED decorative lamps	LF	Upper 95% confidence band	68	77	85	92
		Modeled average	66	73	80	87
		Lower 95% confidence band	63	69	75	81
	ES	Upper 95% confidence band	63	68	72	76
		Modeled average	60	63	65	68
		Lower 95% confidence band	57	58	59	60
LED PAR-BR-R lamps	LF	Upper 95% confidence band	68	73	78	82
		Modeled average	67	72	76	80
		Lower 95% confidence band	66	70	74	78
	ES	Upper 95% confidence band	65	70	75	79
		Modeled average	64	69	73	77
		Lower 95% confidence band	63	67	71	74
LED MR lamps	LF	Upper 95% confidence band	64	68	72	76
		Modeled average	62	66	69	73
		Lower 95% confidence band	61	64	67	70
	ES	Upper 95% confidence band	64	71	76	82
		Modeled average	62	67	72	77
		Lower 95% confidence band	60	64	68	72

Table 5.2 Projected efficacy for key LED luminaire and retrofit categories

Product category	Dataset	Curve	Projected efficacy at start of year (lm/W)			
			2014	2015	2016	2017
LED downlight luminaires	LF	Upper 95% confidence band	63	68	73	78
		Modeled average	62	66	71	75
		Lower 95% confidence band	60	65	68	72
	ES	Upper 95% confidence band	56	58	59	60
		Modeled average	55	55	55	55
		Lower 95% confidence band	53	52	51	50
LED downlight retrofit units	ES	Upper 95% confidence band	66	70	74	77
		Modeled average	64	66	69	71
		Lower 95% confidence band	61	63	64	66
LED troffer luminaires	LF	Upper 95% confidence band	97	106	114	122
		Modeled average	95	103	110	117
		Lower 95% confidence band	93	100	106	111
	DLC	Upper 95% confidence band	*	*	*	*
		Modeled average	*	*	*	*
		Lower 95% confidence band	*	*	*	*
LED highbay & lowbay luminaires	LF	Upper 95% confidence band	98	106	113	121
		Modeled average	95	101	106	111
		Lower 95% confidence band	92	96	99	102
	DLC	Upper 95% confidence band	95	101	108	113
		Modeled average	93	98	103	107
		Lower 95% confidence band	91	95	98	101
LED parking garage luminaires	LF	Upper 95% confidence band	89	95	100	105
		Modeled average	86	91	95	99
		Lower 95% confidence band	83	87	90	93
	DLC	Upper 95% confidence band	88	94	100	105
		Modeled average	85	90	94	98
		Lower 95% confidence band	82	85	88	90
LED area/roadway luminaires	LF	Upper 95% confidence band	84	89	94	99
		Modeled average	83	88	92	96
		Lower 95% confidence band	82	86	90	93
	DLC	Upper 95% confidence band	88	94	100	106
		Modeled average	86	92	97	102
		Lower 95% confidence band	84	89	94	98

* No projections given for this dataset.

7. *If an equation is used, what should it be?* The calculation appears to be an attempt to mask a requirement for high CRI. The only way to reach the minimum CRI is to have efficacy far above the DOE projected average for Energy Star performance.

   If a lamp has min CRI (82), then efficacy must be at least 89 lm/W to meet Tier 1.
   (Contrast with the DOE projection for Energy Star lamps of 70 lm/W in 2017.)
   If a lamp has min efficacy (55) then CRI must be at least 93.3 to meet Tier 1.

   If a lamp has min CRI (84) then efficacy must be at least 98 lm/W to meet Tier 2.
   If a lamp has min efficacy (65 lm/W) then CRI must be at least 95 to meet Tier 2.

   Different applications require different color quality and efficiency. We suggest that CEC simply specify a minimum for each parameter (CRI 80, Efficacy 70) for omnidirectional lamps. The equation adds unnecessary complication for no benefit. We could play around with numbers to get something more reasonable, but I don't think it is worth it. If they really have to have an equation, then make it:

   Tier 1: 3 x CRI + Efficacy = 310
   Tier 2: 3 x CRI + Efficacy =320

   This gives more reasonable limits:
   If a lamp has min CRI (80), then efficacy must be at least 70 lm/W to meet Tier 1.
   If a lamp has min efficacy (55) then CRI must be at least 85 to meet Tier 1.

   If a lamp has min CRI (80) then efficacy must be at least 80 lm/W to meet Tier 2.
   If a lamp has min efficacy (65 lm/W) then CRI must be at least 85 to meet Tier 2.

Consumer preference

CRI is not a good measure of consumer preference. This has been most succinctly explained in Kevin Houser's recent letter to the US Department of Energy. In particular:

"Importantly, and especially significant to this proposed rulemaking, CRI has been shown to fail to characterize visual impressions for LED lamps [CIE, 2007]. CRI can be gamed [Smet and others, 2013] and it is not suitable as a spectral optimization criterion."

Tight limits on CRI restrict the manufacturer's ability to design lamps that do align with customer preference, which may differ from application to application.

Bottom line:

Different applications require different color quality and efficiency. We suggest that CEC simply specify a minimum for each parameter (CRI 80, Efficacy 60 for MR lamps and CRI 80, Efficacy 70 for Omnidirectional Lamps). Use the Energy Star specification for color accuracy of 7 McAdam steps. Acknowledge the role of price in the market and specify the performance parameters to allow customers to choose products for a range of applications and price.

Flicker:

The title 20 specification on flicker is overly restrictive for some frequencies and too lax for others. It states:

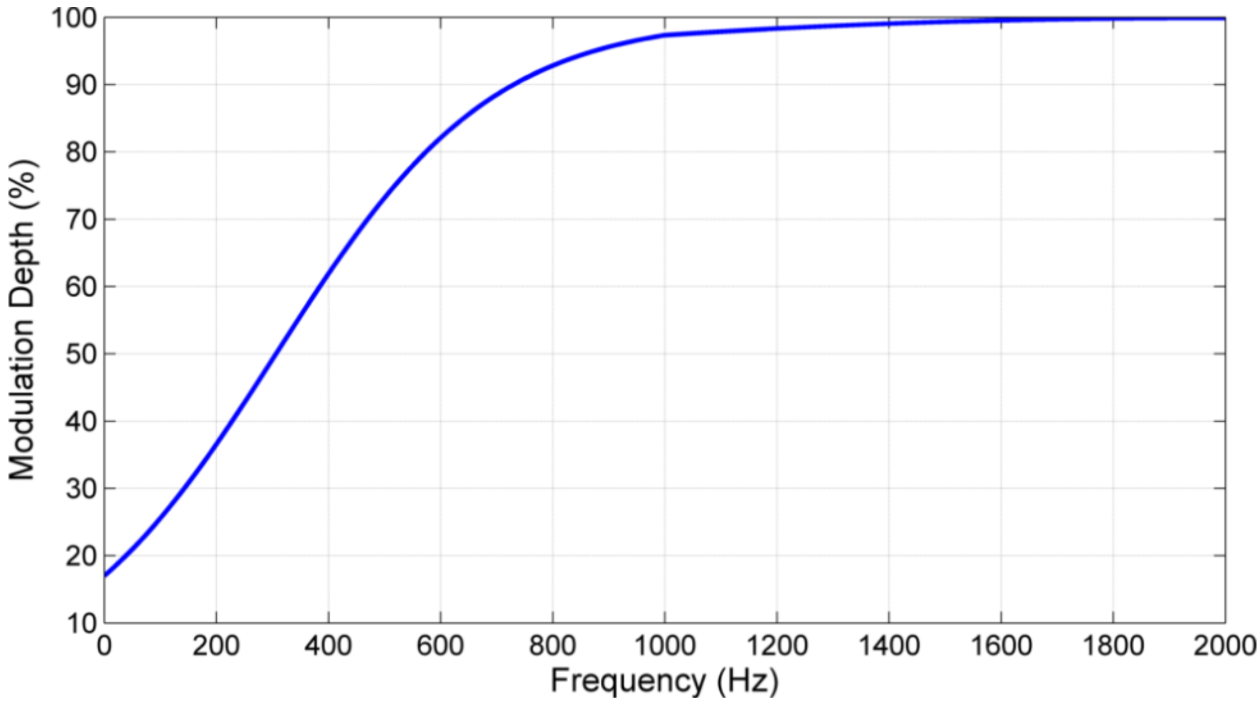
> "Dimmer controls that can directly control lamps shall provide electrical outputs to lamps for reduced flicker operation through the dimming range so that the light output has an amplitude modulation of less than 30 percent for frequencies less than 200 Hz without causing premature lamp failure."

This specification makes no allowance for the dependence of human flicker sensitivity either on frequency or on wave shape. For sine wave modulation, the visibility threshold for stroboscopic effects[1], expressed in terms of modulation depth, is shown in the figure below. At a particular frequency, modulation depths above the curve can be detected by most people. Below the curve, they are not detected by most people. The threshold changes for different wave shapes, in a way that depends on the Fourier components of the light output waveform. A full Fourier approach would take account of both frequency and wave shape effects[2]. Sensitivity to flicker also depends on the application. Flicker in outdoor street lighting or in stairwells is more tolerated than in indoor offices, for instance. Therefore, a curve of *acceptability* may be above the *visibility threshold* curve. Different curves may be needed for different applications.

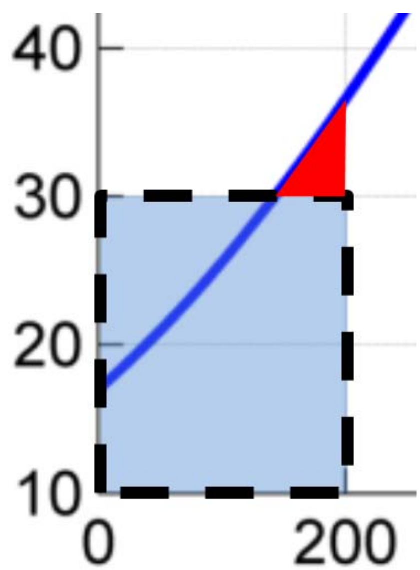
[1] The visibility curve is more complicated below about 80 Hz, where effects other than stroboscopic effects play a role.

[2] Vogels, I. , Sekulovski, D. and Perz, M. (2011). Visible artefacts of LEDs, Proceedings of the 27th Session of the CIE, 42-51.

Sekulovski, D. , Perz, M. and Vogels, I. (2012). Modelling the visibility of the stroboscopic effect, Proceedings of CIE 2012 Lighting Quality & Energy Efficiency, September 2012, Hangzhou, China, 439-449.



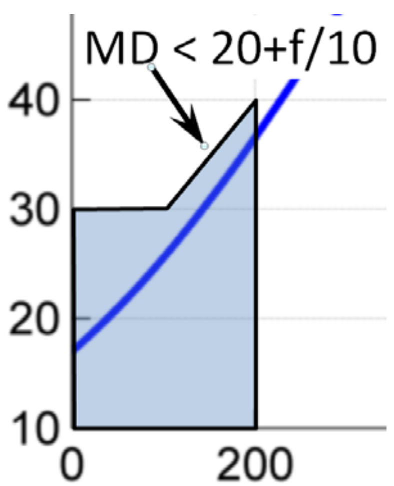
Zooming in on the region from 0 to 200 Hz in the figure above, the shaded rectangular region with dashed outline represents the conditions allowed by the Title 20 specification. The red triangle is forbidden by the Title 20 specification, but flicker in this region is not visible to most observers. Title 20, as a MINIMUM specification, should not exclude acceptable regions where flicker is not even be detected.



The Title 20 specification does a poor job of defining acceptable flicker levels. Specifications on flicker should wait until the experts (in IEEE and in IEC) conclude their work on this topic and produce a solid standard.

If CEC is unwilling to remove the flicker specification and wait for agreement in standards organizations, then CEC should at the very least modify the present specification to allow use of the acceptable flicker region denoted by the red triangle in the figure above. We suggest modifying the specification to allow flicker in the region shown in the figure below. The specification would then be:

> "Dimmer controls that can directly control lamps shall provide electrical outputs to lamps for reduced flicker operation through the dimming range so that the light output has an amplitude modulation of:
>
> - less than 30 percent for frequencies less than 100 Hz
> - below the line: Modulation Depth = 20% + Frequency/10, for frequencies from 100 to 200 Hz
>
> without causing premature lamp failure."



In any case, any flicker specification should be moved from Title 20 to Title 24, where the testing procedure is proposed. Having the specification in one document and the test procedure in another is unnecessarily complicated.

Appendix

Why can't CRI 90 be as inexpensive and efficient as CRI 80?

It is possible to make lamps that provide CRI 90. It has been done in many products (many of which have subsequently been discontinued). Lamps with CRI 90 are presently receiving rebates according to the CEC Quality LED Lamp Specification. It is possible to make CRI 90 lamps with high efficacy, but there are major challenges to widespread creation and adoption of such lamps. CRI 90 is obtainable in three distinct ways:

1. The simplest way (and the way used in most white CRI 80 LED products today) is to use a blue LED to excite a yellow phosphor. Some of the blue light from the LED is mixed with the light emitted by the phosphor to produce white light of the desired color temperature (CCT). The phosphor formulation must be modified to produce light with CRI 90. In order to obtain 90 CRI, phosphor that produces more red light must be used. This approach inevitably results in lower LED efficacy, because more energy is lost in converting a blue photon to a red photon, than to a green or yellow photon. Also, some of the broad band emission from the phosphor is in the infrared spectral region. Because LED efficacy is lower, in order for a lamp to produce the same amount of light, more power is needed. Typically, the extra power required is about 15-20%. This means more LEDs are needed, the electronics must provide more power, and the heatsinking must dissipate more power. Depending on the exact lamp design and LED selection/configuration, the optics may also need to be larger. This approach results in higher cost, both for initial lamp purchase and for the ongoing electricity use to power the lamp. There are research efforts to produce narrow band red phosphors, which, if successful, will reduce the amount of light lost in the infrared, but will still lose energy relative to typical CRI 80 LEDs, because more photons must still be converted from blue to red.
2. The second way is to use two (or more) colors of LEDs (e.g. phosphor-converted white + red). The advantage of this approach is that the extra red light is generated directly by a red LED, so efficacy is higher than with approach 1. (It is no longer necessary to generate red light by converting a blue photon to a red photon.) The difficulty with this approach is that color consistency is more difficult to maintain with two LED colors. Both colors must be controlled separately, requiring two channels in the driving electronics. Because of the inevitable different temperature dependence of the two colors of LEDs, if fixed currents are provided to the two colors, then color will change as the lamp warms up, and color will vary at different ambient temperatures. The other difficulty, even if two channels are used, is that the two colors of LEDs, which are built from different materials systems, degrade differently over time. Inevitably, color will drift much more over time

than with approach 1, leading to unsatisfying color performance. There are ways to avoid this differential degradation:

a. Add more complicated (and expensive) electronics that perform both optical and thermal feedback to maintain constant color.
b. Use the approach used in the L Prize lamps. In this case, the LEDs are substantially under driven to reduce degradation. However, this requires many more LEDs to reach the necessary light output, and therefore much higher cost.

Approach 2 may yield efficacy for CRI 90 products that is nearly equal to that of CRI 80 products. However, much more complicated electronics, sensing, and different optics are also required. If these measures are not taken, color maintenance and reliability issues will be much bigger issues than with approach 1. Initial cost will inevitably be higher.

3. The third way is to filter out some of the non-red light from phosphor-converted LEDs so that the remaining light meets the CRI and R9 specifications. This is the least efficient approach, because it starts with a CRI 80 LED and completely discards a portion of the light. At least one CA-qualified lamp uses this method. The 80 CRI version of that lamp uses 9.5W, in its 60W incandescent equivalent. The 90 CRI version uses 13.5W or 42% more energy than the 80 CRI version. Approach 3 results in the poorest lamp efficacy of the three approaches.

It is to be expected that the cost of CRI 90 products will go down, and the efficacy will go up. However, the percentage difference between CRI 90 and CRI 80 products will remain, because CRI 80 products will also improve. In fact, because CRI 80 products are being well-accepted in the rest of the world, and CRI 90 is not an attractive feature, the difference is more likely to worsen the argument for CRI 90 as time goes by, and greater effort is dedicated to higher-volume CRI 80 products.