Flicker happens. But does it have to?

Introduction

Nearly all AC-powered traditional light sources exhibit some degree of periodic modulation or flicker. The effects of undesired flicker from artificial light sources have been a persistent problem, going back as far as the 19th century when gas lamps became widespread. An article published in *Cyclopedia of Mechanical Engineering* in 1908 describes the use of coal gas used for shop lighting: “this light is objectionable on account of the fact that it vitiates the air…the light flickers, even in still air, which makes it very trying to one’s eyes when engaged on fine work.”

Although desirable in some situations and not perceived equally by all people, flicker is a phenomenon that should be avoided—or at least minimized—in most lighting applications. This article presents results of testing performed on numerous solid-state lighting (SSL) luminaires, showing the amount of flicker found in various types of these luminaires; and suggests some measures that enable lighting designers to minimize flicker in SSL-based lighting products.

Physiology

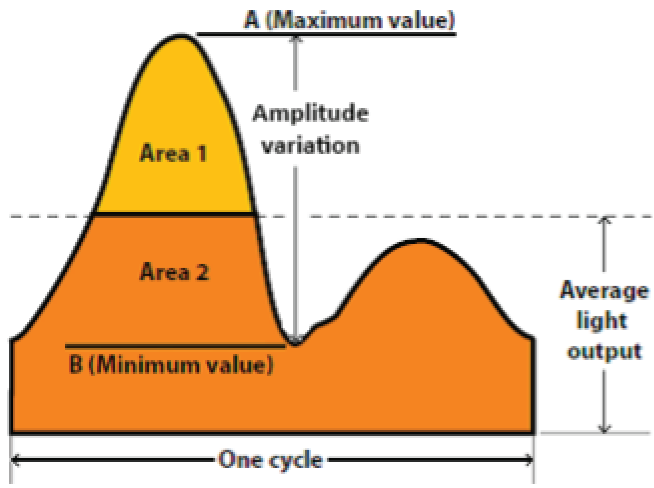
The second volume of *The Illuminating Engineer*, published in 1908, features an article that discusses the results of experiments to determine the, “vanishing-flicker frequency” – the threshold where the effect is no longer observed. This is now known as the flicker fusion threshold or rate, and is influenced by six factors.

1. Frequency of the light modulation
2. Amplitude of the light modulation
3. Average illumination intensity
4. Wavelength
5. Position on the retina at which stimulation occurs
6. Degree of light or dark adaptation

Studies have shown that visible flicker is usually noticed at frequencies below 100 Hz and invisible above 500 Hz. Both visible and non-visible flicker are of concern. The negative physiological effects of flicker are well studied and documented. They include headaches, migraines, eyestrain, distraction, and in severe cases, epileptic seizures. Issues with the strobe effect—which causes objects to appear to be moving at different rates than they truly are on factory floors, roadways, and sports lighting—have been the topic of numerous studies.

Metrics and Industry Standards

Although flicker has been studied in great detail, an official industry standard does not exist to fully quantify the effects of flickering light sources; however, one well-known method is defined by the Illuminating Engineering Society (IES) in the RP-16-10 standard, where percent flicker is a relative measure of the cyclic variation in the amplitude of a light source, and flicker index is a measure of the cyclic variation taking into account the shape of the waveform. Figure 1 shows a sample waveform and how percent flicker and flicker index are calculated.[1] The drawback to this method is that it addresses only two of the six factors previously mentioned. In addition, it assumes that a light source will always flicker at a fixed frequency and amplitude, and does not address random, erratic events that cause flicker, such as a sudden decrease in electrical current or voltage.



$$\text{Percent Flicker} = 100\% \times \frac{A - B}{A + B} \qquad \text{Flicker Index} = \frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}}$$

Figure 1: Calculation of percent flicker and flicker index

Figure 2 shows the correlation between percent flicker and flicker index for a sinusoidal wave.

[1] U.S. Department of Energy Building Technologies Office Solid State Lighting Technology Fact Sheet (March 2013)

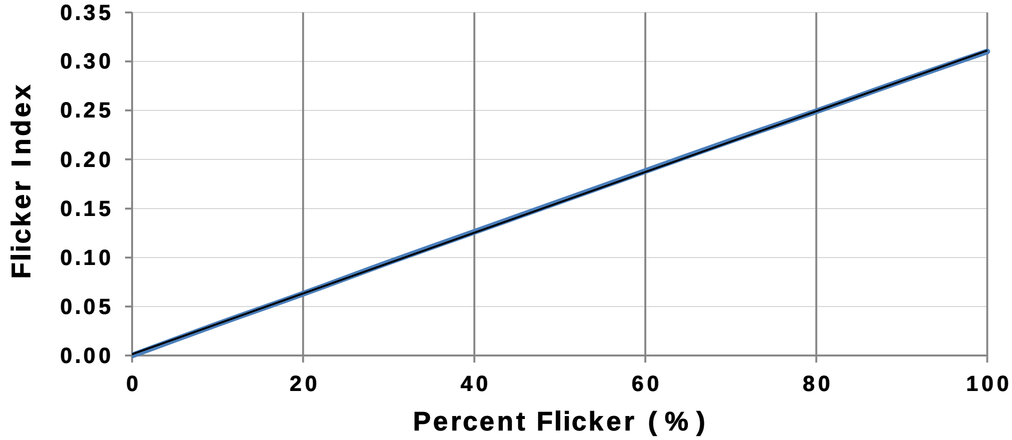


Figure 2: Correlation of percent flicker and flicker index

The ENERGY STAR® requirement for lamps, due to go into effect Sept. 30, 2014, specifies that the highest percent flicker and highest flicker index be reported, but does not specify a maximum allowable limit for either.[2]

The Alliance for Solid-State Illumination System and Technologies (ASSIST)[3] defines flicker acceptability criteria based on their testing. Using the ASSIST criteria, at 100 Hz, percent flicker greater than 20 percent is unacceptable, and at 120 Hz, percent flicker greater than 30 percent is unacceptable.

Though not discussed here, dimmer compatibility is a critical issue for market acceptance of many SSL-based luminaires. Changing the input current for the LED(s) in a luminaire to effect dimming has the potential to cause the luminaire to flicker.

Flicker in Traditional Lighting

All AC-powered light sources, including fluorescent, high-intensity discharge (HID) and even incandescent lamps, flicker. Additionally, many traditional lighting sources produce a noticeable flicker as they near their end of life. Table 1 shows the flicker index and percent flicker for typical lighting technologies.

2 ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.0
www.energystar.gov/products/specs/sites/products/files/ENERGY%20STAR%20Lamps%20V1%200%20Final%20Specification.pdf

3 Flicker Parameters for Reducing Stroboscopic Effects from Solid-state Lighting Systems, Volume 11, Issue 1
www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-Flicker.pdf

Technology	Flicker Index	Percent Flicker
Spiral CFL	0.02	7.7
Quad-tube CFL w/magnetic ballast[4]	0.11	37.0
T12 linear w/ magnetic ballast[4]	0.07	28.4
Quad-tube CFL w/electronic ballast[4]	0.00	1.8
25W Self-ballasted CMH PAR38[4]	0.02	6.5
40W Halogen R20[4]	0.02	6.7
Metal halide lamp[5]	0.16	52
HPS lamp[5]	0.30	95

Table 1: Flicker index and percent flicker for typical lighting technologies

The range of flicker produced by an incandescent lamp depends on the filament's thermal capacity. Table 2 shows the dependency of flicker index and percent flicker on AC line frequency. As the table shows, at lower frequencies the depth of modulation, and the flicker, increases.

<table>
<tr><th rowspan="2">Characteristic</th><th colspan="3">Frequency</th></tr>
<tr><th>20 Hz</th><th>30 Hz</th><th>60 Hz</th></tr>
<tr><td>Flicker index</td><td>0.078</td><td>0.053</td><td>0.023</td></tr>
<tr><td>Percent flicker</td><td>25</td><td>17</td><td>8</td></tr>
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Table 2: Percent flicker and flicker index for incandescent lamps

Figure 3 shows the amplitude of the light output of an aged compact fluorescent (CFL) lamp that was nearing its end-of-life, immediately after power was applied to it. The variations in amplitude are significant enough to be observable as flicker.

4 http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/poplawski_caliper_lightfair2011.pdf

5 http://www.cormusa.org/uploads/2012_2.10_Bullough_CORM_2012_Stroboscopic_Effects.pdf; flicker index is estimated

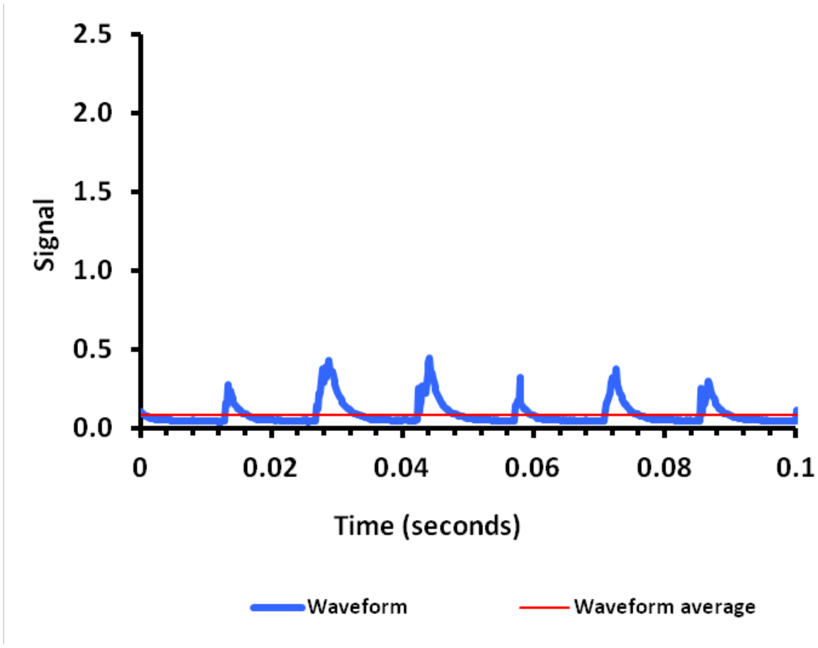

Figure 3: CFL flicker after power applied

Figure 4 shows the amplitude of the light output of the same CFL lamp after it has warmed up for a few minutes and reached a steady-state. The variations in amplitude, though still present, are smaller and less likely to be perceived as flicker.

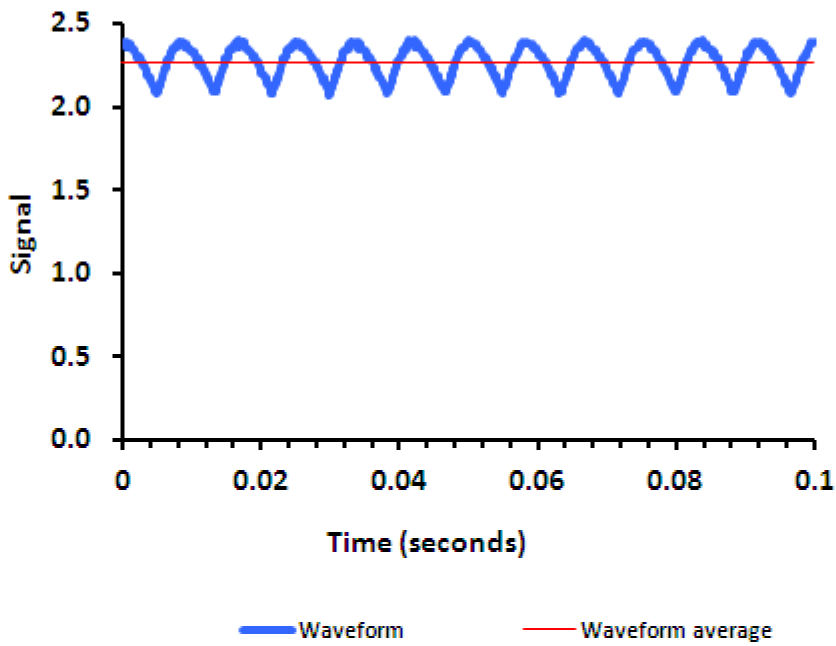

Figure 4: CFL after warm-up

LED Testing

Flicker is also nothing new with SSL. As a new technology, SSL is put under more scrutiny than the traditional light sources it is destined to replace, which is understandable after the many issues compact fluorescent lighting (CFL) had when it was first introduced to the market.

Through its Cree® Services Thermal, Electrical, Mechanical, Photometric and Optical (TEMPO) testing service, Cree has tested hundreds of SSL luminaires from streetlights to MR16 lamps. Most of the attention has focused on the ripple frequency that occurs on the output of the LED drivers, which is typically two times that of the input. For example, if the input voltage frequency is 60 Hz, the ripple frequency is 120 Hz.

The light output of an LED correlates closely with the output waveform of its driver. Figure 5 shows a waveform of the ripple current from a driver.[6] Figure 6 shows the resulting waveform of the light output of an LED connected to the driver.[7] In this example, the driver ripple current fluctuates 46 percent and the resulting percent flicker of the LED is 36 percent

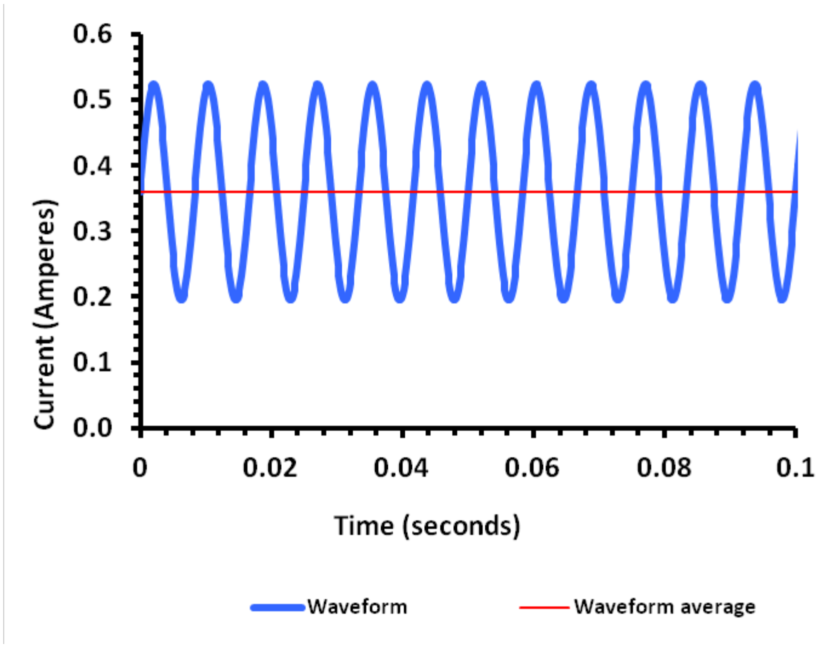

Figure 5: Driver output ripple current

[6] Measured using an oscilloscope and current probe
[7] Measured using a photosensor and amplifier connected to an oscilloscope

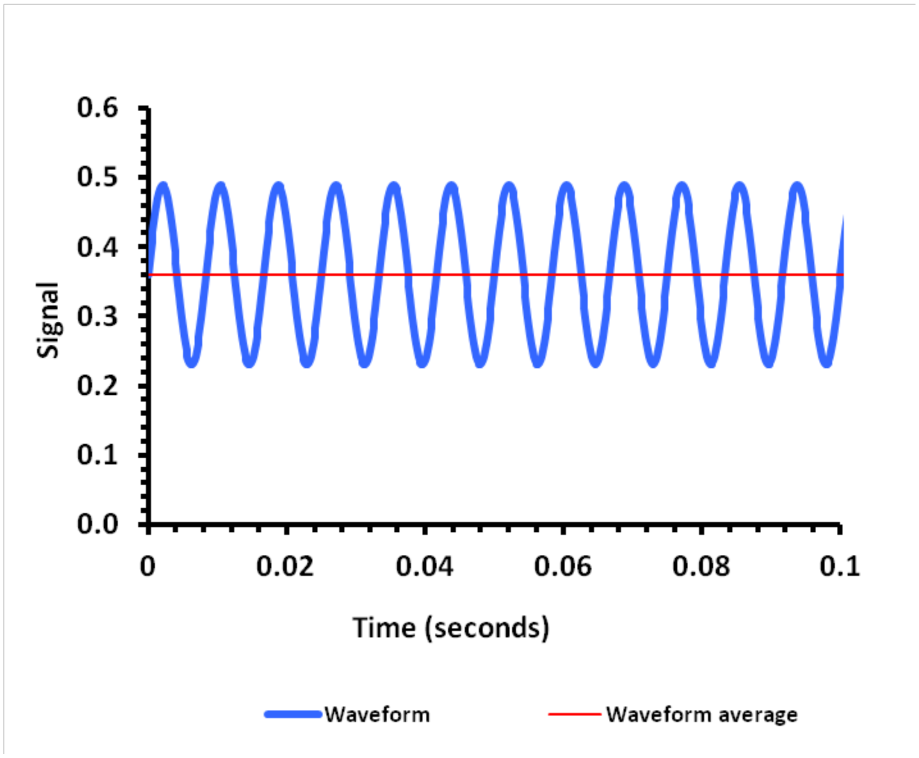

Figure 6: Measured Light Output

Flicker is also present with pulse-width modulation (PWM), a technique commonly used to dim LEDs. Figure 7 shows the flicker index versus duty cycle for a square wave at three different modulation percentages. The worst case flicker index, with the value approaching 1.0, would be for a light that flashes in short, low-frequency bursts.

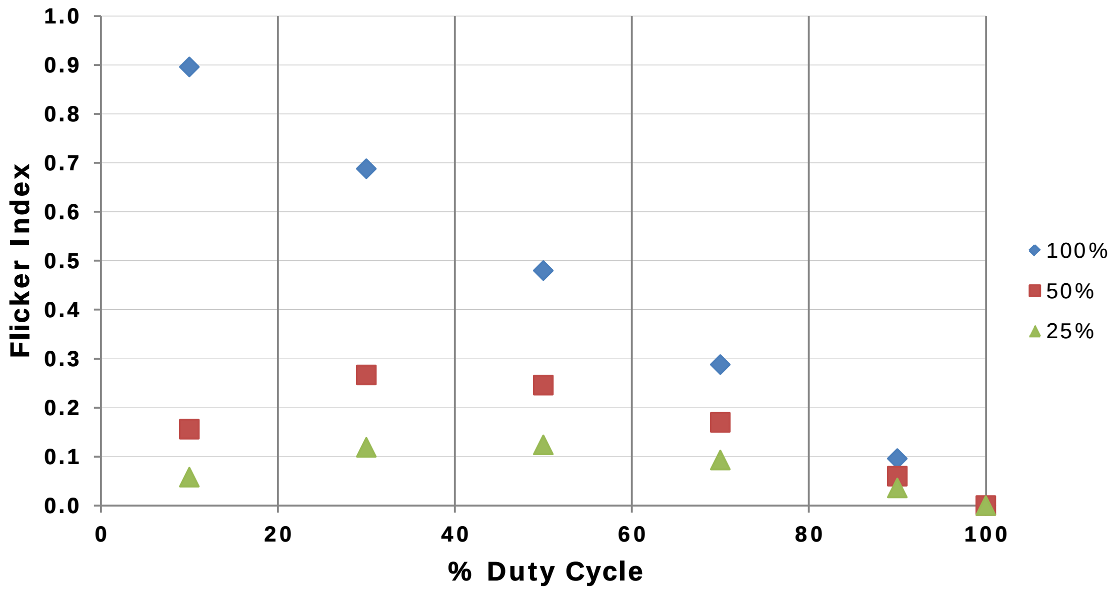

Figure 7: Flicker index for square wave

Table 3 shows the results for 103 SSL products tested, grouped by the driver output frequency. Approximately two-thirds of the products produced output current waveforms at either 100 or 120 Hz, depending on the AC line frequency. Roughly a quarter of the products had drivers that produced a smooth, filtered DC output regardless of the input voltage frequency. Less than 8 percent had outputs at frequencies between 120 Hz and 10 kHz.

Driver Output Frequency (Hz)	Number Tested	Percent of Total
100	26	25%
120	41	40%
>120 & <10,000	8	8%
DC	28	27%
Total	103	

Table 3: Driver output frequency for tested LED luminaires and lamps

Table 4 shows that 69 percent of the products that operated at 100 Hz and 71 percent of the products that operated at 120 Hz had an acceptable percent flicker, for a combined average of 70 percent.

Driver Output Frequency (Hz)	Percent Flicker Range	Number Tested	Percent of Total
100	0-20%	18	69%
	20-100%	8	31%
120	0-30%	29	71%
	30-100%	12	29%

Table 4: Percent flicker for LED luminaires and lamps

By comparison, all 28 of the products with DC driver output had a percent flicker of 10 percent or less, with 25 of them having a percent flicker of 5 percent.

Table 5 shows that the percent flicker for the categories of products tested ranges from a high of 97 percent to a low of 0.7 percent.

Category Number	Category Name	Number Tested	Minimum Percent Flicker	Maximum Percent Flicker
1	Screw-base lamp	12	13.1%	58%
2	Tube replacement	6	18.5%	41%
3	MR16/GU10	4	1.7%	76%
4	Other lamp	3	2.8%	6%
5	Street/roadway	10	1.1%	97%
6	High/low bay	16	0.8%	57%
7	Linear/troffer	16	0.7%	47%
8	Down light	13	1.2%	77%
9	Other outdoor	18	1.6%	37%
10	Other indoor	4	0.8%	37%

Table 5: Range of percent flicker for LED luminaires and lamps

Figure 8 shows the variability in the percent flicker for the products tested. For most categories, the percent flicker values are within an acceptable range, with a small number of outliers at the maximum end of the range. In the case of the MR-16 lamps (category 3), two of the results are for the same product. With a 12 VDC input, the percent flicker was only 5 percent; however, with a 12 VAC input, the percent flicker was 76 percent.

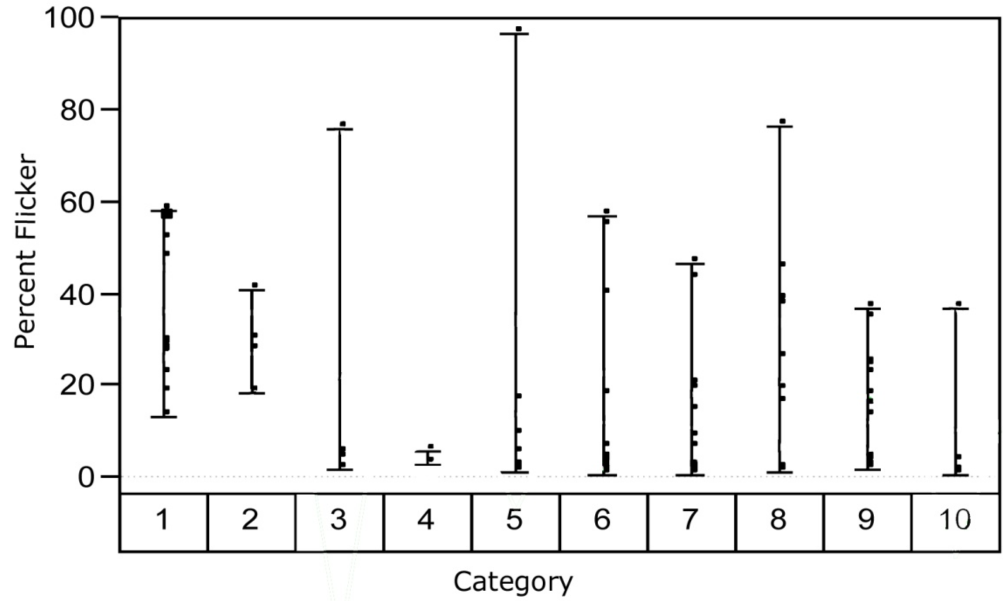

Figure 8: Percent flicker variability

Solutions to flicker

The following actions can be taken to minimize flicker in an SSL-based luminaire, depending on the design approach. If designing a custom driver for a luminaire, capacitance should be added to the output of the driver to filter out the AC ripple component; however, this comes with the trade-off of potentially decreasing system reliability, especially if low-quality capacitors are used. In many applications, such as replacement lamps, it may not be possible to add sufficient capacitance because of physical space constraints.

If a luminaire designer chooses to use a commercially available (i.e. off-the-shelf) driver, a driver that minimizes the amount of driver ripple current should be selected. If information on the percent ripple is not provided, it is important for a designer to get this data from the driver manufacturer before making a selection.

One cause of flickering, mentioned only briefly so far, is compatibility issues with dimming and control circuitry. It is important to specify and verify that the products are indeed compatible with the dimmers or other control circuits used in the lighting system. Problems can be caused by a faulty photosensor or timer.

Furthermore, random, intermittent flickering could be an indication of some other problem in the lighting system such as loose wiring and interconnections. Possible problems with the quality of the electrical supply can also result in power fluctuations. If those causes are suspected, it is important to investigate further to prevent any potential safety hazards.

Conclusions

Test results from a sample population of several SSL products show a wide range in flicker; however, a large majority of those products perform the same or better than other traditional light sources. A well-designed driver (i.e., one with a low ripple, high frequency output current) can reduce the perceived flicker produced by an SSL luminaire. Some LED driver companies specify the output ripple current in their data sheets; others do not. When selecting or designing a driver for an SSL luminaire, extra focus should be given to the flicker that will be produced. One could design a luminaire with superior specifications that is not chosen for installation because of something as easy to minimize as flicker.

Flicker index and percent flicker are typically not listed in product datasheets or labeling. Until they are, it is critical for the lighting designer to either obtain this information from the luminaire manufacturer to or conduct luminaire testing to measure flicker directly.