Due to the increased availability and cost-effectiveness of LED multifaceted reflector (MR) lamps, residential and commercial users are looking to these products for an energy-efficient alternative to traditional, halogen MR sources. While the energy savings associated with this switch are easy to see, actual product performance may be less clear-cut. Consumers have experienced performance issues including visible flicker and audible humming, which have been linked to the use of the LED lamps with certain types of electrical components including some types of dimmer switches and low-voltage transformers.

To help better understand the current state of the LED MR market and associated performance issues, researchers in California evaluated a cross-section of commercially available LED MR16 lamps, the most common type of MR lamp, to better understand the product’s compatibility with electrical components designed for use with traditional halogen sources. Researchers at the California Lighting Technology Center (CLTC) at UC Davis conducted performance evaluations of 20 commercially available LED MR16 lamps operated in conjunction with multiple types of low-voltage transformers, LED drivers and dimmer switches. The primary study objective was to identify links between poor lamp performance, specific LED driver designs and other standard electrical components.

Flicker and noise issues associated with LED MR16 lamps often occur because the LED products draw less current than the halogen MR16s they are designed to replace. Most existing electronic transformers and dimmer switches are designed to operate with a halogen lamps’ larger linear load. LED lamps are a smaller, non-linear load. They use switched mode power supplies (SMPS) in their drivers to transform DC-DC voltage levels after rectification. Simple SMPS implementations often do not draw enough current to reliably turn on the transformer or dimmer sub-components, nor do they continue to draw enough current consistently for these components to appear continuously ON. This results in variation of the LED ON-time from cycle to cycle and it’s this variation in light level at low enough frequencies that can be perceived as visible light flicker.

STUDY DESIGN

CLTC selected 20 commercially available, LED MR16 products for testing along with three different low-voltage transformers and two types of phase-cut dimmer switches. Testing focused on 12V, LED MR16 lamps with GU5.3 bases. Five samples of each product were used for deconstruction, an activity conducted to identify and catalogue the type of driver topology utilized by each product. Manufacturers typically employ a buck, boost or buck-boost SMPS topology in their drivers in order to try and avoid the types of performance issues previously described. Researchers sought to understand if driver topology had any effect on overall lamp and system performance. In addition to testing LED MR16 lamp performance with these various system components, researchers also tested lamp performance with respect to dimming level and the number of lamps installed on the circuit.

Each of the 20 products were tested with all possible combinations of components and operating conditions: transformer type, dimmer type (including no dimmer), dimming level and lamp number (Table 1), resulting in a performance data set of 600 different test scenarios.

One lamp per product was deconstructed to identify its driver topology by removing the components around the circuit boards to reveal the top code of the driver integrated circuit (IC). This allowed for determination of the LED driver IC model and manufacturer, which lead to driver datasheets that included information on the driver’s electrical topology. CLTC staff contacted manufacturers for details of their lamp’s design where deconstruction activities failed to reveal the specific LED driver used.

LED MR16 system performance was first quantified according to the system’s overall electrical efficiency and the efficiency of each of the individual system components. Electrical effi-
Efficiency is defined as the output power divided by the total electrical power consumed. Electrical component efficiency was determined by measuring the power output at five points in the lamp system: power supply, dimmer, transformer (all lamps), transformer (single lamp) and the driver (Figure 1). Measurement of the driver output was achieved by desoldering and rewiring leads to the LED package (Figure 2). Lamp performance was also quantified in terms of the severity of visible flicker. A test operator observed each of the test combinations and recorded the severity of the visible flicker using a qualitative scale. Observations were made by a single operator to avoid potential errors imparted by using multiple operators with different visual flicker sensitivity levels.

Researchers characterized a high-performance system as one with high, overall system efficiency and no visible flicker.

RESULTS AND DISCUSSION
Researchers found that, regardless of the electrical system components or operating conditions, LED MR16 systems never achieved electrical efficiency greater than 80 percent. The average efficiency of the system for a given lamp, when considering its performance in all test scenarios, was much lower, and ranged between 38 and 65 percent. Generally, the most efficient systems were found to be ones...
with multiple lamps on the circuit and operating with an electronic transformer designed specifically for use with LED lamps. All measured system efficiency data is provided in Table 2.

To better understand and further rank the significance of each component and operating condition on overall electrical efficiency, researchers calculated the percent difference in efficiency between the most and least efficient configuration of each test dimension (Table 3). Overall system efficiency was found to be most dependent on components separate from the lamp such as the transformer, number of lamps, dimmer type and dimmer level, compared to lamp driver topology, which was one of the least important factors. It was found that the transformer and number of lamps had the largest effect on overall system efficiency with changes in the transformer configuration producing as much as a 30 percent difference in system efficiency. In addition, generally drivers with boost and buck-boost topologies were more efficient than drivers using the buck topology.

VISIBLE Flicker

Visible flicker was also found to be highly dependent on transformer type. The worst performing configuration utilized an electronic transformer marketed for use with halogen lamps and was associated with 90 percent of the combinations with perceptible flicker. The magnetic transformer was the best performing transformer and associated with only 3 percent of combinations with perceptible flicker. See Table 4 for results of flicker tests.

Flicker data was used to calculate the ratio of average visible flicker severity to maximum visible flicker severity for each configuration. Then, to rank the significance of each component type and operating condition on visible flicker, the configuration with the highest ratio was divided by the configuration with the lowest ratio for each test dimension. Overall, results show that, with respect to visible flicker, components or conditions ranked most influential to least, are transformer type, dimmer type, dimming level, driver topology and number of lamps (Table 5).

CONCLUSIONS

Transformer type, dimmer type, number of lamps, driver topology and dimming level had different effects on overall system efficiency and visual flicker.

- Transformer type was the most significant factor for both flicker severity and system efficiency.

Table 2. Overall system efficiencies for each test combination.
The electronic transformer marketed for use with halogen lamps was associated with the majority of perceptible flicker. The magnetic transformer resulted in much lower system efficiency than the other two transformer configurations, however it was associated with the least amount of perceptible flicker.

- **Dimmer type ranked second in importance for flicker severity and third for electrical system efficiency.** Often, adding a dimmer, even without using it to dim, increased perceptible flicker.

- **The number of lamps ranked second for system efficiency, but had the smallest effect on flicker.**

- **Driver topology was ranked fourth for both flicker and system efficiency.** Boost topologies were both the most efficient and contributed the least to flicker. Several of the driver IC specification sheets mention compatibility with electronic transformers and all drivers with this note resulted in zero flicker for all test combinations. Using a driver that includes these compatibility claims was found to result in the lamp being compatible with a wide variety of other system components.

- **Dimming level was the least significant factor for efficiency, however overall lamp performance was largely better at 100 percent output than at 50 percent dimmed.** Dimming was the third most influential factor on flicker.

Some important conclusions can be drawn from the testing. System components, apart from the LED MR16 lamp, had a greater effect on the system’s overall electrical efficiency and visual flicker than the lamp’s internal driver topology. Transformer type was the most significant factor in overall lamp performance. To safely avoid visible flicker in a LED MR16 system, consumers should purchase lamps with a driver designed for compatibility with electronic transformers, or use an electronic transformer designed specifically for LED lamps. LED MR16 lamps
should not be used with a dimmer switch or, if dimming is necessary, only used with a reverse-phase dimmer.

**NEXT STEPS**

To better understand issues with visual flicker, a statistically significant flicker observation study is needed. The current study utilized a single observer to rank any perceptible flicker. Future research should include a large, diverse group of observers to perform the measurements. Results could be used to estimate the mean response of the total population, as well as understand variation among observers of different demographic profiles. Results of such a study could be leveraged during development of a set of test and measurement algorithms that predict the severity of perceived flicker based on the analysis of the driver’s current waveform. Results could be compared to the subjective observation study to refine the model and, ultimately, provide a tool for manufacturers to use during product development. CLTC is currently seeking testing partners for this project. If interested, please contact cltc@ucdavis.edu.

In the near term, much work is needed to improve consumer awareness of the issues surrounding LED replacement lamp performance, regardless of product category. Manufacturers need a clear way to present electrical compatibility information on product packaging, and consumers require education on how to interpret and act on this information to ensure they install products that will perform to their expectations.

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