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Objection to NOTICE OF PROPOSED ACTION PROPOSED AMENDMENTS TO APPLIANCE EFFICIENCY REGULATIONS California Code of Regulations, Title 20, Sections 1601 through 1609 CALIFORNIA ENERGY COMMISSION Docket Number 15-AAER-6

Additional submitted attachment is included below.

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Docket Number 15-AAER-6

Comments by Robert Clear
Retired lighting researcher, and fellow of the Illuminating Engineering Society of North America

A former colleague of mine notified me about the above proposed action on LED lights on Wednesday, Novemeber 25. I accordingly have not had sufficient time to completely review the proposed action and the supporting staff report. I nonetheless have found a number of significant errors, general sloppiness (in both directions with regards to supporting or not supporting staff proposals), misinterpretations, and unexplained or unjustified assumptions in the supporting staff report. I am therefore submitting an objection to the proposed amendments.

More specifically, I object because the proposed regulations undervalue the importance of energy efficiency, which is a very strange comment to make about a regulation supposedly developed to promote energy efficiency. They do this by undervaluing the future value of energy, and overvaluing the worth of a long lamp life, and a high CRI. In place of the proposed standard I propose that the standard should be set to eliminate the bottom XX% of current lamp efficacies (XX to be determined, but if the cost data is actually real, which I am not sure of given the mistakes in the report, I would set it at 80%) with a timeline for tightening the standard as the technology continues to improve. I further propose that there should be labeling for lifetime and possibly CRI, but no required minima.

In addition to the above major objection, I am also concerned that the proposal is insufficiently strict with respect to power factor and flicker, and overly restrictive regarding the candlepower distribution for general service lamps.

I have noted that there are errors in the staff report because the types of errors made me concerned that the staff were not familiar with lighting issues, and might make serious errors in their analysis. For example, the report states that "Haitz's Law assert that LEDs will become exponentially more efficient ... over time" (page 23). On page 25 the report compounds the error by asserting that "LED manufacturers have made claims to develop LEDs of light intensity tenfold, that is from 50 lumens per watt to 500 lumens per watt.". Any efficiency measure is likely to be bounded, and in fact lighting efficiencies are approaching their theoretical limit. The maximum attainable efficacy of monochromatic 555 nm light is only 683 lumens per watt, and and the maximum efficacy for "white" lights is closer to 400 lumens per watt (with the exact value depending on what is counted as "white"). Note that efficiency is unitless, while efficacy has units of lumens per watt. An efficacy of 683 lumens per watt is equivalent to a photopic (visual) efficiency of 100%). A quick check of the references listed in the report indicates that the staff did not understand them. Haitz's law is stated as claiming that the lumen output per LED package is increasing exponentially. This is not the same as the efficacy, as the output of the package depends upon its size and its power density, as well as its efficacy. Similarly a check of the reference which supposedly supports the 500 lumen per watt claim indicates that it actually claims an increase in lumen output per area of the LED package, not per watt of input.

The lack of lighting expertise is most noticeable in the supposed justification for minimum CRIs. The report implies that CRI is a measure of how "accurately" colors are rendered, and is therefore is a measure of "how well a lamp is doing the job of "providing white light"'. In discussing CRI further, the report further states that the work of a general service lamp is "to both illuminate a room and provide the ability to discern colors". To justify a trade-off between efficacy the report states that "a lamp with a fuller color gamut and high color rendering cannot have as many lumens per watt as a monochromatic source at the peak of the curve", and then asserts that "several residential room types demand color accuracy, including the kitchen and bathroom, where grooming and food preparation/consumption occur.".

CRI is not a measure of "whiteness". It is a measure of how close the colors of eight test objects illuminated by a test lamp match the colors of the test objects when illuminated by a reference light source (a blackbody or a phase of daylight) of the same color temperature. A high color temperature lamp will tend to have a bluish tint, and can make a matte white surface appear reddish in contrast (http://www.lrc.rpi.edu/programs/solidstate/assist/whitelight.asp). Similarly , a low color temperature source will look yellowish or reddish, and will tend to make a matte white surface greener by contrast. You see the color temperature of a lamp directly. You do not directly see the CRI of a lamp.

CRI is not a measure of how "accurate" colors are rendered. It is a measure of color shift relative to a reference light source of similar CCT, but colors also shift when the color temperature changes. This means that objects do not have a "true" color. "Accuracy " under these conditions is a misnomer.

Gamut is typically defined as the area of color space spanned by the eight test lamps used in the CRI calculation. A low CRI lamp can have a larger gamut than a high CRI lamp if the deviations from the reference lamp are in the direction of greater color saturation.

CRI is related to color memory. An object that is a particular color under one light source, may be discernibly different under a source with a different CRI, or for that matter the same CRI if we use CRIa, which is an average value, or are looking at a more saturated color than the standard CRI test samples. CRI does not have a straight-forward effect on the ability to discern differences between objects of different spectral reflectances. A low CRI source will increase some differences, and decrease other differences compared to the reference source. If a particular balance between colors is desired, in a room or for a particular artwork, then CRI can make difference. But it should be noted even here that there are major caveats. Aside from the fact that CRI is a very imperfect measure of the color differences, it is easy to design a room or create artwork that has the desired color balance under most low CRI lamps. Complicating the color balance issue further is the influence of time and long-term color adaptation. Long-term adaptation to a different colored environment, such as could be caused by the use of low CRI lamps, causes a long-term shift in perceived color balances (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3025050/). On an anecdotal level I have seen this effect on myself and on other members of our household. A young lady who has a room in our house responded to my inquiry about how she felt about our house lighting (CRI ranging from 50 to 80) by stating that it seemed different, but not bad, when she moved in, but that now she has been here for several years the lighting of the houses of friends that have incandescent lighting (CRI =100) seems off, or wrong.

The assertion that certain rooms "demand color accuracy" (high CRI) can be seen to be hyperbole when viewed against the history of residential fluorescent lighting here, and even more so in places like Japan or Taiwan where fluorescent lighting was essentially standard. I installed low CRI (50 to 60) fluorescent lighting in the 1970s, as that was what was available. To my knowledge, I never been harmed by it, or particularly even noticed that there was a problem. I, and the other members of my household are adapted to the lighting, and no longer see the colors of food, for instance, as being different from what is expected. As noted earlier, a low CRI does not mean that color differences are eliminated. This means that we can distinguish problems with food items. There are also two young ladies in the house who do, at times, wear cosmetics or hair dye. Neither of them reported problems, when asked directly while I was writing these comments, with the color, or color rendering of the lighting. Both young ladies are artists. Neither of them likes to work under incandescent lighting, despite its high CRI, because it is too yellow.

I am strongly opposed to minimum CRI requirements. I am in favor of setting the minimum required efficacy low enough to allow high (90+) CRI lamps, as there will be a subset of the population that is attached to the look of incandescent lighting. I am ambivalent about labeling, as CRI is a very imperfect measure even as applied to the issue of discerning color shifts. CRI was developed using the CIELUV space, which is outdated at this point. There have been criticisms of the ability of CRI to accurately rate color appearance shifts, especially with regard to LED lamps. Note for instance R. W. G. Hunter, and M.R. Pointer, "Measuring Color"
https://books.google.com/books?id=0LVMLOSEeqoC&pg=PA147&lpg=PA147&dq=CRI+and+just+noticeable
+difference&source=bl&ots=CjMTAjStaK&sig=hzIOlRSzLgu0_yCVH_LNEzwaGuI&hl=en&sa=X&ved=0ahUKEwihh93DhLXJAhWELIgKHU59CBYQ6AEIJjAC#v=o
nepage&q=CRI%20and%20just%20noticeable%20difference&f=false
which describes an example of a CRI 71 lamp that gives color rendering closer to the reference lamp than an alternate CRI 82 lamp. Another example of where CRI may be misleading is that it is not a preference rating. Note:
http://www.olino.org/us/articles/2009/11/30/a-close-look-at-the-color-rendering-index-cri-or-ra
where a preference test had lamps of CRI 23 (really low) and 63 being rated as preferred to a standard incandescent or halogen lamp (CRI = 98). My preference for labeling would be to block the lamps into a low, medium, and high categories, as I do not believe that greater precision is meaningful.

In addition to CRI, I am also concerned about having minimum lifetime requirements, instead of just simply labeling. The problem here is that there is a trade-off between lifetime and output, as well as efficacy, and presumably cost. Driving an LED with higher current increases its output, with some

cost in efficacy. Increasing the output makes it possible to reach a wider range of uses, and is therefore desirable, even though there is cost in efficacy, since the LED efficacies are still much higher than for the alternate technologies.

There is also a cost issue. Cheaper electronics are likely to result in shorter life, but this is worth it if increases the range of situations where the lamps are used. In terms of cost analysis it is important to remember that there is range of uses. The staff report uses average yearly hours of use, but there is a wide range of use around this average. I have a standard incandescent lamp in a closet that is still working 30 years after being installed. It is still works because it is only being a used only one or two hours a month. The lower the use, the less important energy efficacy is, and the more important first cost becomes.

There is one other major problem in specifying a long minimum lifetime. LED technology is not yet mature, and efficacies are still improving. If the minimum lifetime is 25,000 hours, and the use is on the order of 1,000 hours per year (moderately heavy use for a residential setting), then the lamp will last 25 years. If the lamp has only a 10,000 hour life, it will (on average) get replaced in 10 years. This means that the less expensive, slightly less efficient LED will be replaced 15 years earlier than the more expensive lamp. The net energy use over the 25 year period is lower for the cheap shorter life lamp, than for the more expensive long-life lamp.

In my introductory comments I also noted that I felt that staff had undervalued the importance of energy efficiency. In tables B-2 to B-4 the cost of electricity appears to be discounted by 3% annually. If the state is at all concerned with the potential problems of global warming, this is inappropriate. A negative discount rate essentially sends the cost of future problems to zero, regardless of their actual magnitude. There are other problems with the cost analyses, the most obvious of which I am just going to be able to mention, due to lack of time to analyze their effect and to write these comments. One of the problems is the use of a single, 14 lumens/watt, for incandescent general service lighting. This both under and over estimates the efficacies. The halogen replacement for the 100 watt bulb has an efficacy of 18 lumens/watt. On the other hand, specialty bulbs, long-life and rough service are still available. I just pulled several 60 watt, 130 volt bulbs out of a new construction. Their efficacy was 9 lumens per watt. Another problem is the analysis of cost versus CRI and efficacy shown in figure 20. The data for this figure is for chipsets, not final products. The efficacy and lumen output of chips depends upon the test current. The test currents for these chips was not restricted to a fixed fraction of the maximum rated current for the chips, which means that the efficacy and cost per lumen may have little relation to the values used to generate the figure.

I do not have time for an extended discussion of my other concerns with this proposed action. I have the following brief comments:

1) The proposal requires a minimum of 0.7 for the power factor of general service lamps, but does not put a limit on the power factor for directional lamps, because they supposedly are going to be similar to the products they are displacing. There is no logic in this distinction. Furthermore, if there is an expectation that the power factor of directional lamps will be high, then there is no problem in requiring it to be high, since manufacturers would supposedly do it anyway. Require a minimum power factor for both types of lamps. LED lamps will become common. We should not be degrading the utility system power factor.

2) The proposal puts limits on flicker while dimming. The limits listed are much greater than what is being recommended by the IEEE: IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers, IEEE Std 1789™-2015. The IEEE document recommends limiting modulation to 2.5% times the frequency below 90 Hertz, and to below 8% times the frequency from 90 Hertz to 1250 Hertz.

3) The proposal puts limits on the candlepower distribution for general service lamps that seem far tighter than is needed.