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Philips additional comments on the Title 24 flicker specification

Additional submitted attachment is included below.

Docket 17-BSTD-01

Additional Comments on Title 24 flicker specification

The specification for flicker in Title 24 has changed over time. There was a flicker definition in Title 24 as far back as 1988, though it extended only as high as 30Hz. In 1992, it was changed to a vague definition that mentioned 30% in connection with 'frequency and modulation' and apparently applied across all frequencies. In 2008, an upper limit of 200Hz was added and it became clear that 30% referred to amplitude modulation. However, the 2008 version of Appendix JA-1 somewhat confusingly used the previous (1992) definition. A definition was not readily found in the 2013 version, either in Title 24 or in the Joint Appendices, although "reduced flicker" is mentioned once in NA7. In 2016, the test method of JA10 was added and the (2008) definition reappeared, at which point the specification could actually be applied to products with a defined test. Annex A includes the relevant excerpts from several different years of Title 24 and the Joint Appendices.

The analyses that led to the original specification, and to the changes over time, do not appear in the official CEC dockets from the relevant years. For 2016, a paper by Jonathan McHugh and Mike McGaraghan (http://www.mchughenergy.com/papers/McHugh-QuantifyingFlicker_2016IES_ConfPaper-v4.pdf) describes the history of Title 24, and describes the test procedure in JA10. The paper provides rationale for the flicker specification itself (30% modulation depth below 200 Hz) by citing two studies. The paper states:

> "As mentioned earlier, studies on imperceptible physiological flicker by Veitch and McColl (1995) and Wilkins et al. (1989) found performance and headache effects from magnetically ballasted fluorescent lighting (with around 30% modulation depth at 120 Hz)."

Examination of the two references makes it unclear what the basis is for the statement above.

1. The effects observed by Wilkins were actually obtained with magnetically-ballasted fluorescent lamps having modulation depth of 43-49% at 100 Hz (Annex B), which is considerably different[1] than what is mentioned in the McHugh and McGaraghan paper. Wilkins did observe an increase in headaches and eyestrain under some circumstances.

2. Veitch and McColl used magnetic ballasts at 120 Hz, but with modulation depths of 45.3, 42.7 and 98.5%. Although the frequency is indeed 120 Hz, the modulation depth is not close to 30%.

3. Veitch and McColl observed no health related effects, including headaches. The performance effects that they did observe were significant for only one of six contrast ratios, even though they used modulation depth as high as 98.5%. This is surprisingly weak evidence. See Annex B for excerpts of their main results.

[1] The human sensitivity to flicker and stroboscopic effect depends strongly on frequency and to modulation depth.

If these two papers are indeed the basis for the CEC specification, then the analysis done to establish the CEC specification is flawed. A specification of 40% at 100 Hz would have avoided all conditions that led to health-related effects reported in either of the two references. Incidentally, 40% modulation depth at 100 Hz corresponds to SVM = 1.6, the specification in NEMA-77.

We request that the CEC confirm whether the quoted text above from the McHugh/McGaraghan paper is the basis for the Title 24 flicker specification. If it is, then please review the McHugh/McGaraghan paper, the Wilkins and Veitch references, and our comments in this document. If not, please provide us with the data and documentation that forms the basis of the Title 24 specification.

Annex A: Evolution of flicker requirements in CA

Title 24 (1988)
http://www.energy.ca.gov/title24/standards_archive/1988_standards/CEC-400-1988-001.PDF

> FLICKER-FREE OPERATION means that the light does not oscillate on and off in the readily noticeable frequency range of 0.01 to 30 Hertz.

Title 24 (1992)
http://www.energy.ca.gov/title24/standards_archive/1992_standards/CEC-400-1992-001.PDF

> REDUCED FLICKER OPERATION is the operation of a light, in which the light has a visual flicker less than 30% for frequency and modulation.

Title 24 (2008)
http://www.energy.ca.gov/2008publications/CEC-400-2008-001/CEC-400-2008-001-CMF.PDF

> 2. If the device is a dimmer controlling incandescent or fluorescent lamps, 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, and without causing premature lamp failure; and

Title 24 (2008) JA1
http://www.energy.ca.gov/2008publications/CEC-400-2008-004/CEC-400-2008-004-CMF.PDF

> *REDUCED FLICKER OPERATION* is the operation of a light, in which the light has a visual flicker less than 30 percent, for frequency and modulation.

Title 24 (2016) JA8
http://www.energy.ca.gov/2015publications/CEC-400-2015-038/CEC-400-2015-038-CMF.pdf

> (c) Light source in combination with specified control shall provide “reduced flicker operation” when tested at 100 percent and 20 percent of full light output, where reduced flicker operation is defined as having percent amplitude modulation (percent flicker) less than 30 percent at frequencies less than 200Hz, tested according to the requirements in Joint Appendix JA-10.

JA10 contains the testing procedure.

Annex B: Arnold Wilkins paper

A. Wilkins, et al., Lighting Res. Technol. 21(1) 11-18 (1989)

Summary The weekly incidence of headaches among office workers was compared when the offices were lit by fluorescent lighting where the fluorescent tubes were operated by (*a*) a conventional switch-start circuit with choke ballast providing illumination that pulsated with a modulation depth of 43–49% and a principal frequency component at 100 Hz; (*b*) an electronic start circuit with choke ballast giving illumination with similar characteristics; (*c*) an electronic ballast driving the lamps at about 32 kHz and reducing the 100 Hz modulation to less than 7%. In a double-blind cross-over design, the average incidence of headaches and eyestrain was more than halved under high-frequency lighting. The incidence was unaffected by the speed with which the tubes ignited. Headaches tended to decrease with the height of the office above the ground and thus with increasing natural light. Office occupants chose to switch on the high-frequency lighting for 30% longer on average.

Annex C: Veitch & McColl paper

J.A. Veitch and S.L. McColl, Lighting Res. Technol. 27(4) 243-256 (1995)
A version may be found at: http://web.mit.edu/parmstr/Public/NRCan/nrcc38944.pdf

Table 1 shows the values of the IESNA flicker index for the CW, FCW, and FS lamps. These values correspond to peak-to-peak modulation of 45.3% (CW), 42.7% (FCW), and 98.5% (FS), which are comparable to values reported previously for European lamps at 50 Hz AC supply. [44] The FS lamps exhibit more than twice as much luminous modulation as the other light source conditions, reflecting chromatic as well as luminous modulation (cf. Ref. 4). The filter reduced the modulation of the CW lamps only to a small degree.

The results of this experiment support the hypothesis that luminous modulation affects visual performance. They do not support the hypothesis that the chromatic modulation that results from

the interaction of fluorescent lamps and ballasts itself influences visual performance or visual comfort; nor do they support the suggestion that the spectral composition of light affects visual performance or visual comfort. The main effect for flicker rate, in which high-frequency flicker led to improved visual performance, was small when considered over the whole range of contrasts tested; but for the luminance contrast of .21, the effect was large.

From Section 8.1

In interpreting MANOVA results, one interprets the univariate tests only if the corresponding multivariate test reaches statistical significance. In this analysis, only the flicker rate contrast produced a statistically significant overall MANOVA test [Wilks' lambda = 0.677, F (6,40) = 3.19; $p < .02$]. This was associated with a significant univariate effect for row pair G/H [F (1,45) = 15.99, $p < .01$]. Performance on this row, for which contrast was .21, was significantly better in the HF condition ($M = 11.94$) than the LF condition ($M = 11.40$). The two rows with lower contrasts (.13 and .08, respectively) did not show significant effects; however, the scores on these more difficult rows were considerably more variable (their standard deviations are 30 - 50 % higher than for row G/H), which would have obscured any significant difference.

8.2 Time on visual performance task.

The time taken on the visual performance task was measured by the total number of seconds from the start until the participant reported being unable to see any more rings. The raw data were positively skewed; therefore, a logarithmic transformation was applied to yield a more normal distribution. Means and standard deviations for time on visual performance task for all experimental conditions are found in Table 4. The results of the ANOVA for time on visual performance task are provided in Table 5. None of the comparisons revealed statistically significant effects. Likewise, there was very little explained variance in these data; the R^2 values were all very small.

8.4 Visual comfort.

Visual comfort was measured by calculating the mean rating on the seven visual comfort items. Possible values ranged from one to seven, with lower values indicating better visual comfort. The internal consistency of the visual comfort scale was acceptable: Cronbach's alpha of reliability was .84.

The descriptive statistics for the visual comfort scale are shown in Table 4. The overall mean comfort score was 2.80 (SD = 1.16), indicating that on average, across all conditions, the participants were somewhat visually comfortable. In no condition was there indication of discomfort; none of the means was greater than the neutral point of the scale (4). Visual comfo was somewhat poorer in the low-frequency flicker condition than the high-frequency flicker

condition; however, this difference was not statistically significant (see Table 5). None of the main effects or interactions revealed a statistically significant effect, and the proportion of explained variance was very small.

From Section 9 Health Status

First, we examined the correlations between the residual error from the visual performance MANOVA and two continuous variables: the total number of health conditions reported with a self or family history, and the total frequency of health problem complaints. The sum of the squared residuals across all VALiD rows and both ballast conditions was used as the indicator of the unexplained error. There was no correlation between this value and either health indicator.

See also the comments (particularly by Mark Rea) following the paper.