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Additional submitted attachment is included below.

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April 19, 2021

Docket #s 19-BSTD-03 and 21-BSTD-02
California Energy Commission
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Re: Environmental harm associated with edits to Table 150.0-A and new Table 160.5-A in 2022 Title 24 Draft Express Terms (TN #: 236876 in Docket Number: 19-BSTD-03)

In response to the California Energy Commission's Notice of Preparation of an Environmental Impact Report for the 2022 Amendments to the Energy Code, I recommend that the CEC evaluate the impacts of these amendments on indoor environmental quality including exposure to flicker (light modulation). In this light, I recommend that the CEC evaluate the proposed changes to Table 150.0-A which is also replicated in Table 160.5-A in the new multifamily chapter of the Energy Code.

I think that the proposed changes to Table 150.0-A will significantly reduce the scope of residential LED light sources covered by the Joint Appendix JA8 lighting quality requirements. In addition to losing the direct environmental protection benefits resulting from installed lighting qualifying with the JA8 requirements, the test and list aspect of publishing flicker data in the JA8 database provides the capabilities of consumers and designers to select luminaires that exceed the minimum requirements of JA8 and are compliant with the IEEE Standard 1789-2015, *"Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers."* My recommendation is to revert the requirements in these tables back to the content as contained in table 150.0-A in the 2019 version of Title 24, part 6.

Description of Table 150.0-A and the Impact of Proposed Changes in Draft Express Terms

Figure 1 contains the unedited Table 150.0-A from the 2019 standards. As written for 2019, the high efficacy lighting requirements were relatively easy to enforce. Light sources in the left-hand column of the Table 150.0-A were exempted from the JA8 requirements including: legacy high efficacy light sources (HID, fluorescent, induction), colored inseparable solid state lighting and outdoor lighting. All other light sources indoors and those in recessed cans or in luminaires with screw bases were required to pass the JA8 tests, place their test results in the JA8 database and label the lamps or luminaires "JA8-2019."

Light sources that are certified and labelled as JA compliant have been tested for:

- Luminous efficacy – at least 45 lm/W
- Power factor at least 90%
- Start time no less than ½ a second
- Color quality – color rendering index (CRI) no less than 90
- Color temperature – no greater than 4,000 Kelvin
- Longevity – at least 15,000 hours
- Dimmability
- Low flicker operation, less than 30% flicker for frequencies less than 200 Hz.
- Low audible noise – less than 24 dBA at 1 meter

TABLE 150.0-A CLASSIFICATION OF HIGH EFFICACY LIGHT SOURCES

High Efficacy Light Sources Light sources shall comply with one of the columns below:	
Light sources in this column other than those installed in ceiling recessed downlight luminaires are classified as high efficacy and are **not** required to comply with Reference Joint Appendix JA8	Light sources in this column are only considered to be high efficacy if they are certified to the Commission as High Efficacy Light Sources in accordance with Reference Joint Appendix JA8 and marked as required by JA8.
1. Pin-based linear fluorescent or compact fluorescent light sources using electronic ballasts. 2. Pulse-start metal halide light sources. 3. High pressure sodium light sources. 4. Luminaires with hardwired high frequency generator and induction lamp. 5. LED light sources installed outdoors. 6. Inseparable SSL luminaires containing colored light sources that are installed to provide decorative lighting.	8. All light sources installed in ceiling recessed downlight luminaires. Note that ceiling recessed downlight luminaires shall not have screw bases regardless of lamp type as described in Section 150.0(k)1C. 9. Any light source not otherwise listed in this table.

Figure 1: 2019 (unedited) version of Table 150.0-A Classification of High Efficacy Light Sources

Not only are these products tested and certified to the Energy Commission of their attributes along these quality metrics, but their results are listed into a publicly available appliance efficiency database.[1] The value of test and list appliance databases is that they provide the capability for the consumer to select higher performing products. A comparable example is that in years past, prior to regulations about nutrition labelling, "low sodium" (as in salt) could mean anything and the amount of sodium was not quantified, thus people with special nutrition needs could not readily know what they were getting. This has changed with required nutritional labelling. Similarly, prior to the 2016 Title 24 JA8 database, there was no publicly available data available for flicker, especially for the type of flicker that is not visible but has been linked to headaches and poor task performance. The JA8 database allows the consumer and the lighting designer to select light sources that not only meet the flicker requirements of JA8 but also can meet the requirements of IEEE 1789-2015, which is more stringent than the basic flicker criteria in JA8. More on this topic will be covered later.

Table 1: Count of LED Models and Relative Percent by Light Source Type (downloaded February 9, 2021)

Light Emitting Diode	Models	%
Decorative Lamp	1,466	2%
Directional Lamp	1,706	3%
Inseparable Luminaire	54,174	87%
Light Engine	1,747	3%
Omnidirectional Lamp	1,656	3%
Small Diameter Directional Lamp	72	0%
Strip Lighting	1,202	2%
Totals	**62,023**	**100%**

[1] Modernized Appliance Efficiency Database System (MAEDBS). https://cacertappliances.energy.ca.gov/Pages/Search/AdvancedSearch.aspx

The JA8 MAEDBS database has been widely used and greatly expanded the scope of what luminaires could be considered high efficacy light sources. Prior to the 2016 standards luminaires with removable lamps were not considered high efficacy as there was a concern that poor quality high efficacy lamps would be replaced with low efficacy incandescents. With the introduction of JA8 high quality, high efficacy light source requirements and labelling, design flexibility was expanded to allow luminaires with removable lamps.

TABLE 150.0-A CLASSIFICATION OF HIGH LUMINOUS EFFICACY LIGHT SOURCES

~~**High Efficacy Light Sources**~~ ~~Light sources shall comply with one of the columns below:~~	
Light sources in this column other than ~~those installed in~~ ceiling recessed downlight luminaires are classified as high luminous efficacy and are **not** required to comply with Reference Joint Appendix JA8	Light sources in this column are required to comply with Reference Joint Appendix JA8~~only considered to be high efficacy if they~~ and they ~~are certified to the Commission as High Efficacy Light Sources in accordance with~~shall be certified to the Commission for complying with Reference Joint Appendix JA8 and marked as required by JA8.
~~1. Pin-based linear fluorescent or compact fluorescent light sources using electronic ballasts.~~ ~~2. Pulse-start metal halide light sources.~~ ~~3. High pressure sodium light sources.~~ ~~4. Luminaires with hardwired high frequency generator and induction lamp.~~ 1~~5~~. LED light sources installed outdoors. 2~~6~~. Inseparable Solid State Lighting (SSL) luminaires ~~containing~~ and colored light sources that are installed to provide decorative, accent, display, or special effect lighting. 3. Dim-to-warm and tunable-white LED light sources with at least one light source controller setting of 4000K or less and color rendering index (CRI) rating of 80 or greater. 4. Color-tunable LED light sources. 5. LED lamps compliant with Title 20 as general service lamps and with a correlated color temperature (CCT) of 4000K or less. 6. Pin-based linear fluorescent or compact fluorescent light sources using electronic ballasts. 7. High intensity discharge (HID) light sources including pulse start metal halide and high pressure sodium light sources. 8. Luminaires with hardwired high frequency generator and induction lamp. 9. Infrared and ultraviolet light sources.	~~8~~10. All light sources installed in ceiling recessed downlight luminaires, except color-tunable LED, dim-to-warm LED and tunable-white LED light sources. Note that ceiling recessed downlight luminaires shall not have screw bases regardless of lamp type as described in Section 150.0(k)1C. ~~9~~11. Any light source not otherwise listed in this table.

Figure 2: Edited version of Table 150.0-A as contained in the 2022 Title 24 Draft Express Terms

Table 1 contains the count of models by different LED light sources in the JA8 database. Though the vast majority (over 54,000) of the model listings in the JA8 database are for integral luminaires, the 4,900 JA8 certified lamps allows a significantly larger sample of luminaires to be certified for use in new residential construction as any luminaire outside of recessed downlights containing JA8 lamps qualifies as compliant with the requirements of the 2019 Title 24 part 6 energy code.

Figure 2 illustrates the edits that were made to Table 150.0-A as contained in the 2022 Title 24 Draft Express Terms posted February 22. The edits to the list of exempted legacy light sources in the left-hand column of the table result in most of the light sources in the JA8 database to be no longer certified. The simplicity of enforcing of the lighting standard would be undermined as most LED sources would no longer be required to be labelled.

My interpretation of the expressed terms edits to Table 150.0-A and the reduced coverage of the JA8 requirements are as follows:

> 2~~6~~. Inseparable Solid State Lighting (SSL) luminaires ~~containing~~ and colored light sources that are installed to provide decorative, accent, display, or special effect lighting.

Originally the exempted lighting was the relatively small fraction of inseparable solid state (LED and OLED) lighting luminaires containing a colored light sources. Note this exemption is for inseparable SSL lighting and does not include luminaires containing colored screw-in lamps. At time of inspection, complying screw base luminaires would contain JA8 lamps; the occupant could install colored "party bulbs" inspection but the new home would be initially constructed with high quality JA8 lamps.

The relatively small wording change, replacing "containing" with "and," would significantly expand the JA8 exception to all inseparable SSL luminaires and all colored light sources. As shown earlier in Table 1, Inseparable Luminaires comprise 87% of the LED models in the JA8 database. This would eliminate the lighting quality and environmental protection benefits of this entire class of residential light sources. If the intent was to limit the exception to the intersection of colored light sources and integral SSL luminaires, this has not been achieved; the original wording, "Inseparable Solid State Lighting (SSL) luminaires containing colored light sources," is much less ambiguous. For simplicity of enforcement, the purpose of installation is also ambiguous, it would be better to leave this requirement simply "Inseparable Solid State Lighting (SSL) luminaires containing colored light sources" and delete "installed to provide decorative, lighting."

> 3. Dim-to-warm and tunable-white LED light sources with at least one light source controller setting of 4000K or less and color rendering index (CRI) rating of 80 or greater.

This exception for dim to warm and tunable white lighting would remove all of the testing and listing requirements in JA8 for these light sources. This is a growing area of the LED lighting market, given how this is written some manufacturers would like to provide products with a lower color rendering index (80 instead of 90 CRI) in new homes. However, this proposal would not only reduce the requirement for color rendition but also eliminate requirements for flicker, noise, longevity etc. Note that this proposed exemption to JA8 rating and labelling would apply to all light sources including screw in lamps and light sources in recessed lighting. If there is a compelling rationale to lower the color rendition of dim to warm light sources, this should be disclosed and consider changing only the CRI requirements for dim to warm and color tunable sources in JA8 rather than eliminating all of the lighting quality protections in JA8.

4. Color-tunable LED light sources.

If the color tunable lighting is capable of providing white light this is potentially a light source that is not just ornamental but providing general illumination in the dwelling. The same concerns apply to this exception as expressed for tunable white sources. Please consider retaining all if not most of the consumer protections contained in JA8 for these sources.

5. LED lamps compliant with Title 20 as general service lamps and with a correlated color temperature (CCT) of 4000K or less.

Around 13% of the light sources in the JA8 MAEDBS database are lamps. About half of these are Title 20 general service lamps. These lamps are contained in the Title 20 database for LED general service lamps however, the reporting requirements for flicker are limited to: *report "yes" for "reduced flicker operation" described in section 1606, otherwise report "no."*[2] Thus this would remove the benefit of a test and list standard for Title 20 general service lamps. As will be described later this will hinder differentiating those products that barely comply with the low flicker operation requirements from those that meet the recommendation of the IEEE 1789-2015 low flicker risk recommendations.

From a compliance perspective, instead of building inspection staff spot checking for the "JA8" label they have to parse between whether the light source is general service, ornamental, large diameter directional, or small diameter directional. In addition to the other uncertainty about what is a Title 20 general service lamp, what is a dim to warm control etc., this is a recipe for non-enforcement.

In summary the proposed changes would undermine the JA8 test and list database as a compliance tool as an increasingly small fraction of LED indoor lighting would be required to test, list and label. CEC staff have not held a public meeting to discuss these changes or their rationale. Thus in developing the EIR, a description of rationale behind removing the consumer and environmental protections afforded by the JA8 regulatory regime, and what alternatives were considered for mitigating the harm would be necessary as part of a finding of no negative environmental impact.

One newly exempted light source proposed for addition to the left-hand column light of Table 150.0-A and 160.5-A I support in concept exempting infrared and ultraviolet light sources as they are clearly not white light sources. The express terms have proposed adding these sources as follows:

9. Infrared and ultraviolet light sources.

Note that hardwired fluorescent, HID and induction light sources are already exempted. I don't believe that it is intended to allow screw base luminaires to be exempted with screw-in colored lamps including infrared or ultraviolet lamps. For those who are uncertain if ultraviolet or infrared light sources are "colored light" this exemption could be more compactly and unambiguously covered in the exemption for SSL lighting containing colored light sources:

6. Inseparable Solid State Lighting (SSL) luminaires containing colored light sources including infrared and ultraviolet light sources. ~~that are installed to provide decorative lighting.~~

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[2] Table K-1 Test Methods for State-Regulated LED Lamps and LED State-Regulated Small Diameter Directional Lamps

The Energy Commission has the Authority and Responsibility to Minimize IEQ Impacts of End Uses.

Looking to the precedent of the 1992 Title 24, part 6 standards, the CEC has been balancing trade-offs between indoor environmental quality and energy savings for almost 30 years. Some examples from the 1992 standards include:

- Section 118(b) – limitation on use of urea formaldehyde foam insulation
- Section 119(d) – limitation on ultrasound and microwave energy emitted from occupancy sensors
- Section 119(e) &(f) – requirement for *"low flicker operation"* of daylighting control and lumen maintenance control dimmers. Low flicker operation was defined as, *"the operation of a light, in which the light has a visual flicker less than 30% for frequency and modulation."*
- Section 121(b)2 – minimum outside air quantities
- Section 121(c)2 – preoccupancy ventilation

The limitations on ultrasonic energy is a useful analogy to considerations in regards to imperceptible flicker. Occupancy sensors that emitted sound would be unacceptable from market position. However, the authors of the Title 24, part 6 standard recognized that excessively high ultrasound levels, even though not perceived, could have a deleterious impact on human health and adopted ultrasound limits to match those recommended by American Conference of Governmental Industrial Hygienists (ACGIH).

For the 1992 standards, the apparent purpose of low flicker operation requirements for daylighting and lumen maintenance lighting controls was to minimize the annoyance from visible flicker. Various projects had reported energy savings controls being disabled in response to flicker.

During the development of the 2008 version of Title 24, lighting manufacturers contacted the California Energy Commission and indicated that pulse width modulated LEDs could have 100% amplitude modulation but at high enough frequencies where flicker would not be a problem. By this time there was an increasing awareness that flicker had physiological effects beyond what was associated with perceptual flicker most notably with complaints about magnetically ballasted fluorescents. At the time there was little market data on how much flicker was in the products that were being sold, thus a conservatively low frequency was selected to set the basis of the new flicker definition. The cut-off frequency of 200 Hz was selected to capture ripple from a poorly filtered rectifier at 120 Hz and at 30% amplitude modulation, this was comparable to magnetically ballasted fluorescent lighting. By 2008 reduced flicker was considered an added benefit from electronically ballasted fluorescent lighting in addition to the energy savings. Thus in the 2008 version of Title 24, low flicker operation was redefined as *"the light output has an amplitude modulation of less than 30 percent for frequencies less than 200 Hz."*

Though the definition of "reduced flicker operation," clearly defined the maximum percent amplitude modulation (30%) and the maximum frequency considered (200 Hz), there was no defined test method for collecting the data or processing it. In lieu of a test method, a subjective visible inspection of no visible flicker was accepted assertions as meeting the intent of the standard. This was despite the knowledge that the new definition of flicker was intended to capture some imperceptible flicker impacts.

This subjective evaluation of low flicker operation was replaced with Joint Appendix JA10 *"Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements"* in the 2016 version of Title 24, part 6 and the data is publicly posted in the JA8 database. As shown in Table 1, there are now over 60,000 LED light sources that have been tested and tested their results in the JA8 database.

Flicker (Light Modulation) and Its Impact on Human Health and Performance

Physiological flicker is amplitude modulation of light at frequencies that affects human physiology. Physiological flicker encompasses both perceptible flicker and imperceptible flicker. Perceptual flicker is flicker than can be consciously detected. Perceptual flicker includes both directly perceived flicker and indirectly perceived flicker. Directly perceived flicker takes place under relatively ideal conditions of little movement by 1) the observer 2) the eyes of the observer or 3) objects in the visual field.

Imperceptible flicker is flicker that is not noticed but still has an impact on human physiology. Berman et al (1991) has documented with electroretinogram (ERG) measurements that there are physiological responses to modulating light sources well above the perceptual critical fusion frequency (CFF) *"…our results show that a measurable but gradually decreasing ERG signal is obtained from stimuli oscillating at rates up to 200 Hz."*

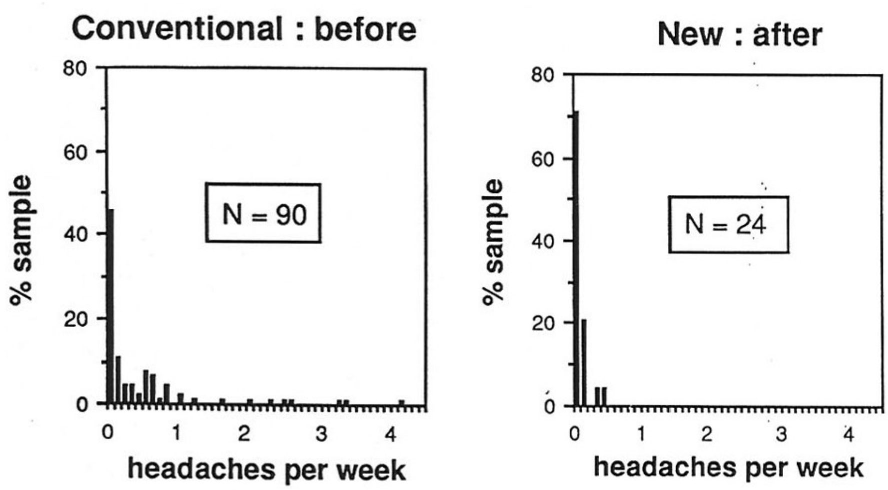

Figure 3: Number of Headaches with Magnetic (100 Hz) Ballasts vs Electronic

Studies on imperceptible flicker by Veitch (1995) and Wilkins et al (1989) found performance and headache effects from magnetically ballasted fluorescent lighting (with around 30% modulation depth at 120 Hz).[3] Wilkins reported that "headaches and eyestrain were reduced by a factor of two or more when the controlling circuitry was changed to the new high-frequency ballast and the light no longer fluctuated in intensity…" Wilkins also wrote that "as can be seen

[3] Wilkins, et al (1989) The measured percent flicker or percent amplitude modulation of magnetic ballasts in this study is between 27% and 33%. This has been missed by some reviewers that did not recognize that modulation was presented in terms of peak-to-trough modulation. *"Most lamps were cool white (Thorne Cool White) and gave a light modulation of 49-50% of maximum. The remainder were white and (Wotan 23) and gave a modulation of 43-47%."* This uses a "peak-to-trough" metric of modulation, where PT = (Max – Min)/Max. Percent flicker or percent amplitude modulation is AM = (Max-Min)/(Max + Min). AM = PT/(2-PT). The resulting range of percent flicker in the Wilkens et al paper is between 27% and 33%. This calculation was confirmed with Dr. Wilkins.

from a comparison of the histograms for new and conventional lighting …, the tail of the distributions is longer in the case of conventional lighting: a few subjects suffered headaches or eyestrain frequently and they did so mainly under conventional lighting.” (Underline added for emphasis).

In the left-hand graph in Figure 3, seven people out of the 90 sampled had headaches more than 2 times per week and none of the subsample of 24 people who received electronic ballasts in the right hand graph have more than one headache a week. Conventional lighting here means magnetically ballasted fluorescent lighting. What is important about this finding is that a modest but significant population (8%?) of people is more sensitive to flicker. It implies that for broad acceptance and embrace of this technology we should be considering not just what avoids deleterious health effects for the average person but also for people who are more sensitive to flicker.

With the long life of LEDs and imperceptible flicker being correlated with headaches, it is important that while achieving the State’s greenhouse reduction goals, that the state is retaining the protections that encourages the lighting market to continue to compete on lighting quality including low flicker lighting. For competitive markets there needs to be free access to information so that the consumer can be aware of features or benefits that are otherwise invisible.

The Institute of Electrical and Electronics Engineers IEEE 1789-2015 Standard, "Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers." has helped the lighting industry understand that the effect of flicker on the human organism varies by both depth of modulation and frequency. This standard has synthesized the various studies that indicate that there are physiological impacts of modulating light associated with direct perception of flicker (including seizures for some people) but that there are also physiological impacts beyond the range of frequencies that are associated with direct perception of flicker. This is the only flicker standard that has undertaken the rigorous ANSI standard development process that not only includes public review but also requires that the committee membership is balanced among different interest groups.

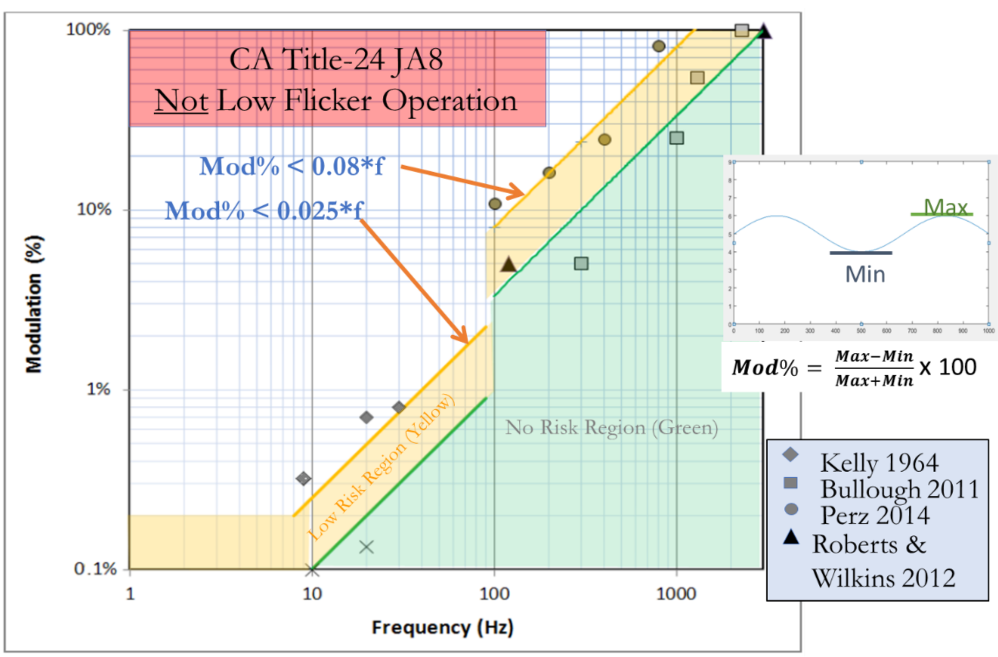

Figure 4: IEEE PAR 1789-2015 Low Risk and No Risk Regions

A key outcome of this synthesis of the research to date was a recommendation document that included a two dimensional risk map of frequencies and modulation (%) as shown **Figure 4**, with three primary regions: 1) No Risk Region (Green) where there is little expectation of any physiological effect, also known as the "No Observable Effect Level" (NOEL). This is where physiological response so far is not measurable. 2) Low Risk Region (Yellow) where a physiological response is detected but the response is small and deemed to be unlikely to be damaging and 3) Not Low Risk Region (White) where there may be a range of risk from not much risk to the severe risk associated with triggering epileptic seizures or vertigo with relatively modest amplitude modulation at low frequencies.

Superimposed on the upper left-hand corner of this risk map is a red box labelled "CA Title 24 JA8 Not Low Flicker Operation." This box defines an area on the graph that is greater than 30% amplitude modulation for frequencies less than 200 Hz. By definition, this combination of amplitude modulation and frequency is non-compliant with the current definition of "low flicker operation." While researching the development of the JA10 test method, approximately half of LED lamps were performing worse and had amplitude modulation greater than 30% for frequencies less than 200 Hz. These lamps would not comply with JA8. However, once a technical specification was written, industry responded and there are now a huge number of complying lamps and luminaires.

However, there is a gap in regulation between the CA JA8 excluded light sources and what IEEE 1789 designates as low risk. In the short term, this gap can be addressed through incentive programs and education of designers and specifiers as well as reach standards such as WELL, LEED, and the International Green Construction Code (IgCC). All these efforts to close the gaps between minimum code compliance and enhanced flicker protection require information about the flicker performance of light sources such as is contained in the JA8 database. It is within this context that I am concerned about removing requirements for "low flicker operation" and test and list requirements for color tunable and dim to warm sources and removing the test and list requirements for Title 20 covered general service LEDs.

How to Measure Flicker in a Format Compatible with IEEE 1789?

Though the physiological process is a lot more complex, the shape of the risk map implies a system that is less sensitive with increasing frequency. A method of conducting this evaluation is to use a low pass filter and eliminate all frequency components above a frequency of interest and then calculate the amplitude modulation for the filtered waveform.

A repeatable method of filtering of the high sample rate data is to filter the data mathematically using Fourier Transform analysis. The key steps in this procedure are shown in Figure 5 and are based upon the procedure described in Lehman et al. (2011) and in IEEE 1789. These steps are implemented in California Title 24 Joint Appendix JA10 where the data is filtered for all frequencies below the following cut-off frequencies: 40 Hz, 90 Hz, 200 Hz, 400 Hz and 1,000 Hz and then published in the Joint Appendix JA8 database.

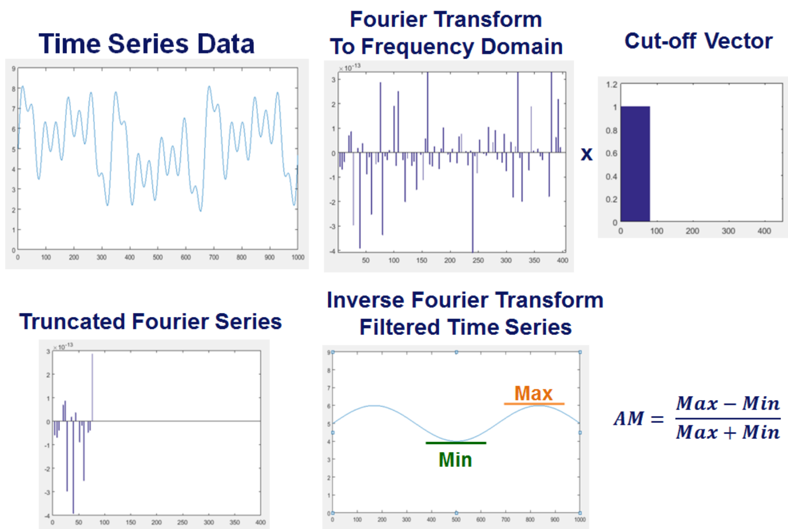

Figure 5: Fourier Filtering of Photometric Data to Calculate Amplitude Modulation below Cut-off Frequency

Does a Publicly Available Database of Flicker Performance Provide an Environmental Benefit?

In supporting an evaluation of how important it is to maintain a test and list database, answering the following questions would be helpful.

1. Is there any benefit to lower flicker?
2. Is there variability in the market in regards to flicker?
3. Are the IEEE 1789 low risk targets currently achieved by any market participants?
4. Is achieving the IEEE 1789 low risk targets reliant on any one proprietary technology?
5. Does the flicker information assist in market transformation activities?

Is there any benefit to lower flicker?

The prior section describes health benefits (less headaches). A study by Veitch and McColl (1995) which measured the time to identify the direction of the gap in a Landolt Ring test found "Visual performance scores of 18-24-year-old male and female university students were significantly higher in the high-frequency flicker condition than the low-frequency flicker condition." In developing the JA8 requirements for high quality, high efficiency lighting and underlying motivation was to prevent the migration to low efficacy lighting if lighting quality of the high efficacy lighting was deficient to the legacy incandescent sources. When people described their dissatisfaction with fluorescent lighting common theme was color quality and flicker. Thus, there may be health satisfaction and energy benefit to low flicker lighting.

Is there variability in the market in regards to flicker?

There is wide variability in levels of flicker from 100% amplitude modulation at 120 Hz to significantly less flicker than incandescents. Early tests on LED lamps found that 50% of lamps would fail the 30% low flicker operation definition. When developing an improved flicker standard for the ASHRAE 189.1 standard for the design of high performance green buildings the flicker performance of JA8 compliant light sources was evaluated and we found that there is a significant amount of variability between light source types and within light source types. More detail is given the next section of this letter.

Are the IEEE 1789-2015 low risk targets currently achieved by any market participants?

The short answer is yes, the fraction of light sources in the JA8 database complying with the IEEE 1789 low risk targets varies between 11% and 67% depending upon light source type (see Table 3 below).

Is achieving the IEEE 1789 low risk targets reliant on any one proprietary technology?

No. Many products from many different manufacturers are complying with the IEEE 1789 low risk targets. The fraction of manufacturers in the JA8 database which have products which can comply with the IEEE Std 1789 low risk targets is between 25% to 50% of the manufacturers of each light source type in the JA8 database (see Table 4 below).

Does testing, and listing flicker information assist in market transformation activities?

Testing and listing of appliance efficiency information has been a key component of transforming markets for higher efficiency. Weil and McMahon (2001) noted that *"It has further been calculated that each Euro spent under the labeling program for refrigerators has led to actions by manufacturers and member states that will result in avoided consumer electricity bills worth 100,000 Euro."* The effect of information labelling on consumer protection and market transformation has been the basis of EnergyGuide labels, Nutrition Facts labels for packaged food, and IIHS and NHTSA safety ratings of cars[4]. These ratings not only allow consumers to choose but also provide feedback to regulators about market readiness of higher standards.

The following analysis was conducted two years ago for developing the flicker portion of Addendum BE "Lighting Quality" to ASHRAE 189.1-2017 *Standard for the Design of High Performance, Green Buildings*.[5] At the time there were half as many light sources in the JA8 database (around 30,000) but the results and the process are illustrative of helping code bodies understand whether more protective flicker standards are achievable, non-proprietary, economic and place undue burden on the lighting market.

Capability of the Lighting Market to Meet IEEE 1789 Low Risk Flicker Recommendations

Many people agree that IEEE PAR 1789 is the standard of care for flicker. It is the only ANSI standard that includes technical recommendations on precautionary levels of percent flicker for different frequencies that are unlikely to result in health risks. Some disagree whether the presence of flicker is a "health risk" or just an annoyance for sensitive populations. Regardless of the position on IEEE 1789, there was general agreement that lower flicker is better, and the flicker limits developed in Addendum BE were acceptable for a reach standard as it was shown there was a critical mass of light sources that could achieve the proposed limits.

Currently the JA10 test method and recording specification calls for processing the data for 5 cut-off frequencies (40, 90, 200, 400 and 1,000 Hz). As the cut off frequencies are increased, all of the lower frequencies are included in the filtered waveform and evaluated for how much the waveform varies or is modulated from lowest intensity to highest intensity. At low frequencies to which the eye is most sensitive, even relatively small variations are visible and as these fluctuations get larger they are not just annoying but also can trigger photosensitive-epileptic

[4] Insurance Institute for Highway Safety crash test ratings, National Highway Traffic Safety Administration star rating

[5] https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/189_1_2017_be_20200810.pdf

seizures for some people. Given that the evaluation at low frequencies were found to be acceptable, as one increases the cut-off frequencies higher amounts of amplitude modulation or variability of between the lowest and highest intensity is acceptable. This wide band approach to evaluating flicker results in some judgement decisions in how to set maximum amplitude limits for each of the broadband bins that are below different cut-off frequencies.

Table 2: Amplitude Modulation for Evaluating JA10 Flicker data in JA8 database

T-24 JA10 Cut-off frequency Hz	Amplitude Modulation Relaxed IEEE	Relaxed AM & Relaxed AM x 1.4 @ 90 & 200 Hz	Amplitude Modulation IEEE Midpoint	"Midpoint" Frequencies for AM Calculation (Hz)
40	1.0%	1.0%	1.0%	40
90	2.3%	3.2%	1.6%	65
200	16.0%	22.4%	9.6%	120
400	32.0%	32.0%	24.0%	300
1,000	80.0%	80.0%	56.0%	700

If the JA10 data were collected and evaluated over time, a relaxed metric of compliance is one where the allowed maximum amplitude modulation is calculated for boundary between the low-risk region (yellow) and the not low risk region (white) at the cut-off frequency. This considered "relaxed" as the frequency contributing to the greatest variability in the signal is likely less than at the cut-off frequency.

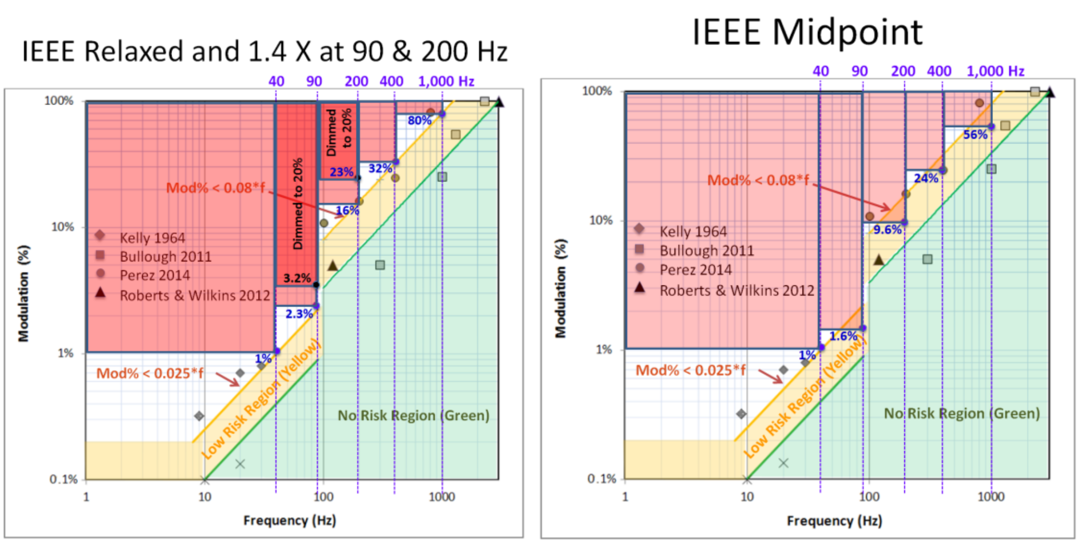

Figure 6: Representation of JA10 Noncompliant Modulation% vs Frequency Zones in Red Boxes with "IEEE Relaxed and 1.4 x Relaxed Values @90 and 200 Hz" and "IEEE Midpoint" Criteria

The "Relaxed IEEE" column in **Table 2** uses the cut-off frequency as the basis of the maximum percent amplitude modulation limit. Products that comply with the maximum percent amplitude modulation (AM) for the "Relaxed IEEE" would reflect equipment performance below the red boxes shown in the left half of **Figure 6**. In other words, any products with measured amplitude modulation above the limits listed when plotted would be in any of the red boxes in the upper left-hand corner of Figure 6 are not compliant. It should be noted that the 16% modulation limit for the low pass filtered results with 200 Hz cut-off frequency is equivalent to 0.58 SVM for a 120 Hz sinusoidal waveform.

The "Relaxed IEEE" limits are indeed relaxed and do not match well the IEEE specifications. Especially problematic with this approach is that for the frequencies that are below 200 Hz the dominant frequency driving amplitude modulation for this signal is 120 Hz. The recommended maximum amplitude modulation at 120 Hz is 0.08 x 120 = 9.6%. It should be noted that the 9.6% modulation limit for the low pass filtered results with 200 Hz cut-off frequency is equivalent to 0.35 SVM for a 120 Hz sinusoidal waveform.

This led to a selection of more representative "midpoint" frequencies for evaluating appropriate maximum percent amplitude modulation values for the data in each broadband (low pass) evaluation of data below each cut-off frequency. Complying products are below the red boxes in the left half of Table 5.

There is one more evaluation group in the JA8 MAEDBS database. When evaluating what fraction of the directional or omnidirectional lamps in the MAEDBS database would comply with the "relaxed IEEE" or the "IEEE midpoint" amplitude modulation limits, not enough products complied when dimmed to 20% of light output. By trial and error we adjusted the allowable amplitude modulation limits so that a sufficient fraction of directional and omnidirectional lamps would pass when they were dimmed to 20% of light output. A sufficient pass rate for lamps when dimmed to 20% was accomplished by setting the maximum allowable amplitude modulation to 140% of the relaxed IEEE amplitude modulation limits for cut-off frequencies of 90 Hz and 200 Hz. The 20% dimmed data for all other cut-off frequencies would still be compared against the relaxed IEEE amplitude modulation limits. This evaluation is entitled in the Tables below "Relaxed IEEE x 1.4 (90 & 200 Hz) 20%." Thus this proposal is intended to be protective of human health and performance while accounting for the current levels of amplitude modulation performance in the current SSL (solid state lighting) market.

Table 3 Fraction of California JA8 High Efficacy Light Sources in MAEDBS database passing various evaluation criteria (green values proposed for lamps and blue values for other sources).

Light Source Type	Count of Products	Passing Relaxed IEEE (Full Output) & 1.4 x Relaxed IEEE (20% output)	Passing IEEE Midpoint (Full and 20% Output)
Decorative Lamp	211	71%	67%
Directional Lamp	654	33%	13%
Inseparable Luminaire	35,933	56%	44%
Light Engine	1,178	67%	31%
Omnidirectional Lamp	595	55%	12%

Our recommended amplitude modulation limits are highlighted in green for lamps and in blue for all other light sources. For decorative, directional and omnidirectional maps we are recommending that the full light output modulation limits be based on "Relaxed IEEE" and when dimmed to 20% the modulation limits be based on "Relaxed IEEE x 1.4 (90 & 200 Hz)." For most lamp types, complying lamps are around 50% of these types of lamps in the MAEDBS database. For all combinations of directional lamps and dimmers, the passing rate is 33%.

Table 4: Total Number of Manufacturers of JA8 High Efficacy Lighting in MAEDBS database and count of manufactures with passing products for different criteria (green values proposed for lamps and blue values for other sources).

Luminaire Type	Total Count of Manufacturers by Light Source	Manuf with complying products: Relaxed IEEE (Full Output) & 1.4 x Relaxed IEEE (20% output)	Manuf with complying products: Passing IEEE Midpoint (Full and 20% Output)
Decorative Lamp	19	9	9
Directional Lamp	38	29	11
Inseparable Luminaire	203	150	98
Light Engine	36	26	11
Omnidirectional Lamp	43	22	13

We wanted to ensure that the proposed standard would not be achievable by only a few manufacturers or would otherwise limit compliance with the standard to a proprietary technology. As can be seen in the counts of manufacturers that have submitted products to the California database, there are many manufactures with hundreds of products that comply. For integral luminaires that are thousands of products that comply with the proposed standard.

Table 5: Proposed Maximum Percent Modulation with respect to low pass cut-off frequencies for specified lamps and for all other light sources.

	Specified Lamps[a]		All other light sources	
Cut-off frequency Hz	Amplitude Modulation at full output	Amplitude Modulation at 20% output	Amplitude Modulation at full output	Amplitude Modulation at 20% output
40	1.0%	1.0%	1.0%	1.0%
90	2.3%	3.2%	1.6%	1.6%
200	16.0%	22.4%	9.6%	9.6%
400	32.0%	32.0%	24.0%	24.0%
1000	80.0%	80.0%	56.0%	56.0%

[a] Integrated lamps intended to be connected to the electric power grid with the following ANSI standard base types: E26, E26d, E17, E11, E12, G4, G9, GU10, GU24, GU5.3, and GX5.3 and rated nominal operating voltages of 120, 240 or 277 VAC, or 12 or 24 VAC or VDC

Table 4 contains the proposed limits that resulted from this evaluation. In this table as a footnote is a description of the lamp types that are considered “Specified Lamps.” This description by lamp base is the same list of ANSI lamp bases that is used the ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 2.1 (Effective October 1, 2017).

As mentioned above, this analysis of the JA8 database was used to develop a flicker specification for lighting quality that was adopted into the ASHRAE 189.1-2020 standard. This lighting standard makes up the technical content of the 2021 International Green Construction Code (IgCC). The presence of a maintained JA8 database will immensely simplify designing to this new reach code.

Conclusions/Recommendations

- LED light sources can have very high flicker (up to 100% amplitude modulation at 120 Hz) and also very low flicker (just a couple percent, which is much lower than incandescents).
- The JA8 database is the only publicly available maintained manufacturer certified database that I am aware of that is able to provide a good comparison the flicker (light modulation) of products with the low-risk targets in IEEE-1789.
- The proposed changes to Table 150.0-A and 160.5-A in the 2022 draft proposed express terms would undermine the database by exempting most residential LED lighting products from having to test and list in the JA8 database and associated labelling.
- These proposed changes would also undermine an effective enforcement regime which expects all LEDs capable of producing white light to be labelled JA8.
- Similarly, this proposed change would remove the current requirement that all recessed lighting would contain JA8 labelled sources. This also would undermine the certainty and unambiguity of the inspection process.
- With most LED light sources being exempted, one would expect that less products would be entered into the JA8 database making it more difficult to compare the flicker of performance of competing products and making it more difficult to comply with reach standards such as the IgCC or local codes with more protective flicker standards.
- The net effect of these conclusions is that the proposed 2022 Title 24, part 6 standard is less protective in regard to flicker and other aspects of lighting quality regulated by JA8.
- I recommend that the CEC and its sister agencies evaluate the negative environmental impact of these changes to Table 150.0-A and duplicating these same harmful effects in Table 160.5-A. I also recommend that over the long term these agencies evaluate the environmental benefits of regulating flicker in alignment with IEEE-1789.
- I recommend that the 2022 Title 24 draft express terms proposed changes to Table 150.0-A be reversed back the original language for Table 150.0-A in the 2019 Title 24 and this also be used as the basis to the newly added Table 160.5-A *"Classification of Dwelling Unit High Luminous Efficacy Light Sources."*

Sincerely,

Jon McHugh, PE

Principal

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