McHugh Energy Consultants

efficiency research
analysis
policy

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Re: ENERGY STAR Luminaires 2.1 Draft Comments

Dear Ms Janz-Sell and the ENERGY STAR program,

Thank you for updating ENERGY STAR criteria for luminaires and for providing the opportunity for members of the public to comment on these updates. The ENERGY STAR label and brand is well recognized for energy savings and product quality. I welcome the recognition that ENERGY STAR is placing on the value of measuring flicker and developing criteria for qualifying luminaires.

Importance of ENERGY STAR's decision to collect and report flicker performance of luminaires

Reliable performance data of lighting products is a key component of promoting energy efficient luminaires as they must use less Watts per lumen, and provide comparable amenity as the low efficacy light sources they replace. These amenities include lasting as long as advertised, is safe, maintains a predictable stable color, operates without buzz or hum, and … does not flicker excessively.

For those of us who have operated lighting efficiency programs back in the days of magnetically ballasted fluorescent lighting we realize the importance of avoiding light sources that have comparable flicker of these poorly performing devices with amplitude modulation (percent flicker) of around 30% at 100-120 Hz. The flicker from these magnetic sources was imperceptible or barely perceptible. Some people were more sensitive to these magnetic sources and in one study, around 20% of building occupants would have regular headaches under magnetic ballasts that would go away when replaced by electronically ballasted fluorescent lighting operating at 10,000+ Hz. [1]

The transition to electronic ballasts for fluorescent lighting was welcomed, not only for the increased energy savings but also because this simultaneously reduced complaints about flicker and headaches.

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[1] Wilkins, A. J., I. Nimmo-Smith, A. I. Slater, and L. Bedocs, 1989. *"Fluorescent lighting, headaches, and eyestrain,"* Lighting Research and Technology, vol. 21, p. 11-18. 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.

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McHugh Energy participated in an LED testing program that included flicker measurements of LED lamps. This research found a wide range of flicker performance from 79% percent flicker (worse than magnetically ballasted fluorescent lamps, around 30% flicker) to less than 1% flicker for filtered data with a cut-off frequency of 200 Hz (better than incandescent lamps with flicker around 10%).[2] These results were for LED lamps at full light output. Thus the need for flicker reporting is not limited to dimming light sources only but for all LED light sources.

Consumers benefit from testing that identifies which combinations of lamps and dimmers do not result in visible flicker. But what is most valuable for the consumer, the specifier and for future regulations, is the flicker performance of products with waveforms that are not directly perceivable as visible flicker but which have physiological impacts over the long term, as outlined in IEEE PAR 1789.

Recommendation for a Test and List Standard Compatible with the Structure of IEEE PAR 1789-2015

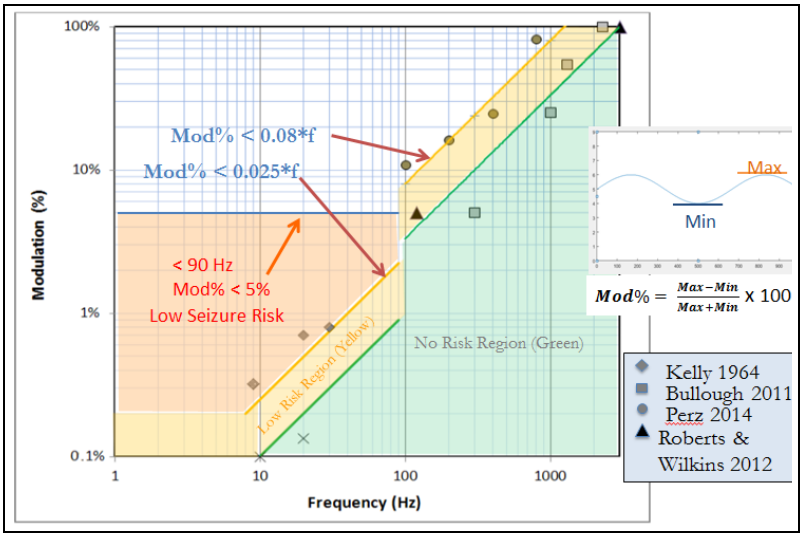

Figure 1: IEEE PAR 1789-2015 Low Risk and No Risk Regions

The proposed ENERGY STAR Luminaires 2.1 draft has recognized IEEE PAR 1789-2015 as the Reference Standard for flicker. The Institute of Electrical and Electronics Engineers IEEE PAR 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.

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 (%) that the committee evaluated as likely to have no risk of physiological impact and another region that likely has a low risk of impact. How much higher depth of modulation is acceptable above the low risk region is an area of controversy.

[2] Note that modulation percent, percent amplitude modulation, and percent flicker refer to the same metric which is given by the AM (percent amplitude modulation) equation above.

If it turns out that designing LED drivers to meet the IEEE standard is relatively inexpensive and does not have other deleterious effects on performance, this would seem to be the prudent thing to do. How can ENERGY STAR evaluate the capability of the entire market that participates in the program to deliver low flicker sources unless data is collected in a format that can readily be analyzed in relation to the entire breadth of frequencies included in the IEEE standard?

McHugh Energy recommends a test and list standard to provide the data necessary for informed consumer choice and product differentiation. A test and list standard, provides a market signal for manufacturers to differentiate themselves and compete on the basis of their flicker performance, similar to the market signal ENERGY STAR and EnergyGuide provide in regards to energy efficiency. The question is what test method and what test metrics result in the easiest and fairest comparison with the IEEE standard?

Value of ENERGY STAR collecting and reporting modulation (%) values vs. frequency in California 2016 Title 24 JA10 format.

The California's Title 24 Reference Joint Appendix JA10, *Test Method for Measuring Flicker of Lighting Systems*,[3] is well suited for comparing product performance with the recommendations in IEEE PAR 1789. The data collected in California's Title 24 JA10 are broadband representations of percent flicker (percent amplitude modulation), for all frequencies below the cut-off frequencies of 1,000, 400, 200, 90 and 40 Hz in addition to unfiltered percent flicker. The benefit is that one can plot these data points on the IEEE PAR 1789 risk map for modulation percent versus frequency and have a good understanding of flicker performance below each of these cut-off frequencies.

The JA10 test method is widely used as it is required for California's Title 24, JA8-2016 certification of high quality efficacious light sources. JA8 certified light sources are required for most luminaires and lamps installed in new California residential construction permitted since January 1, 2017. A recent review of the data in the JA8-2016 MAEDBS appliance efficiency database[4] indicated the database now contains over 15,000 inseparable luminaires and 656 light engines.

If only one flicker test metric is going to be used, using the JA10 metric is preferable. This desire to have a test method and a flicker metric that can be directly compared to the IEEE PAR 1789 standard is not a criticism of NEMA 77. NEMA 77-2017, *Standard for Temporal Light Artifacts: Test Methods and Guidance for Acceptance Criteria,* proposes a test method and metrics that addresses directly observed visible flicker (Pst, short term flicker indicator) and directly observed stroboscopic effect (SVM, stroboscopic visibility metric). It is similar to IEEE PAR 1789 in that the impact of flicker is a function of frequency, but the metrics Pst and SVM are complex weighted functions cannot be directly assessed against the IEEE PAR 1789 standard. That is, products tested for Pst and SVM cannot easily be plotted on the low risk / no risk graph to see if they meet the recommended levels of flicker. Additionally Pst and SVM do not address other types of flicker such as phantom array effects. Reporting Pst and SVM in addition to the JA10 values would be a good outcome. The same test data can be used to generate the SVM and JA10 values.

[3]Pages JA10-1 to JA10-4 (electronic pages 271-274). http://www.energy.ca.gov/2015publications/CEC-400-2015-038/CEC-400-2015-038-CMF.pdf

[4] Modernized Appliance Efficiency Database System (MAEDBS). http://www.energy.ca.gov/appliances/forms/index.html

ENERGY STAR Luminaire 2.1 Draft Flicker Requirements not Sufficiently Protective

ENERGY STAR's compact fluorescent base criteria for flicker require that the fundamental frequency is between 20 kHz and 33 kHz or above 40 kHz. This requirement reflects the concern described at the beginning of this letter about the problems associated with magnetically ballasted lighting with a fundamental frequency of 120 Hz. It is not clear what is meant by "Optional: Meet NEMA 77-2017 for temporal light modulation limits." If this is an optional declaration, that would be acceptable.

Since the NEMA-77 allowed values for SVM are so high (up to 1.6) this would not be comparable to requiring that the fundamental frequency is in the 20+ kHz range. Thus if this optional declaration of NEMA 77 compliance means that complying with NEMA 77 can be considered in lieu of passing the fundamental frequency requirement, this is not a good alternative. At 120 Hz, a device with a sinusoidal waveform having an amplitude modulation of 44% would meet NEMA's maximum SVM metric of 1.6. This is about 50% higher amplitude modulation than the magnetically ballasted fluorescent luminaires linked to headaches in the Wilkins et al. study described earlier.

For LED luminaires, the 120 Hz minimum fundamental frequency is a "no-standard standard." Most products have a fundamental frequency of 120 Hz, from products with very high percent flicker to those with virtually no flicker. In general at full light output the main contributor to high amplitude modulation at low frequencies is the 120 Hz ripple from rectified 60 Hz AC input voltage. As described above, considering all products with SVM $\leq$ 1.6 is not a protective standard for flicker. It is worth repeating what is said in the NEMA 77 standard about the recommended limits in this industry document (underline added for emphasis): *"Attempts by regulators and others to specify universal TLA parameters may result in either extremely long and expensive testing programs (as well as overdesigned products) or the risk that TLA, for certain applications and operating conditions, although endorsed by the regulating or other body, will be unacceptably high.*

IES has formed a working group that will address limits on Pst and SVM for different applications. NEMA defers to the greater application expertise in IES. Until IES has completed their work, the general guidelines of Table 6 for broad application areas are suggested."

Is there an alternative metric that has wide acceptance as an industry standard and yet does not hinder the market for high performance SSL products?

Proposal to Set Flicker Criteria based upon IEEE PAR 1789 and Market Data from California's JA8-2016 database

Currently IEEE PAR 1789 is the standard of care that the ENERGY STAR Luminaires 2.1 draft specification lists as the reference document. If the JA10 data were collected, a conservative metric of compliance that would be close to the top end of the "low risk" region is as shown in Table 1:

Table 1: Maximum Amplitude Modulation Limits for Compliance with "Low Risk" Recommendations of IEEE PAR 1789 using data collected by 2016 Title 24, part 6, Joint Appendix JA10

Cut-off frequency	Max % Amplitude Modulation 1 x IEEE 1789
40 Hz	1.0%
90 Hz	2.3%
200 Hz	16%
400 Hz	32%
1,000 Hz	80%

Products that comply with the maximum percent amplitude modulation in Table 1 would reflect equipment performance below the red boxes shown in Figure 2. In other words products with amplitude modulation above the limits listed when plotted would be in one of the red boxes in the upper left-hand corner of Figure 2 that are labelled "Not Compliant." The 16% modulation limit for the low-pass filtered results with 200 Hz cut-off frequency is around 0.58 SVM for a 120 Hz sinusoidal waveform.

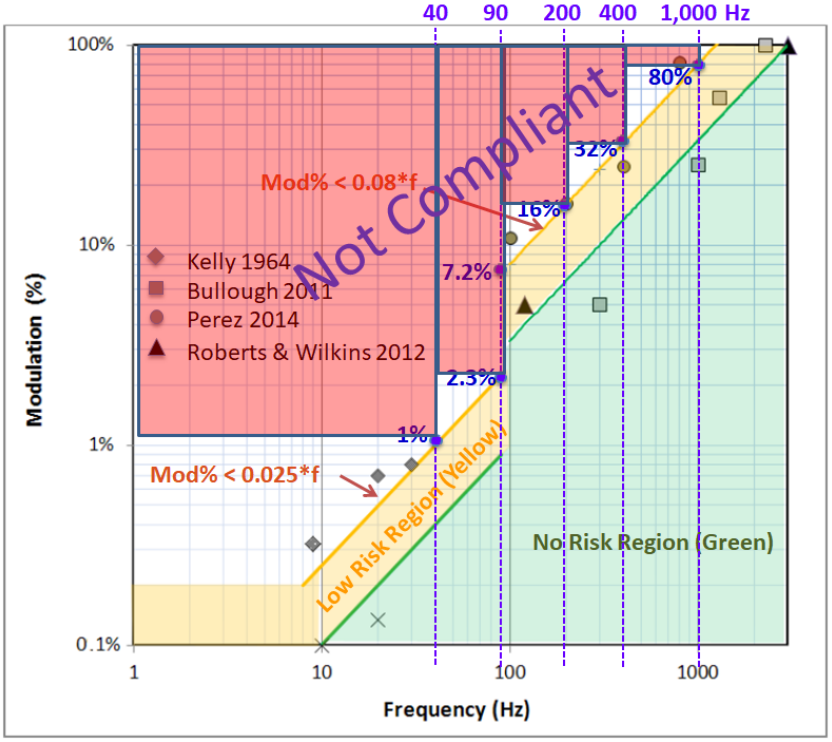

Figure 2: JA10 broadband modulation data for showing compliance with IEEE PAR 1789 guidelines for low risk.

There may be some disagreement about whether these requirements are reasonable for the products that are covered by the ENERGY STAR program. That is why it is so important to collect this information in a repeatable, useful manner for all program participants and to publish the data similar to what California is doing in their MAEDBS appliance efficiency database for JA8-2016 res high efficacy lighting. From this data one can evaluate the trade-off between cost, performance and amenity in this protective standard.

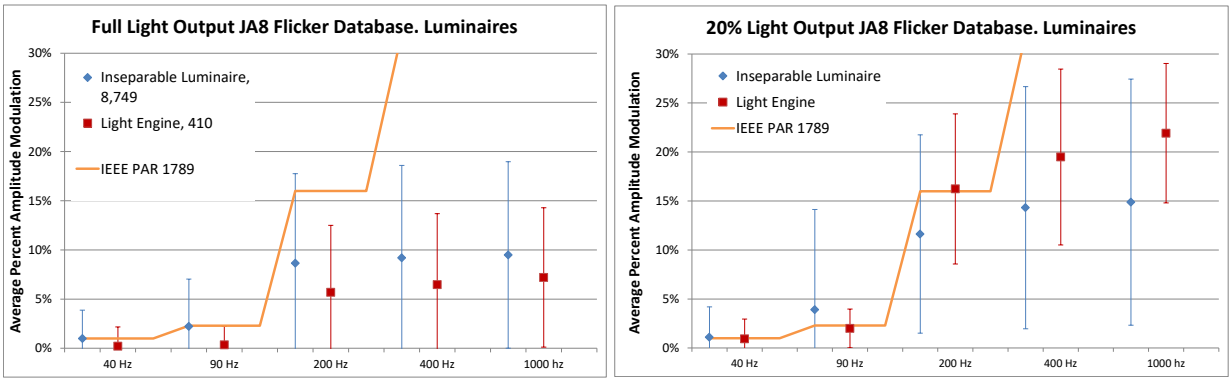

Figure 3: Average and Standard Deviation of Amplitude Modulation at Full Light Output and Dimmed to 20% of Full Light Output

The following whisker plot results in Figure 3 are from an evaluation of the MAEDBS JA8-2016 database several months ago when there were only 8,749 inseparable luminaires and 410 light engines.

The performance is markedly different for these luminaires when at full light output and dimmed to 20%. It raises the question whether there should be different requirements when dimmed as compared to full light output. As shown in Table 2, the third column indicates what fraction of JA8-2016 compliant luminaires would comply with the IEEE PAR 1789 recommendations at full light output. The fourth column indicates what fraction would comply with the IEEE limits if dimmed to 20%; however, note that a little more than half of inseparable luminaires would comply but only 30% of light engines would meet this recommended maximum flicker criteria when dimmed.

Table 2: MAEDBS JA8-2016 database: Luminaire Compliance with IEEE PAR 1789 at Full Light Output and Dimmed to 20% Light Output

	Dimming Level ->	Full Output	20% Output	20% Output	Full AND 20%
Light Source Type	Metrics	Comply with 1 x IEEE 1789	Comply with 1 x IEEE 1790	1 x IEEE 1789 except 1.4 x IEEE 1789 @ 90 & 200 Hz	Full - 1 x IEEE AND 20% 1.4 x IEEE
Inseparable Luminaire	Total	8749	8749	8749	8749
Inseparable Luminaire	Comply with PAR 1789	5920	4444	5623	4855
Inseparable Luminaire	**% comply with PAR 1789**	**68%**	**51%**	**64%**	**55%**
Light Engine	Total	410	410	410	410
Light Engine	Comply with PAR 1789	366	124	376	359
Light Engine	**% comply with PAR 1789**	**89%**	**30%**	**92%**	**88%**

This finding of less than a third of light engines complying when tested in their dimmed state led to evaluating a moderate relaxation of the IEEE requirements at 90 and 200 Hz for dimmed state compliance. The amplitude magnitude limits for the 90 Hz and 200 Hz cut-off frequencies were adjusted to 1.4 times the IEEE limits but the rest of the amplitude modulation limits were left alone for the other frequencies (40, 400 and 1,000 Hz). Column 5 displays that with this relaxation of requirements 92% of JA8 certified light engines would comply. The sixth and last column identifies what fraction of lamps would meet BOTH the requirements in column 3 AND in column 5. From these findings, McHugh Energy is proposing that ENERGY STAR consider the amplitude modulation limits posted in Table 3.

Table 3: California Market-Based JA10 Amplitude Modulation Limits Approaching IEEE 1789 but with Relaxation of 90 Hz and 200 Hz for 20% Dimmed State

	Full Output	20% Dimming
Cut-off frequency	Max % Amplitude Modulation 1 x IEEE 1789	Max % Amp Modulation 1.4 x IEEE 1789 @90 & 200 Hz
40 Hz	1.0%	1.0%
90 Hz	2.3%	3.2%
200 Hz	16%	22%
400 Hz	32%	32%
1,000 Hz	80%	100%

The first two columns of this table would reflect equipment performance below the red boxes shown in Figure 2. As discussed above, the third column represents some relief when dimmed to 20% by requiring the IEEE standard for most of the frequencies, but for the data where the virtual low pass filter has a 90 and 200 Hz cut-off frequency, the maximum amplitude values are equivalent to 1.4 times the IEEE PAR 1789 recommended values. These increased values are in the shaded cells in the third column. Note when dimmed to 20%, the 22% maximum amplitude modulation value for the 200 Hz cut-off frequency is comparable to a SVM = 0.78 for a 120 Hz sinusoidal waveform.

In the near term, ENERGY STAR may want to just collect the data in the JA10 format and have more extended deliberative process for setting the flicker limits for qualifying products. However, if the data is not collected in a format for easy retrieval and evaluation, this would hinder this process. My recommendation is to require that flicker data be measured and evaluated using the Title 24 JA10 format so an informed discussion can be held on future updates to the ENERGY STAR Luminaire specifications. I am also supportive of processing the data so that the NEMA 77 metrics of Pst and SVM are also collected and posted in a public database. The cross-comparison the JA10 and NEMA 77 metrics would be desirable and require only a little extra processing of the same data.

Undesirable that ENERGY STAR reference NEMA 77 flicker criteria for qualifying lamps

As described above, there is no harm in ENERGY STAR collecting waveform data and publishing the NEMA 77 metrics of Pst and SVM in addition to the JA10 formatted data. In fact it is desirable for cross-comparison of the data. However using NEMA 77's recommended criteria of Pst ≤ 1.0 and SVM ≤ 1.6 for qualifying as an ENERGY STAR lamp implies an endorsement of these limits. As an example the transcripts from the February 5, 2018 California building efficiency standards workshop include this testimony from Alex Bosenberg of NEMA,[5] *"ENERGY STAR lamps and ENERGY STAR luminaires, both are referencing NEMA 77."* In this proceeding, NEMA is asking the California Energy Commission

[5] p. 180. (electronic page 181). California Energy Commission. *Lead Commissioner Hearing 2019 Energy Code and CALGreen Code*. February 5, 2018. http://docketpublic.energy.ca.gov/PublicDocuments/17-BSTD-02/TN222729_20180226T131504_Transcript_of_02052018_Lead_Commissioner_Hearing_2019_Energy_Co.pdf

to roll back their standards from 30% amplitude modulation for frequencies less than 200 Hz to allowing products that comply with NEMA 77 recommendations.

It may be thought that NEMA 77 is a placeholder until a more deliberative consultation with industry and health experts is undertaken. My concern is that adoption of NEMA 77 limits appears to provide the endorsement and imprimatur from ENERGY STAR that the recommendations in NEMA 77 provide good control of flicker similar to ENERGY STAR limits for color constancy and noise are providing consumer protection on these other quality metrics. This may result in other entities indiscriminately referencing the NEMA 77 flicker limits with the assumption that ENERGY STAR has conducted their due diligence on this aspect of lighting quality.

Even some of the supporters of the Pst and SVM test method, have this to say about an SVM limit of 1.6. *"My concerns are that Pst and SVM would allow too great a modulation in ranges of 60-100 Hz, and the value of 1.6 would allow magnetically ballasted fluorescent which has been linked to headaches and migraines. (Veitch and McColl 1995; Wilkins and Bedocs et al 1989.) I have personal experience with products whose waveforms produce an SVM of 1 to 1.6 where the flicker is clearly visible and annoying. So, here's what I suggest: NEMA 77 is an improvement on a flicker standard. Adopt it provisionally. But, it needs ongoing research and discussion, and the target value of SVM needs to be 1.0 rather than 1.6. Furthermore, SVM is a metric based on VISIBILITY of flicker, not NEUROLOGICAL RESPONSE to flicker. If we learn that those neurological responses are not related to visibility of flicker, then we may have to revisit this issue."*[6]

If ENERGY STAR feels the need to set a "placeholder" flicker limit prior to a more deliberative process, then the following approach is recommended.

- Maximum percent amplitude modulation aligned with the values in IEEE PAR 1789 for full light output (including non-dimming lamps) and for dimming lamps the IEEE limits except 1.4 times these limits for 200 and 90 Hz cut off frequencies (see Table 3). This requirement is met by 4,855 (55%) California JA8 qualified inseparable luminaires and 359 (88%) of JA8 light engines. This is similar to the percentile thresholds used by ENERGY STAR for setting efficiency targets.

To assure this target does not have an undue impact on the ENERGY STAR program, the target could be voluntary and complying products receive an "ENERGY STAR low flicker" designation. If after collecting data for two years at least half of ENERGY STAR luminaires can meet this target, then this target would become mandatory unless there was compelling evidence otherwise. This would provide a date certain trajectory towards low flicker luminaires being another amenity that encourages specifiers to select ENERGY STAR luminaires with confidence in their quality.

[6] Naomi Miller Comments: *Flicker standards aren't perfect but NEMA 77 better than JA8*. 2019 Title 24, Part 6, Building Energy Efficiency Standards Rulemaking. http://docketpublic.energy.ca.gov/PublicDocuments/17-BSTD-02/TN222567_20180215T153340_Naomi_Miller_Comments_Flicker_standards_aren't_perfect_but_NEMA.pdf

Concluding Remarks

The ENERGY STAR Luminaires program is an outstanding energy efficiency program with over 38 Million qualifying luminaires[7] shipped in 2015. This program has saved consumers millions of dollars from reduced energy consumption but it has also been an excellent consumer protection program. It is also a great sales tool for an industry that wants to differentiate itself on quality. With this background, I hope these comments are seen as constructive addition to your deliberations.

Sincerely,

Jon McHugh, PE

Principal, McHugh Energy Consultants Inc.

[7] https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2015_USD_Summary_Report.pdf?7476-61ef