CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Nonresidential Lighting Controls: Clarification and Control Credits

Measure Number: 2016-NR-LTG-5-F

Nonresidential Indoor Lighting Controls

2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team October 2014

This report was prepared by the California Statewide Codes and Standards Enhancement (CASE) Program that is funded, in part, by California utility customers under the auspices of the California Public Utilities Commission.

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Document Information

Category: Codes and Standards

Keywords: Statewide CASE, Statewide Codes and Standards Team, Statewide C&S Team, Codes and Standards Enhancements, Title 24, 2016, efficiency, nonresidential lighting controls, daylighting controls, dimming plus off control, high end trim, tuning, Power Adjustment Factor.

EXECUTIVE SUMMARY

Introduction

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison and Southern California Gas Company – and Los Angeles Department of Water and Power (LADWP) sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is a part of the effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficient design practices and technologies.

The overall goal of this CASE Report is to propose a code change proposal for measure name. The report contains pertinent information that justifies the code change including:

- Description of the code change proposal, the measure history, and existing standards (Section 2);
- Market analysis, including a description of the market structure for specific technologies, market availability, and how the proposed standard will impact building owners and occupants, builders, and equipment manufacturers, distributers, and sellers (Section 3);
- Proposed code change language (Section 4).

Scope of Code Change Proposal

This Lighting Controls Requirement Clarifications and Lighting Control Credits proposal will affect the code documents listed in Table 1. As a clean-up proposal, it broadly impacts the various portions of the standards that address controls. Thus the definitions in Section 100.1 are affected as are the mandatory requirements for lighting controls in Section 110.9 and the mandatory controls that must be installed in Section 130.1 and the Power Adjustment Factors (PAFs) in Section 140.6. One of these controls receiving a Power Adjustment Factor must pass an acceptance test to receive the lighting credit and thus a new acceptance test is added to Reference Nonresidential Appendix NA7.6.4. The power adjustment factor also impact the deemed savings associated with high end trim tuning of dimming systems and this carries over into the t performance approach and thus affects the Nonresidential Alternative Compliance Method (ACM) Reference Manual.

Table 1: Scope of Code Change Proposal

Standards Requirements (see note below)	Appendix	Modeling Algorithms	Forms
100.1 110.9(b)3 [M] 130.1(b)3 [M] 130.1(d)2D [M] 140.6(a)2H [CC] 140.6(a)2J [CC] Table 140.6-A [Ps]	NA7.6.4 [CC]	NACM 3.2.2.2 [Pm] NACM 3.2.2.4 [Pm] NACM 5.4.4 [Pm] NACM 5.4.5 [Pm]	NRCC-LTI-02-E NRCA-LTI-03-A NRCA-LTI-04-A (new)

Note: An (M) indicates mandatory requirements, (Ps) Prescriptive, (CC) Control Credit, (Pm) Performance.

Measure Description

This CASE report provides the rationale for the adoption of the following changes to the California building efficiency standards which simplifies, clarifies and provides compliance credit for inexpensive and effective control strategies.

- Section 100.1 A definition of "initial design illuminance" is added to support the required activities to qualify for a Power Adjustment Factor for "High End Trim Tuning of Dimmable Lighting in Section 140.6(a)2H (see below).
- Section110.9(b)3. This would add clarifying language to the lighting controls requirement that the flicker requirement applies to entire dimming system (control, lamps and ballasts or drivers) and not just the controls. It also references a flicker test method in reference Joint Appendix JA10. The details of this test method and rationale were also contained in the Residential Lighting CASE report. It is repeated here for completeness
- Section 130.1(b)3. This proposed change would replace a hard to enforce, confusing portion of the multi-level lighting controls requirements with a simpler requirement which is easier to enforce. The confusing portion has a requirement to pick one out of five requirements for each enclosed area in addition to all other requirements. However two of the requirements (manual dimming control and demand response) are already required in many situations. The proposal would require clarify the requirement that most commonly applies (manual dimming controls for dimmable luminaires). This will simplify and render this section more enforceable.
- Section 130.1(d)2D. More clearly state the requirements for the accessibility of calibration adjustment control for photocontrol (daylighting control) systems. The primary purpose of this requirement is to prevent tampering with the photosensor and to have the calibration controls readily accessible so that adjustments to daylighting controls can be easily performed by authorized personnel in response to changes in geometry or reflectance of the interior, changes in occupancy or tasks and in response to requests for more or less light from occupants.
- Section 140.6(a)2H. Remove the PAF for Partial-ON Dimming Controls (now a mandatory requirement) and replace with a description of the requirements of the Daylight Dimming Plus OFF controls. It should be noted that ASHRAE 90.1-2013 contains a mandatory requirement for daylighting controls that turn lights all the way

OFF when the space is fully daylit. This proposal is a halfway step towards having daylighting control requirements as stringent as found in ASHRAE 90.1. Ideally this PAF prepares the market for this control strategy being the default or mandatorily required in the 2019 Title 24 standards.

- Section 140.6(a)2J. Replace the description of Manual Dimming or Multiscene Programmable Dimming System controls that qualify for a PAF with the description of Manual Dimming Controls with High end Trim Tuning controls that qualify for a PAF. This section also notes that the initial design illuminance must be on the construction documents and that high end trim must be tuned so that it is within 10% of the initial design illuminance as verified by the acceptance tests as contained in nonresidential appendix NA7.6.4.
- Table 140.6-A Remove two Power Adjustment Factors in Table 140.6-A for Partial-On controls and dimming system controls. The rationale for removing these PAFs is contained in the Nonresidential Lighting Controls Partial-ON Occupancy Sensors CASE report. These changes are included in the proposed changed code in this report for ease of understanding how the proposed changes from both CASE reports would impact this table and this section
- Table 140.6-A Add two Power Adjustment Factors in Table 140.6-A for daylight dimming plus OFF control and tuning of dimming systems.
- NA7.7.6.2 "Acceptance Tests for High End Trim Tuning of Dimmable Lighting." This new acceptance test is added to verify that lighting systems claiming the High End Trim Tuning Power Adjustment factor have tuned the lighting system appropriately.
- JA10 Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements. This test method quantifies the long standing requirement of "low flicker operation for dimming systems. See also the clarification of dimming requirement in Section110.9(b)3.

This proposal interacts with and builds upon the Residential Lighting and the Nonresidential Lighting Controls Partial-ON Occupancy Sensors CASE reports. The full citations for the Residential Lighting and the Nonresidential Lighting Controls Partial-ON Occupancy Sensors CASE reports can be found in the *References* Section of this report.

Section 2 of this report provides detailed information about the code change proposal including: ***Section 2.2 Summary of Changes to Code Documents (page 11)*** provides a section-by-section description of the proposed changes to the standards, appendices, alternative compliance manual and other documents that will be modified by the proposed code change. See the following tables for an inventory of sections of each document that will be modified:

- Table 2: Scope of Code Change Proposal (page 11)
- Table 3: Sections of Standards Impacted by Proposed Code Change (page 12)
- Table 4: Appendices Impacted by Proposed Code Change (page 12)
- Table 5: Sections of ACM Impacted by Proposed Code Change (page 13)

Detailed proposed changes to the text of the building efficiency standards, the reference appendices, and are given in ***Section 4 Proposed Language*** of this report. This section proposes modifications to language with additions identified with <u>underlined</u> text and deletions identified with ~~struck out~~ text.

The following documents will be modified by the proposed change:

- Main text of Title 24, part 6
- Nonresidential Standards Appendix NA7 (acceptance tests)
- Nonresidential Alternative Compliance Method (NACM) Manual.

Market Analysis and Regulatory Impact Assessment

The code simplification aspects of this proposal are cost effective as they reduce compliance cost without loss in energy savings. The lighting controls Power Adjustment Factors (PAFs) provide credit for lighting controls that save significant amounts of energy for little cost. However as PAFs, we are not calculating cost-effectiveness as these requirements do not increase the stringency of the standards but rather provide code incentives for use of technologies that may be required in future version of the standards. Over the long term this proposal increases the wealth of the State of California. California consumers and businesses save more money on energy than they do for financing the efficiency measure. As a result this leaves more money available for discretionary and investment purposes.

The expected impacts of the proposed code change on various stakeholders are summarized below:

- **Impact on contractors:** Simpler code will render it easier to comply. Added control credits will allow more equipment to be installed (both luminaires and controls) which increases bill able work for contractors. The tuning proposal increases the amount of labor on a job and generates work lighting acceptance test professionals.
- **Impact on building designers:** Simpler code will render it easier to comply. Added PAFs provide more design flexibility to comply with code. Some lighting designers may be concerned about increased liability associated with placing design light levels on design documents even though this is good design practice.
- **Impact on occupational safety and health:** Most of the proposed code changes are not expected to have an impact on occupational safety and health. The requirement for calibration adjustments being readily accessible increase occupational safety as it avoids the need for climbing up to the ceiling level to make photocontrol adjustments.
- **Impact on building owners and occupants:** Since this measure is cost-effective, the building owner who pays their energy bills is reducing their energy costs more than their mortgage costs are for the cost of the measure (i.e. there are experiencing net cost savings). For building occupants that are paying for their energy bills, since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experiences by the building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by occupants.
- **Impact on equipment retailers (including manufacturers and distributors):** The Power Adjustments help develop a market for controls that have high end trim and for dimming plus off photocontrols. This slightly increases overall market activity but should have a large impact on these two control categories. There is a small cost on manufacturers to conduct flicker testing on products they sell in California. This cost is small as the cost is defrayed across all the units they sell in California. The test method

is similar to the test method for ENERGY STAR compliance so this test can be structured to the collect the test data once for both purposes.

- **Impact on energy consultants:** Simpler code will render it easier to document compliance. Power adjustment factors increase the complexity of documentation but this a voluntary effort when the owner or designers are looking for more lighting power allowances or they are trying to fully document how more stringent their design is than the minimal requirements of the code for LEED or other building efficiency certification.
- **Impact on building inspectors:** As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes. However, the portion of this proposal that simplifies the code will render it easier to enforce.
- **Statewide Employment Impacts:** as mentioned above on the impact on contractors, when the PAFs are used they generate more work for contractors. High end tuning requires more labor as it requires that each space taking the credit have the high end trim tuned to the design light levels defined for that space. In addition this tuning effort must be verified by an acceptance testing professional, which generates even more work.
- **Impacts on the creation or elimination of businesses in California:** The Lighting Power Adjustment Factors have had a long history of creating the conditions for innovative companies to open up shop in California. The occupancy sensor and daylighting control PAF's in the 1992 Title 24 standards help generate a market for these control types. Thus it is not surprising that a number of controls manufacturers were headquartered in California. More recently the requirement for multi-level controls created a market for these types of controls.
- **Impacts on the potential advantages or disadvantages to California businesses**: The Title 24 energy efficiency standards have for years led the rest of the country and the rest of the world. Many requirements in Title 24 have been adopted by the ASHRAE 90.1 and IECC energy codes in the United States and other codes overseas. Both high end trim and daylight dimming plus off have been used voluntarily by advanced design teams and by companies with large real estate holdings. Manufacturers and designers in California have a leg up on their competitors by having products and service that incorporate reliable energy savings techniques.
- **Impacts on the potential increase or decrease of investments in California:** The lighting controls business has become increasingly globalized so that it is hard to predict just what fraction of increased lighting control investments will be invested in California but it overall direction is positive in terms of more investment in California lighting firms.
- **Impacts on incentives for innovations in products, materials or processes:** Since proposed controls credits are performance based, this allows for equipment suppliers to develop new technologies that meet the requirements more effectively, more inexpensively and potentially providing additional amenity in conjunction with the new functionality.
- **Impacts on the State General Fund, Special Funds and local government:** To the extent that the Power Adjustment Factors allow designers to install lighting power with

more equipment (luminaires and controls) costs, there would be slightly more sales tax and property tax collected. However this is negligible in the context of overall new construction project costs.

- **Cost of enforcement to State Government and local governments:** The clarification and simplification components of this proposal reduce the cost of code enforcement for local jurisdictions. This impact is small.
- **Impacts on migrant workers; persons by age group, race, or religion:** This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to race, religion or age group.
- **Impact on Renters:** This proposal is advantageous to renters as it reduces the cost of utilities which are typically paid by renters. Since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experiences by the landlord, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by renters.
- **Impact on Commuters:** This proposal and all measures adopted by CEC into Title 24, part 6 are not expected to have an impact on commuters

Statewide Energy Impacts

Power adjustment factors (PAFs) are voluntary and their impact depends upon how frequently they are used. The primary impact of the PAFs depend upon how frequently they are used and actual reduction of lighting usage as compared to the reduction embedded in the PAF. The PAFs for tuning of dimming lighting and dimming plus OFF daylighting controls create credit for these controls and provide a code incentive for these controls. If these incentives are used, this gives practitioners and other lighting market participants experience with these controls. The statewide impacts are long term with the main benefit to the state resulting from market acceptance of these controls and ultimately adoption of these control strategies as mandatory measures in future versions of Title 24.

The PAFs have been available in the Title 24 standards since the 1992 version of the code. These PAFs have been effective in helping develop the market for other lighting controls that were later on required by the standards including: occupancy sensors, bi-level occupancy sensors and daylighting controls. These control types are no longer given PAF credit as these controls are a mandatory requirement in Section 130.1 of the standards.

Cost-effectiveness

Cost-effectiveness is not calculated for this set of measures as what is being proposed is clean-up language to various sections and a lighting control credit. Thus the stringency of the standard is not being increased by this proposal and does not require a cost-effectiveness calculation. However it should be noted that the cost-effectiveness of high end trim tuning of controllable lighting was found to the be cost-effective in all space types besides classrooms in the *Requirements for Controllable Lighting* CASE Study that supported the development of the

2013 Title 24 standards. [CASE 2011] Similarly the ASHRAE 90.1 lighting subcommittee evaluated the costs and savings associated with multi-level plus OFF daylighting controls before adopting this control strategy into ASHRAE 90.1-2010.[1] The Pacific Northwest National Laboratory conducted an evaluation of savings from multi-level plus OFF controls which will be briefly discussed later on in this report. [PNNL 2013]

Greenhouse Gas and Water Related Impacts

Greenhouse Gas Impacts

Energy savings are not claimed for these measures and thus there is no claim of Greenhouse Gas savings

Water Use and Water Quality Impacts

The proposed measure is not expected to have any impacts on water use or water quality, excluding impacts that occur at power plants.

Acceptance Testing

The high end trim tuning Power Adjustment Factor requires the tuning of light levels to the initial design illuminance levels tabulated on the construction documents and verified by an independent third party according to the requirements in the proposed Nonresidential Appendix NA7.6.4 “Acceptance Tests for High End Trim Tuning of Dimmable Lighting. This acceptance tests verifies that all lighting systems receiving the credit have their initial design illuminance listed on the construction documents, these lighting systems are capable of high end trim control and that the lighting systems is adjusted so that at full light output the light levels are no greater than 110% of the listed initial design illuminance.

[1] ASHRAE 90.1-2013 Section 9.4.1.1(e) “Automatic daylighting controls for sidelighting” and Section 9.4.1.1(f) “Automatic daylighting controls for toplighting”

1. INTRODUCTION

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison and Southern California Gas Company – and Los Angeles Department of Water and Power (LADWP) sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is a part of the effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficient design practices and technologies.

The overall goal of this CASE Report is to propose changes to the 206 Title 24 part 6 building efficiency standards in regards to Lighting Controls Requirement Clarifications and Lighting Control Credits. The report contains pertinent information that justifies the code change.

Section 2 of this CASE Report provides a description of the measure, how the measure came about, and how the measure helps achieve the state's zero net energy (ZNE) goals. This section presents how the Statewide CASE Team envisions the proposed code change would be enforced and the expected compliance rates. This section also summarized key issues that the Statewide CASE Team addressed during the CASE development process, including issues discussed during IOU-sponsored public stakeholder meetings.

Section 3 presents the market analysis, including a review of the current market structure, a discussion of product availability, and the useful life and persistence of the proposed measure. This section offers an overview of how the proposed standard will impact various stakeholders including builders, building designers, building occupants, equipment retailers (including manufacturers and distributors), energy consultants, and building inspectors. Finally, this section presents estimates of how the proposed change will impact statewide employment.

The report concludes with specific recommendations for language for the Standards, Appendices, Alternate Calculation Manual (ACM) Reference Manual and Compliance Forms.

2. MEASURE DESCRIPTION

2.1 Measure Overview

This nonresidential lighting control proposal to the 2016 Title 24 building efficiency standards is primarily "clean up" and prepares the market for added control requirements in the 2019 standards. Key features of this proposal is to provide credit for high end trim tuning (the energy rationale for requiring controllable lighting) and daylight dimming plus OFF (similar to the mandatory daylighting control requirements in the ASHRAE 90.1-2013 national energy code baseline) and referencing a test method for "low flicker operation" something required by Title 24 for years but not before quantified with a repeatable test method.

2.1.1 Measure Description

Initial Design Illuminance Section 100.1. This definition supports the manual dimming with high end trim tuning PAF. This clarifies that the Initial Design Illuminance value is higher than the Maintained Design Illuminance which is what most designers think of when they hear the term "design illuminance."

Dimming system flicker requirements Section110.9(b)3. This would add clarifying language to the lighting controls requirement that the flicker requirement applies to entire dimming system (control, lamps and ballasts or drivers) and not just the controls. It also references a flicker test method in Reference Joint Appendix JA10.

Multi-level control simplification Section 130.1(b)3. This proposed change would replace a hard to enforce, confusing portion of the multi-level lighting controls requirements with a simpler requirement which is easier to enforce. The confusing portion has a requirement to pick one out of five requirements for each enclosed are in addition to all other requirements. However two of the requirements (manual dimming control and demand response) are already required in many situations. The proposal would require clarify the requirement that most commonly applies (manual dimming controls for dimmable luminaires). This will simplify and render this section more enforceable.

One of the benefits of mandatory requirements is that they are the same for every building and thus they are easy to enforce. This simplicity is lost when a mandatory requirement is structured to be a list of pick one requirement out of a list of five requirements. This format is more readily applied to voluntary rating systems such as LEED where points are assigned for picking more and more options. The requirements for multi-level control have so many control steps for linear fluorescent lighting that the simplest approach is to install continuous dimming controls. When continuous dimming controls are installed Section 130.1(a) [area controls], requires that a manual dimmer control the lights though all control steps. A manual dimmer is one of the five controls required in Section 130.1(b). This proposal would just clarify that when the lighting is continuous dimming that the area control be a manual dimmer. In most cases this proposal does not change the stringency of the standard but makes it more understandable and easier to comply with and enforce.

Daylighting Controls Calibration Accessibility Section 130.1(d)2D.

More clearly state the requirements for the accessibility of calibration adjustment control for photocontrol (daylighting control) systems. The primary purpose of this requirement is to prevent tampering with the photosensor and to have the calibration controls readily accessible so that adjustments to daylighting controls can be easily performed by authorized personnel in response to changes in geometry or reflectance of the interior, changes in occupancy or tasks and in response to requests for more or less light from occupants.

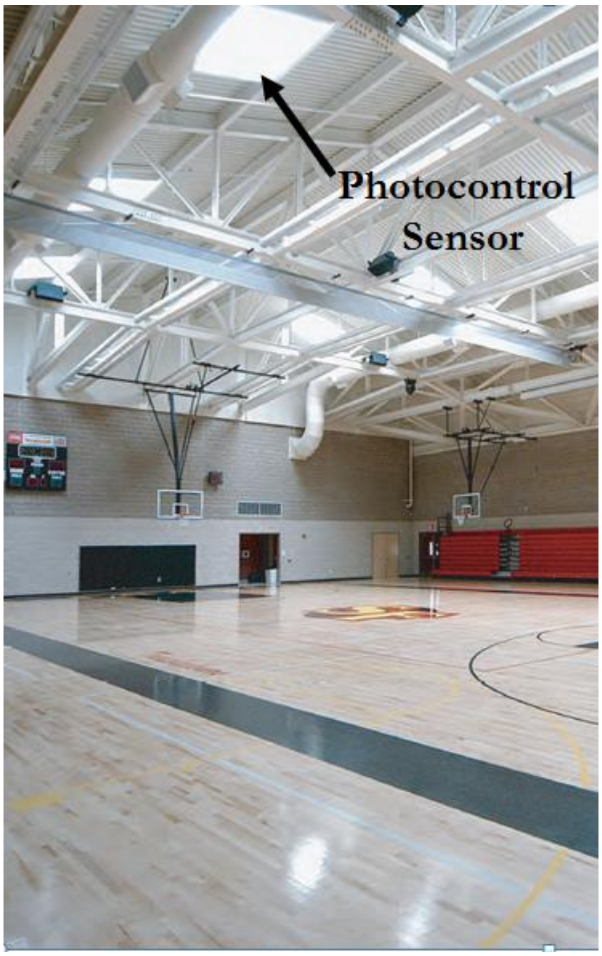

Figure 1: Photocontrol Sensor Location in Skylight Well

Daylight Dimming Plus OFF Controls PAF Section 140.6(a)2H. Replace the description of the PAF for Partial-ON Dimming Controls with a description of the requirements of the Daylight Dimming Plus OFF controls. It should be noted that ASHRAE 90.1-2013 has a mandatory requirement that daylighting controls turn lights all the way OFF when the space is fully daylit. This proposal is a halfway step towards having daylighting control requirements as stringent as found in ASHRAE 90.1. Ideally this PAF prepares the market for this control strategy being the default or the mandatory daylighting controls requirement in the 2019 Title 24 standards.

Manual Dimming Controls with High End Trim Tuning PAF Section 140.6(a)2J. Replace the description of Manual Dimming or Multiscene Programmable Dimming System controls that qualify for a PAF with the description of Manual Dimming Controls with High end Trim Tuning controls that qualify for a PAF. This section also notes that the initial design illuminance must be on the construction documents and that high end trim must be tuned so that it is no greater than 110% of the initial design illuminance as verified by the acceptance tests as contained in nonresidential appendix NA7.6.4. Add two Power Adjustment Factors in Table 140.6-A for daylighting dimming plus OFF control and tuning of dimming systems.

Remove three PAFs and Add two new PAF's in Table 140.6-A The Power Adjustment factors (PAFs) for partial-on controls and manual and scene controls for dimming systems and the combination of manual dimming and partial on control are no longer needed as continuous dimming is essentially required by the 2013 changes to Section 130.1(b) multi-level controls.

The rationale for removing these PAFs is contained in the Nonresidential Lighting Controls Partial-ON Occupancy Sensors draft CASE report. These changes are included in the proposed changed code in this report for ease of understanding how the proposed changes from both CASE reports would impact Table 140.6-A.

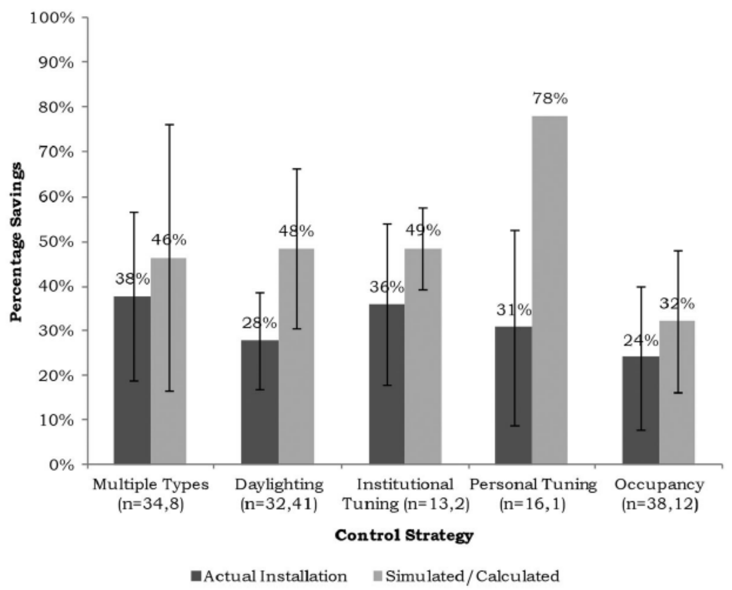

Figure 2: Meta-Study of Lighting Control Savings [LBNL 2012]

This CASE report describes the rationale for adding Power Adjustment Factors for daylight dimming plus OFF control and manual dimming controls with high end trim and tuning. A 10% PAF is proposed for the daylight dimming plus OFF control and 10% PAF is proposed for manual dimming controls with high end trim and tuning.

The 10% PAF for daylight dimming plus OFF control accounts for the typical savings associated with the addition of an OFF control to daylight dimming. Typically dimming fluorescent ballasts consume around 20% of full power when they are fully dimmed. In many applications under skylights or in the primary sidelit zones, one can turn off lights for about half the day as these zones are under full daylight conditions about half the day.

The 10% PAF for manual dimming controls with high end trim and tuning is a very conservative estimate of the savings possible from this control strategy. During the development of the 2013 Title 24 standards, the CASE [2011] report for “Requirements for Controllable Lighting” estimated that for all lighting “tuning lighting to the required level during the initial part of lamp life, a 15% power reduction over the lamping cycle is possible.” This estimate is likely conservative, a metastudy of 31 other institutional tuning studies found an average savings of 38% savings with a standard deviation of 17%. [LBNL 2012]

It should be noted that the LBNL definition of institutional tuning is slightly broader than the high end trim tuning we are proposing. From the report the definition of institutional tuning is: *(1) Adjustment of light levels through commissioning and technology to meet location-specific needs or building policies; or (2) provision of switches or controls for areas or groups of occupants; examples of the former include high-end trim dimming (also known as ballast tuning or reduction of ballast factor), task tuning, and lumen maintenance.*

We recommend that the CEC consider a 10% PAF for tuning but that a PAF as high as 15% would be energy neutral. If a PAF of 10% is used then society potentially would gain an additional 5% energy savings in return for providing more design flexibility to the designer.

Though a 15% PAF would theoretically be energy neutral, it is possible that designers might add some cushion to their estimated initial design lumens, or that tuning is imperfectly conducted. Thus there is some risk with a 15% PAF; this high of a PAF could result in slightly greater energy consumption. Which PAF below 15% PAF should be used is a judgment call.

Even if a 15% PAF were selected, the LBNL study seems to indicate there may still be some net savings from this control credit. For those systems that are installed with high end tuning, future additional savings are possible by more rigorous institutional tuning strategies where each area is tuned closely based on the individual needs of current occupants. Thus this PAF helps incentivize enabling technologies that could save even more energy in the future. The main payoff to the State of California is if this control strategy is used enough to develop a critical mass of designers contractors and inspectors who are able to implement and enforce this strategy effectively so that it will be ready for adoption into future versions of Title 24. If tuning is a mandatory requirement in future versions of Title 24, the full 15%+ of savings would be then realized.

NA7.7.6.2 "Acceptance Tests for High End Trim Tuning of Dimmable Lighting." This new acceptance test is added to verify that lighting systems claiming the High end Trim Tuning Power Adjustment factor have tuned the lighting system appropriately. One of the key questions was how does one repeatedly measure average illuminance in a space. This proposed acceptance tests would make use of the guidance for measuring illuminance in Chapter 9 of the 10th Edition of the IES Handbook.

Nonresidential ACM Reference Manual Proposed changes to the Nonresidential Alternative Compliance Method (ACM) Reference Manual would specify how to provide credit for Daylight Dimming plus OFF Controls and Manual Dimming Controls with High End Trim Tuning. We are proposing that these two PAF control credits are treated differently in the ACM. The daylighting control credit would be simulated using the daylighting model in the nonresidential performance software whereas lighting that is receiving a control credit for tuning would have the installed lighting wattage derated by a factor equal to the PAF.

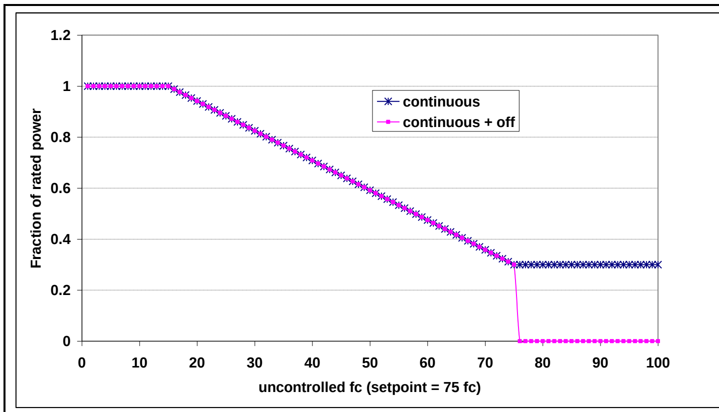

Figure 3: Dimming and Dimming plus OFF control (Fig 10 in NR ACM)

The base case daylight dimming control strategy is dimming with lowest power level being 30% at full dimming and when the PAF is selected and confirmed via the acceptance test, the control is continuous dimming plus off. Figure 3 (Figure 10 of the ACM) plots curves of percent of lighting power for a dimming versus a dimming plus OFF control calculated for a space with a 75 fc setpoint.

2.1.2 Measure History and Existing Standards

Dimming system flicker requirements Section110.9(b)3. The Title 24 standards have had requirements to minimizer flicker for over 20 years as it is recognized as a feature of lighting that is so annoying that it can result in lost energy savings due to the associated controls being disabled and efficient light sources being removed.

The Title 24 standards have had requirements for flicker starting in the 1988 standards and in the 1992 standard contained the following definition: *"REDUCED FLICKER OPERATION is the operation of a light, in which the light has a visual flicker less than 30% for frequency and modulation."* The 1992 Title 24 standards in mandatory Section 119[e] required that dimming daylighting controls *"provide electrical outputs to lamps for reduced flicker operation through the dimming range and without causing premature lamp failure…"*

This requirement remained unchanged until the 2008 Title 24 development process where LED manufacturers commented that LED systems using pulse width modulation for dimming could have amplitude modulation as high as 100% but that this did not result in perceptible flicker because this amplitude modulation was occurring at very high frequencies. After review of the research on flicker it was determined that flicker was a function of both percent amplitude modulation (also known as percent flicker) and the frequency at which the amplitude modulation takes place. In 2008 the definition and the requirement for daylighting controls were combined so that the requirement for daylighting controls include the following: *"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."* This requirement was expanded to cover all dimmers including manual dimmers. Manufacturers have asked how they can comply with the standard but up to this point were not given guidance on a test method.

Percent Amplitude Modulation of any signal is given by the following equation:

$$\text{Percent Amplitude Modulation} = \frac{(\text{Max} - \text{Min})}{(\text{Max} + \text{Min})} \times 100$$

During the 2013 Title 24 revision process, the flicker requirement for dimmers and daylight dimming controls were moved to the California Title 20 Appliance Efficiency Standards Section 1605.3(l)2 "Self Contained Lighting Controls." In Section 110.9(b), each lighting control system has to meet the requirements in the Title 20 standards including those for reduced flicker operation.

This proposal clarifies that the flicker requirements apply to the entire dimming system (dimmer, lamps and ballasts or drivers) and applies to all light sources and specifies a test method for confirming that the source is indeed qualifies as maintaining low flicker operation.

Multi-level control simplification Section 130.1(b)3. The approach of pick one approach out of five was proposed near the end of the development of the 2013 standards. This format is similar to approaches taken in voluntary standards where one can pick from a long list (5 options) to obtain extra points. For a mandatory requirement this results in significant added complexity for little gain. Three out of the five requirements in this section are already required by other mandatory sections of the standards. It should be noted that one of these five choices is high end trim tuning. However if one has dimmable lighting that can be tuned, Section 130.1(a)2C also requires a manual dimmer, one of the other five choices. Thus this approach provides no effective requirement to tune dimming lighting systems.

Daylighting Controls Calibration Accessibility Section 130.1(d)2D. The 2005 T-24 standards first introduced mandatory daylighting controls. In the 2008 Title 24 standards (CASE 2006) additional installation and operating requirements were added to the daylighting controls requirements in response findings from a large sidelighting photocontrols study that identified common causes of photocontrol failure and poor performance. (HMG 2005) One of causes of poor system performance, inaccessibility of calibration adjustments was addressed by Section 131(c) 2Diii: "The location where calibration adjustments are made to the automatic daylighting control device shall be readily accessible to authorized personnel, or located within 2 feet of a ceiling access panel that is no higher than 11 feet above floor level."

The question was raised how does a building inspector make sure that the control is readily accessible to authorized personnel only? The requirement didn't say that it only had to be accessible to authorized personnel as in some cases one is not concerned about tampering by other employees. If one is concerned about authorized people having access one can place the control behind a locked cover or in a secure room.

In the 2013 standards the code language was changed in the renumbered Section 130.1(d)2Di to, "Photosensors shall be located so that they are not readily accessible to unauthorized personnel, and the location where calibration adjustments are made to automatic daylighting controls shall not be readily accessible to unauthorized personnel." This would have the unintended consequence that the calibration adjustments could be inaccessible to anyone including authorized personnel. In fact this is one of the least expensive ways of making the control by placing the photosensor and control logic and calibration adjustment controls on a single unit which can then be located up on the ceiling (which might be 30 feet above the floor).

The ASHRAE 90.1-2013 Energy Standard in Section 9.4.1.1(e)1 has the following requirements for the location of calibration controls for photocontrols: "The calibration adjustments shall be readily accessible." The function testing requirements in ASHRAE 90.1 has the following requirement for photocontrols in Section 9.4.3(c)3: "The location where calibration adjustments are made is readily accessible only to authorized personnel." Thus the current Title 24 requirements are out of synch with ASHRAE 90.1 and are not aligned with earlier research on photocontrol performance.

Daylight Dimming Plus OFF Controls PAF Section 140.6(a)2H. The daylighting control requirements in Section 130.1(d) say this about the minimum light level required at full daylighting.

i. Automatic daylighting controls shall provide functional multi-level lighting having at least the number of control steps specified in TABLE 130.1-A.

and

iv. In areas served by lighting that is daylight controlled, when the illuminance received from the daylight is greater than 150 percent of the design illuminance received from the general lighting system at full power, the general lighting power in that daylight zone shall be reduced by a minimum of 65 percent.

Depending on the light source the minimum light output in Table 130.1-A can be as low as 10% for incandescent lighting, as high as 50% for HID (high intensity discharge) lighting and for incandescents between 20% and 40% on its lowest level. In conjunction with item iv above this results in fluorescent systems dimming to between 20 and 35% under full daylight conditions.

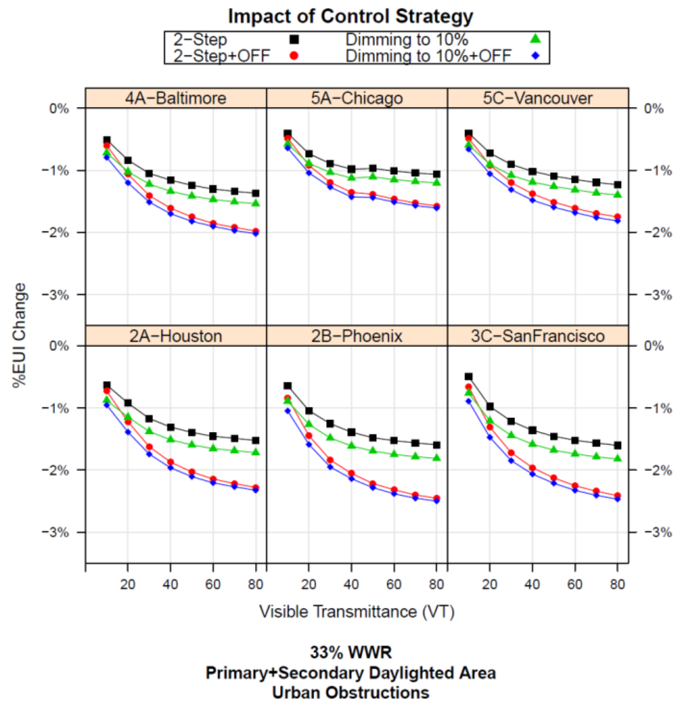

Figure 4: ASHRAE 90.1 Daylighting Controls Comparison

The ASHRAE 90.1-2013 standards have the following minimum light output requirements for automatic daylighting responsive controls for sidelighting in Section 9.4.1.1(e)3 and similar requirements for toplighting in Section 9.4.1.1(f)2:

The photocontrol shall reduce electric lighting in response to available daylight using continuous dimming or with at least one control point between 50% and 70% of design lighting power, a second control point between 20% and 40% of design lighting power or the lowest dimming level the technology allows, and a third control point that turns off all the controlled lighting.

Note that the ASHRAE standard does not require dimming controls but does require that the controlled general lighting in the daylit zone have three different illumination levels plus OFF. The rationale for these requirements is based on a simulation study conducted by PNNL with assistance from Mudit Saxena. This study found that there was little difference in the annual lighting savings between multi-level switching and continuous dimming. However when either control was enhanced by turning lights completely off under full daylight conditions, this saved approximately another 30% of lighting energy. These findings are illustrated in Figure 4. For a simulated office building with a window to wall ratio of 33% and various glazing VT as identified on the x axis (between 10% and 80%) the entire energy consumption of the building is impacted between 0.6% and 2.5% depending upon window VT and the type of daylighting control. It should be noted that the prescriptive minimum VT in Title 24 for nonresidential buildings is 42% for fixed windows and 32% for operable windows. The top two lines in each graph corresponding to least energy savings corresponds to multilevel and dimming controls that do NOT switch all the way OFF. The bottom two lines with greatest energy savings corresponds to dimming or multilevel switching controls that are turned completely OFF under full daylight conditions. From these graphs it is readily apparent that the addition of the OFF stage to the daylighting controls saves approximately another 30% of lighting energy savings when the window VT is around 40%. The results of this study were compelling and motivated the lighting subcommittee to approve this control measure.

Manual Dimming Controls with High end Trim Tuning PAF Section 140.6(a)2J. Tuning of lighting controls is required for daylighting controls as the acceptance tests for daylighting controls requires adjusting controls under no daylight, partial daylight and full daylight. The no daylight adjustment protocol essentially tunes the lighting systems for full light output. During the 2013 Title 24 standards development, one of the largest energy savings measures was the requirement for controllable lighting (Section 130.1(b)). This requirement essentially requires dimmable lighting or lighting with enough controls steps that it closely mimics dimmable lighting. The controllable (dimmable) lighting requirements are required for all general lighting where the installed lighting power density is greater than 0.5 W/sf.

The rationale for requiring dimmable lighting everywhere, and not just in daylit zones or other zones where automatic dimming controls would be used, was that controllable lighting provides savings from tuning in all areas. Since one can only specify and integer value of luminaires and cannot specify fractions of luminaires in a given space, there will be opportunities to more closely match the design illuminance of the space by adjusting the light output of luminaires. The CASE (2011) report "Requirements for Controllable Lighting" estimated that on average for all locations "tuning lighting to the required level during the initial part of lamp life, a 15% power reduction over the lamping cycle is possible."

However in the 2013 standards, there are no mandatory requirements for tuning (outside of the pick one of 5 choices in Section 130.1(b)) and there are no PAFs for tuning. Thus there are no requirements for tuning controllable lighting and there are no credits either. Thus the 2013 Title 24 code provides little compulsion or incentive for designers to specify tuning of controllable lighting.

Remove Three PAF's in Table 140.6-A The Power Adjustment Factor for Partial ON occupancy sensing control PAF helped to motivate designers to specify this control type and for manufacturers to develop a product that met this specification. See the "Nonresidential Lighting Controls: Partial-ON Occupancy Sensors." CASE presentation and CASE report on more detail on where this control is now a mandatory control requirement [CASE, 2014a; CASE 2014c]

The PAF for manual dimming was introduced to encourage dimmable lighting. Dimmable lighting is now a mandatory requirement for most general lighting; as a result, the PAF is no longer needed.

NA7.7.6.2 "Acceptance Tests for High End Trim Tuning of Dimmable Lighting." This new acceptance test is added to verify that those lighting systems that are taking the PAF credit for tuning have effectively been tuned. Though tuning was included in the list of 5 options for

Section 130.1(b)3(A through E), there was no detailed definition of what was required or an acceptance test to validate that it had been done.

The existing acceptance tests for PAF measures are contained in 2013 Title 24 Standards Nonresidential Appendix NA7.7.6 "Lighting Controls Installed to Earn a Power Adjustment Factor (PAF) in Accordance with Section 140.6(a)2." Given that the requirements were for fairly basic control strategies, there was little detail to these tests outside of confirming that the control were installed and appear to be operational. What is proposed for verifying High End Trim Tuning of Dimmable Lighting requires measuring illumination in accordance with the methods in the IES handbook and comparing these results with initial design illuminance levels listed on the construction documents.

A similar tuning proposal has been developed and is under consideration by the ASHRAE 90.1 Energy Standard lighting subcommittee. A similar proposal is being prepared for the energy and indoor environmental working groups for the ASHRAE 189.1 Standard for the Design of High-Performance Green Buildings.

2.1.3 Alignment with Zero Net Energy Goals

Many of the features of this proposal are clean-up to the code language that makes it easier to understand and enforce. However this proposal is also recommending the addition to two energy savings measures that increase energy efficiency: dimming plus off daylighting controls and high end trim tuning of lighting systems. As is described in the description of these measures, both save significant amounts of lighting energy. Both of these measures are proposed as control credits (power adjustment factors) in the 2016 version of Title 24. These control credits are intended to familiarize the nonresidential lighting design and construction industry with this technology on a voluntary basis. This proposal modifies the control credits and the ACM (alternative compliance method) manual so that there is an established way to take credit for these two technologies. Besides using these credits for code compliance these credits can be used to show that a building is more than minimally compliant with Title 24 for LEED (Leadership in Energy & Environmental Design) certification or for participating in utility efficiency incentive programs. The end goal is to include these requirements in future energy codes well in advance of the 2030 target for all new Commercial buildings being ZNE[2] and in advance of the 2025 deadline for the executive order that all new California government buildings are ZNE.[3]

2.1.4 Relationship to Other Title 24 Measures

Power adjustment factors render it easier to comply with the lighting power allowances in Section 140.6 because they provide a wattage credit for lighting designs that incorporate the

[2] CPUC. CA Energy Efficiency Strategic Plan Update 2011. http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/0/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf

[3] Executive Order B-18-12. http://gov.ca.gov/news.php?id=17506

use of the lighting control technologies specified in table 140.6-A "Lighting Power Density Adjustment Factors (PAF). The Partial On Occupancy Controls CASE report has recommended eliminating two Power Adjustment Factors (Partial On Occupant Sensing Control and Dimming Systems). Removing these control systems from the PAF table makes sense they are essentially required by a code that in the 2013 Title 24 standards essentially requires dimming for many spaces in Section 130.1(b) and by the proposal for the 2016 standards for Partial-On Occupancy Sensing Controls mandatory requirements. This proposal for PAFs for Daylight dimming plus OFF controls and High End Trim Tuning give some additional flexibility back to the lighting designer.

In any project where a designer is having a hard time achieving compliance from judicious selection of lighting technology and fixture layout, the designer can specify dimming plus off daylighting controls and high end trim tuning and have a larger lighting budget for compliance. Thus this proposal can offset some of the dislocation associated with complying with the new LPD's proposed for the 2016 standards while saving additional lighting energy.

2.2 Summary of Changes to Code Documents

The sections below provide a summary of how each Title 24 documents will be modified by the proposed change. See Section 4 of this report for detailed proposed revisions to code language.

2.2.1 Catalogue of Proposed Changes

Scope

Table 2 identifies the scope of the code change proposal. This measure will impact the following areas (marked by a "Yes").

Table 2: Scope of Code Change Proposal

Mandatory	Prescriptive	Performance	Compliance Option	Trade-Off	Modeling Algorithms	Forms
Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standards

The proposed code change will modify the sections of the California Building Energy Efficiency Standards (Title 24, Part 6) identified in Table 3.

Table 3: Sections of Standards Impacted by Proposed Code Change

Title 24, Part 6 Section Number	Section Title	Mandatory Prescriptive Performance	Modify Existing New Section
100.1	Initial Design Illuminance	Mandatory	New Definition
110.9(b)3	Dimmers	Mandatory	Modify Existing
130.1(b)	Multi-Level Lighting Controls	Mandatory	Modify Existing
130.1(d)2D	Automatic Daylighting Control Installation and Operation	Mandatory	Modify Existing
140.6(a)2	Reduction of wattage through controls	Prescriptive	Modify Existing
TABLE 140.6-A	Lighting Power Density Adjustment Factors (PAF)	Prescriptive	Modify Existing

Appendices

The proposed code change will modify the sections of the indicated appendices presented in Table 4. If an appendix is not listed, then the proposed code change is not expected to have an effect on that appendix.

Table 4: Appendices Impacted by Proposed Code Change

Standards Joint Appendix JA 1		
Section Number	**Section Title**	**Modify Existing New Section**
JA1	Glossary	Modify Existing
JA10	Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements	New Section
Nonresidential Appendix NA 7 Installation and Acceptance Requirements		
Section Number	**Section Title**	**Modify Existing New Section**
NA7.7.6	Lighting Controls Installed to Earn a Power Adjustment Factor (PAF) in Accordance with Section 140.6(a)2	Modify Existing
NA7.7.6.2	Acceptance Tests for High End Trim Tuning of Dimmable Lighting	New Section

Nonresidential Alternative Calculation Method (ACM) Reference Manual

The proposed code change will modify the sections of the Residential or Nonresidential Alternative Calculation Method References identified in Table 5.

Table 5: Sections of ACM Impacted by Proposed Code Change

Nonresidential Alternative Calculation Method Reference		
Section Number	**Section Title**	**Modify Existing) New Section**
3.2.2.4	Design Illumination Setpoint	Modify Existing
5.4.4	Interior Lighting	Modify Existing
5.4.5	Daylighting Control	Modify Existing

Simulation Engine Adaptations

The proposed code change can be modeled using the current simulation engine. Changes to the simulation engine are not necessary.

2.2.2 Standards Change Summary

This proposal would modify the following sections of the Building Energy Efficiency standards as shown below. See Section 4 "Proposed Language" of this report for the detailed proposed revisions to the standards language.

Changes in Scope

- Nothing in this proposal changes the scope of the standards.

Changes in Mandatory Requirements

- Section110.9(b)3. This would add clarifying language to the lighting controls requirement that the flicker requirement applies to entire dimming system (control, lamps and ballasts or drivers) and not just the controls. It also references a flicker test method in reference joint appendix JA10. The details of this test method and rationale are contained in the Residential Lighting Draft CASE report.
- Section 130.1(b)3. This proposed change would replace a hard to enforce, confusing portion of the multi-level lighting controls requirements with a simpler requirement which is easier to enforce. The confusing portion has a requirement to pick one out of five requirements for each enclosed are in addition to all other requirements. However two of the requirements (manual dimming control and demand response) are already required in many situations. The proposal would require clarify the requirement that most commonly applies (manual dimming controls for dimmable luminaires). This will simplify and render this section more enforceable.
- Section 130.1(d)2D. More clearly state the requirements for the accessibility of calibration adjustment control for photocontrol (daylighting control) systems. The primary purpose of this requirement is to prevent tampering with the photosensor and to have the calibration controls readily accessible so that adjustments to daylighting controls can be easily performed by authorized personnel in response to changes in geometry or reflectance of the interior, changes in occupancy or tasks and in response to requests for more or less light from occupants.

Changes in Prescriptive Requirements

- Add two Power Adjustment Factors in Table 140.6-A for daylighting dimming plus OFF control and manual dimming with high end trim tuning.

2.2.3 Standards Reference Appendices Change Summary

Reference Joint Appendix JA10

Reference Joint Appendix JA10 “Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements” describes a test method for quantifying the amount of flicker from lighting systems. The Title 24 standards have had requirements to minimizer flicker for over 20 years as it is recognized as a feature of lighting that is so annoying that it can result in lost energy savings due to the associated controls being disabled and efficient light sources being removed. However until the addition of this appendix there has not been a consistent reliable test method for enforcing the flicker requirements.

The Title 24 standards have had requirements for flicker starting in the 1988 standards and in the 1992 standard contained the following definition: *“REDUCED FLICKER OPERATION is the operation of a light, in which the light has a visual flicker less than 30% for frequency and modulation.”* The 1992 Title 24 standards in mandatory Section 119[e] required that dimming daylighting controls *“provide electrical outputs to lamps for reduced flicker operation through the dimming range and without causing premature lamp failure…”*

This requirement remained unchanged until the 2008 Title 24 development process where LED manufacturers commented that LED systems using pulse width modulation for dimming could have amplitude modulation as high as 100% but that this did not result in perceptible flicker because this amplitude modulation was occurring at very high frequencies. After review of the research on flicker it was determined that flicker was a function of both percent amplitude modulation (also known as percent flicker) and the frequency at which the amplitude modulation takes place. In 2008 the definition and the requirement for daylighting controls were combined so that the requirement for daylighting controls include the following: *“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.”* This requirement was expanded to cover all dimmers including manual dimmers. Manufacturers have asked how they can comply with the standard but up to this point were not given guidance on a test method.

Percent Amplitude Modulation of any signal is given by the following equation:

$$\text{Percent Amplitude Modulation} = \frac{(\text{Max} - \text{Min})}{(\text{Max} + \text{Min})} \times 100$$

During the 2013 Title 24 revision process, the flicker requirement for dimmers and daylight dimming controls were moved to the California Title 20 Appliance Efficiency Standards Section 1605.3(l)2 “Self Contained Lighting Controls.” In Section 110.9(b), each lighting control system has to meet the requirements in the Title 20 standards including those for reduced flicker operation.

The ENERGY STAR program recognizes that flicker is a concern for the widespread adoption of efficient lighting products and this is especially an issue when lighting is dimmed as some (but not all) dimming methods have the potential to increase flicker. However the ENERGY STAR program only requires that percent flicker and flicker index (a similar metric as percent flicker) be measured and does not set any requirements based on the results of the measurements. In addition, the ENERGY STAR program does not require that these results be filtered by frequency which is needed to address the concerns by the LED industry that the problems with flicker are a function of both amplitude modulation and frequency; something California addressed in 2008 by including a frequency specification.[4] By including flicker testing for light sources with the dimming controls they are intended to be used with, ENERGY STAR explicitly recognized that flicker is not just a function of a particular dimmer control but is a function of the combination of the dimmer, ballast or driver and light source and they are combining this information as part of the process for certifying lamps as ENERGY STAR qualified.

The proposed Reference Joint Appendix JA10 would take the ENERGY STAR flicker protocol a couple of steps further by specifying the minimum sampling rate, sample duration for measuring light output and providing specifications and tools for filtering the higher frequency components of the digitized signal before conducting the percent amplitude modulation calculations.

The filtering of the high sample rate data is performed mathematically using Fourier Transform analysis. The details of this manipulation are described in an IEEE paper: (Lehman et al.) “Proposing Measures of Flicker in the Low Frequencies for Lighting Applications.” The key steps of the process are to convert the time series data into the frequency domain as a Fourier series having the form:

$$x(t) = Xavg + \sum_{m=1}^{\infty} c_m \cos(m\omega t + \phi_m)$$

To filter the data in a low-pass format, the Fourier series terms that are above the cut-off frequency are deleted. This modified or truncated Fourier series is then converted back into the time domain. The filtered time series data is then used to calculate percent amplitude modulation for frequencies below the cut-off frequency. The proposed Reference Joint Appendix JA10 requires that percent amplitude modulation be reported for unfiltered data as well as data filtered with the following cut-off frequencies: 1,000 Hz, 400 Hz, 200 Hz, 90 Hz, and 40 Hz. The data required for meeting the reduced flicker requirements in Reference Joint

[4] The California flicker specification is written to be technology neutral so it does not assume for instance that modulation occurs at 120 Hz as has been often the case for LED with poorly filtered drivers, but could be at other frequencies as might be the case with an unstable arc of a discharge source.

Appendix JA8.6 is only the percent amplitude modulation at full light output and dimmed to 20% of full light output when the data is filtered for 200 Hz. The rest of the percent amplitude modulation data is stored in the CEC database and is available to lighting designers who may want to compare product performance across all of the different frequencies and at the four dimming levels (100%, 80%, 50% and 20%).

In addition to the summary data, the entity submitting data would be required to submit the unfiltered raw high frequency digitized light output data which is used to validate the percent amplitude modulation values submitted to the California Energy Commission.

The "reduced flicker operation" requirements in the current Title 20 appliance standards and proposed for Reference Joint Appendix JA8 are: "reduced flicker operation is defined as having percent amplitude modulation (percent flicker) less than 30% at frequencies less than 200Hz." In addition we are proposing that this definition would be enforced though the test method in JA10. This flicker requirement is not particularly stringent but prohibits the most objectionable flicker in light sources complying with JA8. Once flicker data is available for a broader range of products through this test and list requirement, the Commission may decide that even more stringent flicker requirements are justified in the future revisions to the standards.

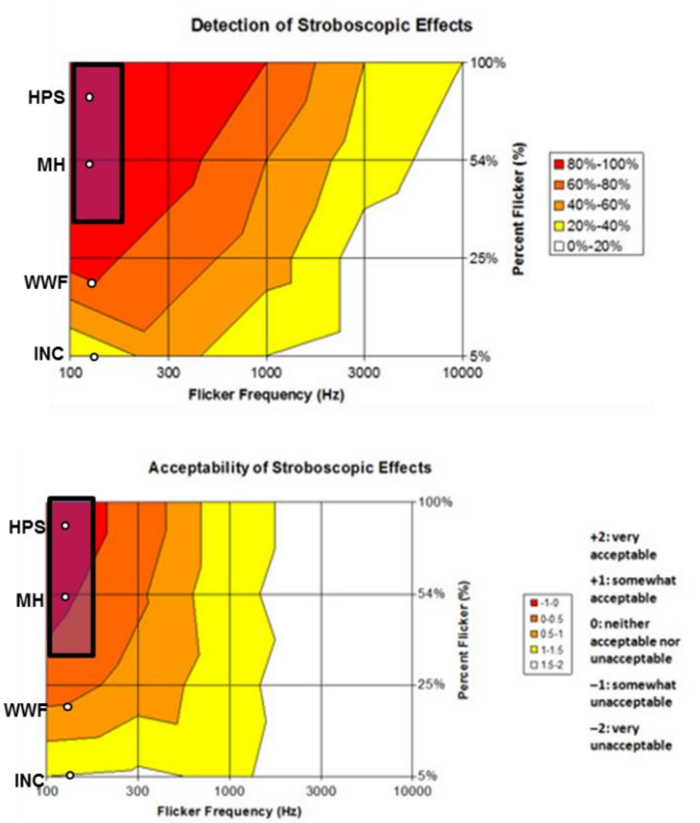

Figure 5: Detection and Acceptability of Stroboscopic Effects (LRC 2012)

Flicker can be related headaches and eyestrain even when the light source is not perceived to flicker (Wilkins et al. 1989). Wilkins compared the number of headaches reported by office workers under two types of fluorescent lamp—a 50Hz AC lamp with an amplitude modulation of around 50%, and a 32kHz lamp with a modulation of around 7%, neither of which gave perceptible flicker. Subjects reported an average of 0.52 headaches per week, a value which halved after the installation of the high-frequency lighting. These results apply to frequencies above the perceptible range of flicker. Thus it seems prudent to reduce flicker significantly below the perceptible range to avoid the possibility of adverse non-visual effects.

Performance can also be impacted

by imperceptible flicker. Veitch (1995) found that the visual performance of 48 undergraduate students was reduced under 60Hz AC lamps compared with 20-60kHz lamps, despite the absence of perceptible flicker.

More recent research by the Light Research Center (LRC 2012) evaluated stroboscopic effects from flickering light sources to evaluate both when people notice these effects and what levels of percent flicker (percent amplitude modulation) were considered unacceptable. The results of this study are graphed in Figure 5. Overlaid on top of these figures is a rectangle in the upper left corner; this rectangle indicates the performance characteristics of products that would not satisfy the Title 24 requirements for "reduced flicker operation," where amplitude modulation (percent flicker) is greater than 30% for frequencies less than 200 Hz. This region of frequencies and amplitude modulation is detectable by at least 80% of the population and the stroboscopic effects are considered very unacceptable.

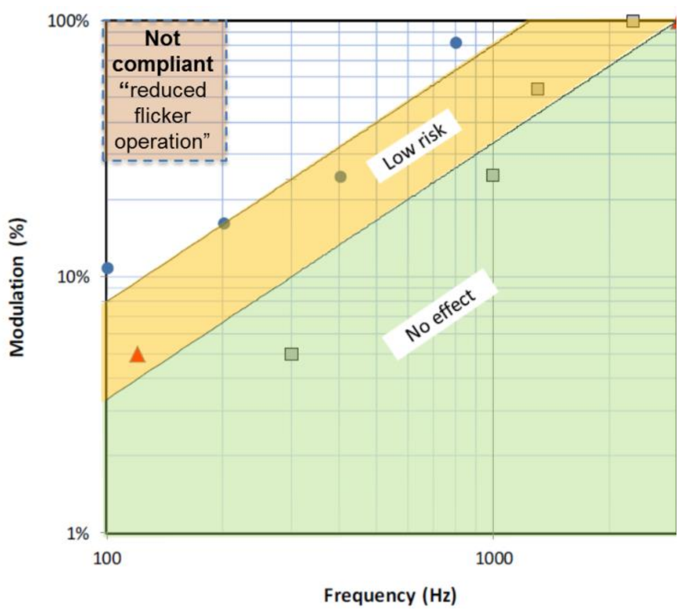

Figure 6: Low risk and no observable effect regions for flicker (Lehman et al 2014) overlaid with region of graph not compliant with "reduced flicker operation" requirement

Another reference point on the relative stringency of the reduced flicker operation requirement is obtained by comparing this requirement to regions of frequency and amplitude modulation that are considered low risk and no effect for flicker by Lehman et al (2014). Figure 6 in the upper left corner overlays the region not compliant with "reduced flicker operation" on top of the regions that are considered low risk by Lehman. It is readily apparent that the regions of amplitude modulation and frequency that do not comply with the T-24 definition of low flicker operation are well above the region defined as being low risk for affects from flicker, indicating that the Title 24 specification may not be stringent enough.

In support of a proposal to the California Appliance Standards on LED Replacement Lamp Quality, (PG&E/SDG&E 2013), flicker testing was conducted on omni-directional LED A-lamps controlled by phase cut dimmers. The results of these initial tests of filtered amplitude modulation measurements of LED A lamps indicates that 52% of products tested were considered to achieve "reduced flicker operation" at full light output and when lamps were dimmed to 20% of full light output.

In Figure 7, the results are filtered so that only the low frequency data less than 200 Hz is evaluated for percent amplitude modulation (percent flicker). If one observes the results in Figure 7, one can see that 13 out of 25 A-lamps are able to pass the "low flicker operation" specification; they have less than 30% amplitude modulation at 100 % full light output and when dimmed down to 25% of full light output. Lamp 13 fails for having too much amplitude modulation at full light out and lamps 15 through 25 fail mostly at both dimming levels. These results indicate the cup is both half full and half empty. Half full in regards to the market being able to provide plenty of products that can meet the flicker requirements before there is a quantitative metric for flicker. But with half of the LED products failing the flicker test indicates that the cup is also half empty; these findings indicate that the market is not self-policing; as has occurred numerous times in the past with food, drugs, and consumer goods, inferior products are sold into markets without testing, labeling and minimum standards. It should be noted that 12% or 3 of the samples out of 25 lamps with photometric date filtered for frequencies less than 200 Hz had amplitude modulation of 100%! Comments that all lamp manufacturers have a quality control expert with a "golden eye" that detects and prevents problematic flicker do not withstand the scrutiny of objective physical testing. Clearly some products are significantly exceeding the modest flicker requirements proposed here, but others are failing badly

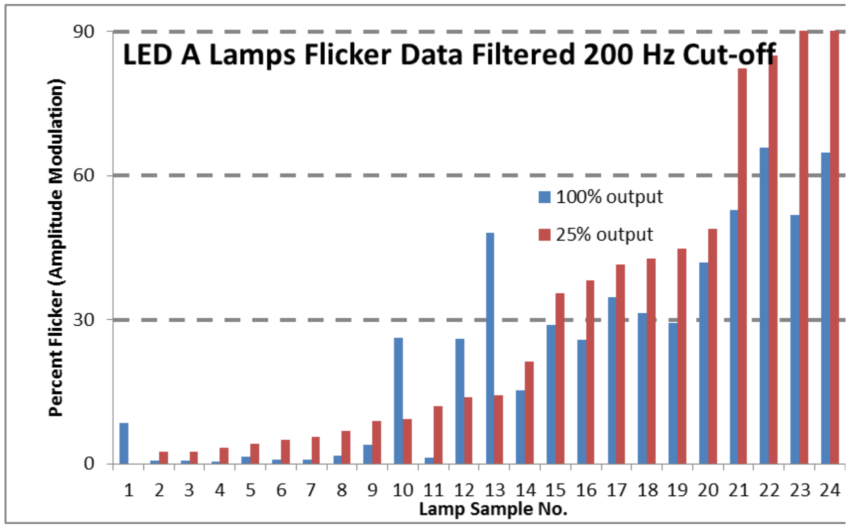

Figure 7: Filtered Flicker Test Data for 25 LED A-lamps (filtered flicker proposed for CA standards)

Currently the ENERGY STAR test protocol does not have the Fourier method filtering as part of their test method. The results of the ENERGY STAR test method without filtering bring up the issues that the CEC addressed in 2008 with the redefinition of "low flicker operation" that accounts for both amplitude modulation (percent flicker) and frequency. Figure 8 illustrates for the same A-lamps what happens if the high frequency photometric data is not filtered, only one product is able keep amplitude modulation less than 30%. Thus unless the manufacturers of the 52% of the LED products that are passing the proposed California flicker criteria have filtered their photometric data with a 200 Hz low pass filter they might believe that their products don't comply when they actually do satisfy the filtered flicker criteria.

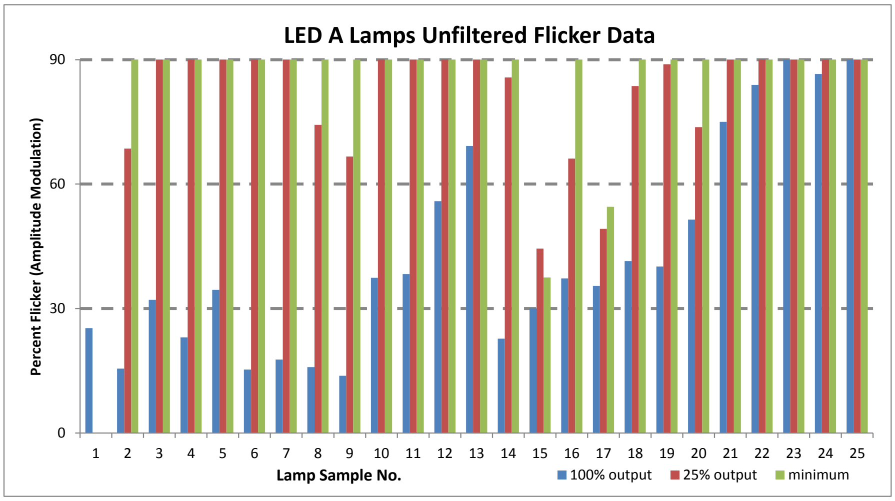

Figure 8: Unfiltered Flicker Test Data for 25 LED A-Lamps (unfiltered flicker not proposed for CA standards)

We have proposed that the CEC host a public domain tool that will filter the flicker data automatically for manufacturers submitting data. However for the use of interested parties, the CASE team has attached a sample of public domain command language for use with the mathematical software MATLAB in Appendix A. If test data is placed in the data format as outlined in TABLE JA-10 (see the JA 10 code language in Section 4.2) this command language will read in the csv (comma separated variables) data file and write a similar data file but insert the correct filtered amplitude modulation. The file must have four strings of data at 100%, 80%, 50% and the greater of 20% or minimum fraction of light output. The CASE team is looking for feedback on how this system of evaluation works and whether this approach alleviates the fears of raised about flicker testing.

Table 6: Comparison of unfiltered percent flicker results between two test labs

	CLTC	PNNL	Difference
Product 1	100.00	99.80	0.20%
Product 2	29.79	30.10	-1.05%
Product 3	11.22	11.00	1.96%
Product 4	100.00	100.00	0.00%

In terms of repeatability of collecting raw data for the flicker test, The California Lighting Technology Center (CLTC) and the Pacific Northwest National Laboratory (PNNL) tested four LED A-lamps with phase cut dimmers and measured percent flicker (the same as amplitude modulation) at full light output. The error between the two sets of data is tiny. We are looking for partners in industry to conduct the tests in their labs and compare the results with what we have found. Building on findings from above, we also want to compare both filtered and unfiltered results.

The CASE team has also conducted flicker testing of five fluorescent dimming ballasts which were controlled with 0-10 VDC controls or digital dimming controls. None of these ballasts were controlled with phase cut dimmers. All of these dimming ballasts had less than 5% percent amplitude modulation at both full light output and dimmed down to 20% of full light output.

Thus we anticipate that once flicker testing is widely conducted, that lamp manufacturers will be designing most of their products to comply with this standard. This proposal also encourages the use of NEMA SSL 7A compliant phase cut dimmers as one can test with their product with only one NEMA SSL7A compliant dimmer and be considered compliant for all NEMA 7A qualified dimmers.

Nonresidential Standards AppendixNA7 – Acceptance Tests

This proposal would modify the following sections of the Standards Appendices as shown below. NA7.6.4 "Acceptance Tests for High End Trim Tuning of Dimmable Lighting." This new acceptance test is added to verify that lighting systems claiming the High end Trim Tuning Power Adjustment factor have tuned the lighting system appropriately.

The high end trim tuning Power Adjustment Factor requires the tuning of light levels to the initial design illuminance levels tabulated on the construction documents and verified by an independent third party according to the requirements in the proposed Nonresidential Appendix NA7.6.4 "Acceptance Tests for High End Trim Tuning of Dimmable Lighting." This acceptance tests verifies that all lighting systems receiving the credit have their initial design illuminance listed on the construction documents, these lighting systems are capable of high end trim control and that the lighting systems is adjusted so that at full light output the light levels are within 10% of the listed initial design illuminance.

This will require the creation of a new acceptance testing form.

2.2.4 Nonresidential Alternative Calculation Method (ACM) Reference Manual Change Summary

This proposal would modify the following sections of the Alternative Calculation Method (ACM) Reference Manual as shown below. See ***Section 4.3 ACM Reference Manual*** of this report for the detailed proposed revisions to the text of the Alternative Calculation Method (ACM) Reference Manual.

Proposed changes to the Nonresidential Alternative Compliance Method (ACM) Reference Manual would specify how to provide credit for Daylight Dimming plus OFF Controls and Manual Dimming Controls with High End Trim Tuning.

In Section 3.2.2.4 "Design Illumination Setpoint", specifies that the designer must document initial design illuminance to take the credit for high end trim tuning PAF. Without this documentation, the installer is unable to tune the lighting and the acceptance testing professional is unable to verify the results of high end trim tuning of dimming lighting.

The PAF subsection of Section 5.4.4 "Interior Lighting" describes how the credit for dimming plus OFF daylighting controls and manual dimming with high end trim tuning are treated differently in the performance method. The daylighting control credit is simulated using the daylighting model in the nonresidential performance software whereas lighting that is receiving a control credit for tuning would have the installed lighting wattage derated by a factor equal to the PAF.

The Daylighting Control Type subsection in Section 5.4.5 "Daylighting Control" describes the base case control and the dimming plus OFF daylighting control. The base case daylight dimming control strategy is dimming with lowest power level being 30% at full dimming and when the PAF is selected and confirmed via the acceptance test, the control is continuous dimming plus off.

2.2.5 Compliance Forms Change Summary

The proposed code change will modify the following compliance forms listed below.

- **NRCC-LTI-02-E** –This existing compliance form will be modified to clarify that continuously dimmable lighting systems must be comply with the low flicker operation requirements in Section 110.9 as tested in accordance with Reference Joint Appendix JA-10.

This proposal will require modifying one acceptance form and the creation of a new acceptance form as described below:

- **NRCA-LTI-03-A** Acceptance testing form (daylighting control acceptance), will need to be revised to check for lights being turned all the way off when applying for the daylight dimming plus OFF PAF.
- **NRCA-LTI-04-A** – This new form will be created to support the acceptance test contained in Appendix NA7.6.4 "Acceptance Tests for High End Trim Tuning of Dimmable Lighting."

2.2.6 Simulation Engine Adaptations

The simulation engine does not need to be modified as it can already apply lighting power adjustment factors associated with pre-calculated PAF's and it already has a rudimentary daylighting simulation capability. What would change are the rule sets for the credit for high end tuning and how credit is given for dimming plus OFF controls.

2.2.7 Other Areas Affected

No other areas affected.

2.3 Code Implementation

2.3.1 Verifying Code Compliance

Most of the changes can be verified using slightly modified existing compliance forms and acceptance forms. The PAF for high end trim tuning would result in the most changes as it requires:

- The designer to place initial design illuminances directly on the plans or on a lighting schedule that is part of the construction documents.
- Requires the contractor to adjust the high end trim settings to match the initial design illuminance levels
- An acceptance testing professional to retest and fill out the acceptance forms.

2.3.2 Code Implementation

The main challenge to code implementation is the issue of acceptance testing. See more discussion below.

2.3.3 Acceptance Testing

The high end trim tuning Power Adjustment Factor requires the tuning of light levels to the initial design illuminance levels tabulated on the construction documents and verified by an independent third party according to the requirements in the proposed Nonresidential Appendix NA7.6.4 "Acceptance Tests for High End Trim Tuning of Dimmable Lighting. This acceptance tests verifies that all lighting systems receiving the credit have their initial design illuminance listed on the construction documents, these lighting systems are capable of high end trim control and that the lighting systems is adjusted so that at full light output the light levels are within 10% of the listed initial design illuminance.

The Acceptance tests were introduced in the 2005 version of the Title 24 standards. The original intent of the acceptance tests was to provide to the installer of setup contractor a series of brief tests that would evaluate common failure modes and give direct feedback to the installing contractor whether the control was performing to the intent of the energy code. The contractor would fix or adjust any control that failed the acceptance test until it passed. Under the 2013 standards this mastery method approach towards controls was replaced with a third party inspector approach that disintegrates the original direct feedback intent of the acceptance tests.

The challenge of the acceptance testing of high end trim tuning is that one person is adjusting the lights and another person if verifying compliance with acceptance tests. The calculated average illuminance of the space is sensitive to where the illumination measurements are collected. Some of this variability is reduced by using a common method (the illumination measurement locations and illumination calculations as described in Chapter 9 of the IES Lighting Handbook 10th Edition. For small spaces this is not an issue as there are a limited number of locations where one can take the measurements. However as described in the IES Handbook, one can sample illuminance readings in a couple of locations in a large space and apply this sampled illuminance to the rest of the space. If the third party acceptance testing verification takes measurements at other sampled locations they may get different illuminances.

Rather than having the acceptance testing professional re-measure all the illuminances in the space used for tuning, it would be more desirable if the installation or tuning contractor filled out the acceptance form and the acceptance testing professional review the forms and take sample measurements where the illumination measurements can be repeatedly and easily defined.

2.4 Issues Addressed During IOU CASE Development Process

The Statewide CASE Team solicited feedback from a variety of stakeholders when developing the code change proposal presented in this report. In addition to personal outreach to key stakeholders, the Statewide CASE Team has also been communicating with the stakeholders in the ASHRAE 90.1 code development process. As mentioned earlier, the ASHRAE 90.1-2013 energy standard requires multi-level plus OFF daylighting controls as a mandatory lighting control measure and the high end trim tuning proposal is under consideration by the ASHRAE 90.1 lighting subcommittee. The issues that were addressed during development of the code change proposal are summarized below.

- *Daylight dimming plus OFF: won't occupants in a space think that the lights are broken if they enter a room with full daylighting, try to switch the lights on but they do not turn on?* The response to this question is that occupancy sensors were disconcerting at first but now people are used to them and understand how they work. Regular occupants in a space will get used to the system and explain to newcomers how the control works. Given that this control is required by ASHRAE 90.1-2013, a critical mass of new buildings will render this commonplace. In this case ASHRAE 90.1 is leading on daylighting controls and Title 24 is following. This proposal is recommending this control strategy only as a voluntary PAF, for a building designer that either wants to show how far they can exceed Title 24 or in return for higher LPDs.
- *High end trim tuning. Lighting designers don't want the liability of placing design light levels on construction documents.* As a control credit, this is a voluntary measure for those designers that want either more lighting power or bragging rights for exceeding Title 24 by a larger margin for receiving LEED credits or utility incentives. Calculating and placing the design illuminances on the construction documents is good lighting practice performed by many lighting designers.
- *How does someone define average task illuminance?* Use the measurement and calculation procedures as described in Chapter 9 of the IES Lighting Handbook 10th Edition.

3. MARKET ANALYSIS

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market players.

3.1 Market Structure

Dimming plus off controls are available from multiple manufacturers and can also be programmed into lighting control panels with software changes. High end trim controls are available on many stand-alone dimmers.

3.2 Market Availability and Current Practices

Dimming plus off controls are used by one of the largest owners of daylit real estate, Wal-Mart. The standard Wal-Mart store design uses skylights with dimming fluorescent lights that dim in response to daylight availability and turn off when the daylight illuminance exceeds the design illuminance. COSTCO uses a multi-level plus OFF switching control for many of its stores. However outside of these large end-users of daylighting controls most of the smaller end-users and many designers have not yet made the transition to dimming plus OFF controls.

3.3 Useful Life, Persistence, and Maintenance

The useful life persistence and maintenance of daylight dimming plus off controls are comparable to the daylight dimming only controls they replace. For fluorescent lighting systems, it is expected that the burning hours of the lamps will be reduced as switching on an off a lamp reduces it burning hours. However if the lamp is turned off for more than 90 minutes, the actual time between replacements increases by switching them off. With appropriate use of illuminance deadband and time delay algorithms, the daylight switching of lamps is reduced to several times per day.

High end trim is built into many stand-alone dimmers and is a capability inherent in many lighting control panels. On stand-alone dimmers the trim control is located under the switch cover and thus not accessible to unauthorized building occupants. For lighting control panels adjustments of high end trim is usually accessible (understandable) to a few people who are maintaining the lighting control system. Thus the persistence of the high end trim is high. Given that lumen depreciation is low for many modern light sources, there is not a need to adjust high end trim settings between lamp replacements. This may change with greater use of LED lighting being served by drivers that do not automatically adjust in response to burn hours or to a closed loop lumen maintenance control.

3.4 Market Impacts and Economic Assessments

3.4.1 Impact on Contractors

Simpler code requirements (such as eliminating the one out of five requirements in Section 130.1(b)) will render it easier to comply and easier to enforce. Added control credits will allow more equipment to be installed (both luminaires and controls) which increases bill able work for contractors. The tuning proposal increases the amount of labor on a job and generates work lighting acceptance test professionals.

3.4.2 Impact on Building Designers

Simpler code will render it easier to comply. Added PAFs provide more design flexibility to comply with code. Some lighting designers may be concerned about increased liability associated with placing design light levels on design documents even though this is good design practice.

3.4.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Department of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules will remain in place. Complying with the proposed code change is not anticipated to have any impact on the safety or health occupants or those involved with the construction, commissioning, and

Most of the proposed code changes are not expected to have an impact on occupational safety and health. The requirement for calibration adjustments being readily accessible increases occupational safety as it avoids the need for climbing up to the ceiling level to make photocontrol adjustments.

3.4.4 Impact on Building Owners and Occupants

Since this measure is cost-effective, the building owner who pays their energy bills is reducing their energy costs more than their mortgage costs are for the cost of the measure (i.e. there are experiencing net cost savings). For building occupants that are paying for their energy bills, since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experiences by the building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by occupants. Impact on Retailers (including manufacturers and distributors)

3.4.5 Impact on Energy Consultants

Simpler code will render it easier to document compliance. Power adjustment factors increase the complexity of documentation but this a voluntary effort when the owner or designers are looking for more lighting power allowances or they are trying to fully document how more stringent their design is than the minimal requirements of the code for LEED or other building efficiency certification.

3.4.6 Impact on Building Inspectors

As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes. However, the portion of this proposal that simplifies the code will render it easier to enforce.

3.4.7 Impact on Statewide Employment

When the PAFs are used they generate more work for contractors. High end tuning requires more labor as it requires that each space taking the credit have the high end trim tuned to the design light levels defined for that space. In addition this tuning effort must be verified by an acceptance testing professional, which generates even more work.

- **Impact on equipment retailers (including manufacturers and distributors):** The Power Adjustments help develop a market for controls that have high end trim and for dimming plus off photocontrols. This slightly increases overall market activity but should have a large impact on these two control categories. There is a small cost on manufacturers to conduct flicker testing on products they sell in California. This cost is small as the cost is defrayed across all the units they sell in California. For LEDs the flicker testing can be combined with te flicker testing required for ENERGY STAR certification.

- **Impact on energy consultants:** no net impact
- **Impact on building inspectors: Statewide Employment Impacts:** as mentioned above on the impact on contractors,
- **Impacts on the potential increase or decrease of investments in California:** similar to other lighting control credits, these lighting control credits may spur investment and innovation by California based lighting control companies.
- **Impacts on incentives for innovations in products, materials or processes:** Since proposed controls credits are performance based, this allows for equipment suppliers to develop new technologies that meet the requirements more effectively, more inexpensively and potentially providing additional amenity in conjunction with the new functionality.
- **Impacts on the State General Fund, Special Funds and local government:** these voluntary PAFs allow for the installation of more equipment in buildings which increases construction costs and thus increases taxes associated with the valuation of new projects.
- **Cost of enforcement to State Government and local governments:** the net impact of this proposal is to reduce complexity of the code and thus slightly reduce the cost of enforcement.
- **Impacts on migrant workers; persons by age group, race, or religion:** This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to race, religion or age group.

3.5 Economic Impacts

As control credits this proposal has limited impacts on the life cycle cost of buildings. However the addition of control credits (PAFs) provides more flexibility to the building designer to add more lighting in exchange for more controls.

3.5.1 Creation or Elimination of Jobs

As a lighting control measure allows more lights and more controls to be installed the net employment impact is to employ more electricians and to sell more lighting products.

3.5.2 Creation or Elimination of Businesses within California

The Lighting Power Adjustment Factors have had a long history of creating the conditions for innovative companies to open up shop in California. The occupancy sensor and daylighting control PAF's in the 1992 Title 24 standards helped generate a market for these control types. Thus it is not surprising that a number of controls manufacturers were headquartered in

California. More recently the requirement for multi-level controls created a market for these types of controls.

3.5.3 Competitive Advantages or Disadvantages for Businesses within California

The Title 24 energy efficiency standards have for years led the rest of the country and the rest of the world. Many requirements in Title 24 have been adopted by the ASHRAE 90.1 and IECC energy codes in the United States and other codes overseas. Both high end trim and daylight dimming plus off have been used voluntarily by advanced design teams and by companies with large real estate holdings. Manufacturers and designers in California have a leg up on their competitors by having products and service that incorporate reliable energy savings techniques

3.5.4 Increase or Decrease of Investments in the State of California

The lighting controls business has become increasingly globalized so that it is hard to predict just what fraction of increased lighting control investments will be invested in California but it overall direction is positive in terms of more investment in California lighting firms.

3.5.5 Incentives for Innovation in Products, Materials, or Processes

Since proposed controls credits are performance based, this allows for equipment suppliers to develop new technologies that meet the requirements more effectively, more inexpensively and potentially providing additional amenity in conjunction with the new functionality.

3.5.6 Effects on the State General Fund, State Special Funds and Local Governments

To the extent that the Power Adjustment Factors allow designers to install lighting power with more equipment (luminaires and controls) costs, there would be slightly more sales tax and property tax collected. However this is negligible in the context of overall new construction project costs.

3.5.6.1 Cost of Enforcement

Cost to the State

As an update to the 2016 Title 24 standards the impact to the state to enforce this change to the standard is negligible. If approved, the state government (CEC) would be involved in the updates to the standards and the reference appendices, the ACM, and the compliance manuals. This change is small as compared to the other changes in the standard and the incremental labor is an even smaller faction of the total effort expended.

Cost to Local Governments

The clarification and simplification components of this proposal reduce the cost of code enforcement for local jurisdictions. This impact is small. Power adjustment factors add complexity to the code but as we are removing two PAF controls and adding two control types the overall impact should be a wash on local government while providing added flexibility for designers and preparing these code requirements for future versions of the standards.

3.5.7 Impacts on Specific Persons

This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to race, religion or age group.

This proposal is advantageous to commercial building tenants as it reduces the cost of utilities which are typically paid by tenants. Since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experienced by the building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by tenants.

This proposal and all measures adopted by CEC into Title 24, part 6 are not expected to have an impact on commuters. This proposal does not advantage nor disadvantage infill projects.

4. PROPOSED LANGUAGE

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2013 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

4.1 Standards

Section 100.1 will be revised in the following manner:

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

LIGHTING definitions:

HIGH END TRIM TUNING is a lighting control strategy in which the maximum light output of an individual or group of luminaires is adjusted to provide the appropriate amount of light for a space, task or area.

INITIAL DESIGN ILLUMINANCE is the designed average illuminance (footcandles or lux) on the task surface, provided by a new lighting system. Initial design illuminance is higher than maintained design illuminance as light loss factors due to aging of the system are not applied.

Section 110.9(b)3 will be revised in the following manner:

3. **Dimmers** shall meet all requirements for Dimmer Control devices in the Title 20 Appliance Efficiency Regulations. The entire dimming system including light sources (lamps or light engines), ballasts or drivers, if applicable, and dimming control shall be designed so the combined performance of the dimming system results in light amplitude modulation (percent flicker) of less than 30 percent for frequencies less than 200 Hz as measured and documented according to the Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements in Reference Joint Appendix JA10. The dimming system shall be able to dim the light source without causing premature failure of the light source.

Section 130.1(b) will be revised in the following manner:

(a) Area Controls.

1. All luminaires shall be functionally controlled with manually switched ON and OFF lighting controls. Each area enclosed by ceiling-height partitions shall be independently controlled.

   EXCEPTION to Section 130.1(a)1: Up to 0.2 watts per square foot of lighting in any area within a building may be continuously illuminated during occupied times to allow for emergency egress, if:

   A. The area is designated an emergency egress area on the plans and specifications submitted to the enforcement agency under Section 10-103(a)2 of Part 1; and

   B. The control switches for the egress lighting are not accessible to unauthorized personnel.

2. The lighting controls shall meet the following requirements:

   A. Be readily accessible; and

   B. Be operated with a manual switch that is located in the same room or area with the lighting that is controlled by that lighting control; and

C. If controlling dimmable luminaires, be a dimmer switch that allows manual ON and OFF functionality, and is capable of manually controlling lighting through all lighting control steps that are required in Section 130.1(b).

EXCEPTION 1 to Section 130.1(a)2: In malls, auditoriums, retail and wholesale sales floors, industrial facilities, convention centers, and arenas, the lighting control shall be located so that a person using the lighting control can see the lights or area controlled by that lighting control, or so that the area being lit is annunciated.

EXCEPTION 2 to Section 130.1(a)2: Public restrooms having two or more stalls may use a manual switch not accessible to unauthorized personnel.

(b) **Multi-Level Lighting Controls.** The general lighting of any enclosed area 100 square feet or larger, with a connected lighting load that exceeds 0.5 watts per square foot shall meet the following requirements:

1. Lighting shall have the required number of control steps and meet the uniformity requirements in accordance with TABLE 130.1-A; and
2. Multi-level lighting controls shall not override the functionally of other lighting controls required for compliance with Sections 130.1(a), and (c) through (e); and
3. Dimmable luminaires shall be controlled according to Section 130.1(a)2C.

~~3. Each luminaire shall be controlled by at least of one of the following methods:~~

~~A. Manual dimming meeting the applicable requirements of Section 130.1(a)~~

~~B. Lumen maintenance as defined in Section 100.1~~

~~C. Tuning as defined in Section 100.1~~

~~D. Automatic daylighting controls in accordance with Section 130.1(d)~~

~~E. Demand responsive lighting controls in accordance with Section 130.1(e)~~

EXCEPTION 1 to Section 130.1(b): Classrooms, with a connected general lighting load of 0.7 watts per square feet and less, shall have at least one control step between 30-70 percent of full rated power.

EXCEPTION 2 to Section 130.1(b): An area enclosed by ceiling height partitions that has only one luminaire with no more than two lamps.

Section 130.1(c)5 will be revised in the following manner:

5. **Areas where Occupant Sensing Controls are required to shut OFF All Lighting**. In offices 250 square feet or smaller, multipurpose rooms of less than 1,000 square feet, classrooms of any size, and conference rooms of any size, lighting shall be controlled with occupant sensing controls to automatically shut OFF all of the lighting when the room is unoccupied. The occupant sensing controls shall function either as a:

A. Partial-On Occupant Sensor, with the automatic ON level set between 50-70 percent of full rated power, OR

b. Vacancy Sensor, where all lighting responds to a manual ON input only.

In addition, controls shall be provided that allow the lights to be manually shut-OFF in accordance with Section 130.1(a) regardless of the sensor status.

EXCEPTION to Section 130.1(c)5: Areas that do not meet the multi-level requirements of Section 130.1(b) shall operate using either Occupant Sensor or Vacancy Sensor control methods.

Section 130.1(d)2D will be revised in the following manner

D. **Automatic Daylighting Control Installation and Operation**. For luminaires in daylight zones, automatic daylighting controls shall be installed and configured to operate according to all of the following requirements:

   i. Photosensors shall be located so that they are not readily accessible to unauthorized personnel.~~,~~ ~~and the~~ The location where calibration adjustments are made to automatic daylighting controls shall ~~not~~ be readily accessible to ~~un~~authorized personnel but may be inside a locked case or under a cover which requires a tool for access.

Section 140.6(a)2 will be revised as follows.

2. **Reduction of wattage through controls.** In calculating actual indoor Lighting Power Density, the installed watts of a luminaire providing general lighting in an area listed in TABLE 140.6-A may be reduced by the product of (i) the number of watts controlled as described in TABLE 140.6-A, times (ii) the applicable Power Adjustment Factor (PAF), if all of the following conditions are met:

   A. An Installation Certificate is submitted in accordance with Section 130.4(b); and

   B. Luminaires and controls meet the applicable requirements of Section 110.9, and Sections 130.0 through 130.5; and

   C. The controlled lighting is permanently installed general lighting systems and the controls are permanently installed nonresidential-rated lighting controls. (Thus, for example, portable lighting, portable lighting controls, and residential rated lighting controls shall not qualify for PAFs.)

   When used for determining PAFs for general lighting in offices, furniture mounted luminaires that comply with all of the following conditions shall qualify as permanently installed general lighting systems:

      i. The furniture mounted luminaires shall be permanently installed no later than the time of building permit inspection; and

      ii. The furniture mounted luminaires shall be permanently hardwired; and

      iii. The furniture mounted lighting system shall be designed to provide indirect general lighting; and

      iv. Before multiplying the installed watts of the furniture mounted luminaire by the applicable PAF, 0.3 watts per square foot of the area illuminated by the furniture mounted luminaires shall be subtracted from installed watts of the furniture mounted luminaires; and

      v. The lighting control for the furniture mounted luminaire complies with all other applicable requirements in Section 140.6(a)2.

   D. At least 50 percent of the light output of the controlled luminaire is within the applicable area listed in TABLE 140.6-A. Luminaires on lighting tracks shall be within the applicable area in order to qualify for a PAF.

   E. Only one PAF from TABLE 140.6-A may be used for each qualifying luminaire. PAFs shall not be added together unless allowed in TABLE 140.6-A.

   F. Only lighting wattage directly controlled in accordance with Section 140.6(a)2 shall be used to reduce the calculated actual indoor Lighting Power Densities as allowed by Section 140.6(a)2. If only a portion of the wattage in a luminaire is controlled in accordance to Section 140.6(a)2, then only that portion of controlled wattage may be reduced in calculating actual indoor Lighting Power Density.

G. Lighting controls used to qualify for a PAF shall be designed and installed in addition to manual, multi-level, and automatic lighting controls required in Section 130.1, and in addition to any other lighting controls required by any provision of Part 6.

~~**EXCEPTION to Section 140.6(a)2G:** Lighting controls designed and installed for the sole purpose of compliance with Section 130.1(b)3 may be used to qualify for a PAF, provided the lighting controls are designed and installed in addition to all manual, and automatic lighting controls otherwise required in Section 130.1.~~

~~H. To qualify for the PAF for a Partial-ON Occupant Sensing Control in TABLE 140.6-A, a Partial-On Occupant Sensing Control shall meet all of the following requirements:~~

~~i. The control shall automatically deactivate all of the lighting power in the area within 30 minutes after the room has been vacated; and~~

~~ii. The first stage shall automatically activate between 30-70 percent of the lighting power in the area and may be a switching or dimming system; and~~

~~iii. The second stage shall require manual activation of the alternate set of lights, and this manual-ON requirements shall not be capable of conversion from manual-ON to automatic-ON functionality via manual switches or dip switches; and~~

~~iv. Switches shall be located in accordance with Section 130.1(a) and shall allow occupants to manually do all of the following regardless of the sensor status: activate the alternate set of lights in accordance with item (iii); activate 100 percent of the lighting power; and deactivate all of the lights.~~

<u>H. To qualify for the PAF for daylight dimming plus off control, the daylight control and controlled luminaires must be capable of continuous dimming in response to daylight availability and to turn lights completely OFF when full daylight is available in the daylit zone. Only those luminaires in the primary sidelit daylit zone and the skylit daylit zone qualify for this PAF.</u>

I. To qualify for the PAF for an occupant sensing control controlling the general lighting in large open plan office areas above workstations, in accordance with TABLE 140.6-A, the following requirements shall be met:

i. The open plan office area shall be greater than 250 square feet; and

ii. This PAF shall be available only in office areas which contain workstations; and

iii. Controlled luminaires shall only be those which provide general lighting directly above the controlled area, or furniture mounted luminaires that comply with Section 140.6(a)2 and provide general lighting directly above the controlled area; and

iv. Qualifying luminaires shall be controlled by occupant sensing controls that meet all of the following requirements, as applicable:

a. Infra-red sensors shall be equipped by the manufacturer, of fitted in the field by the installer, with lenses or shrouds to prevent them from being triggered by movement outside of the controlled area.

b. Ultrasonic sensors shall be tuned to reduce their sensitivity to prevent them from being triggered by movements outside of the controlled area.

c. All other sensors shall be installed and adjusted as necessary to prevent them from being triggered by movements outside of the controlled area.

J. To qualify for the PAF for a Manual Dimming Controls with High End Trim Tuning ~~System~~ PAF ~~or a Multiscene Programmable Dimming System PAF~~ in TABLE 140.6-A, the following requirements shall be met:

i. the lighting shall be controlled with a control that can be manually operated by the user;

ii. the maximum output of the controlled lighting is capable of being adjusted for high end trim tuning;

iii. Initial Design Illuminance is listed on construction documents for all spaces taking the PAF;

iv maximum lighting output is adjustable and is tuned so that average measured illuminance from the controlled lighting is no greater than 110% of the Initial Design Illuminance for that space as verified by the acceptance test in the nonresidential standards appendix NA7.7.6.2 “Acceptance Tests for High End Trim Tuning of Dimmable Lighting.”

K. To qualify for the PAF for a Demand Responsive Control in TABLE 140.6-A, a Demand Responsive Control shall meet all of the following requirements:

i. The building shall be 10,000 square feet or smaller; and

ii. The controlled lighting shall be capable of being automatically reduced in response to a demand response signal; and

iii. Lighting shall be reduced in a manner consistent with uniform level of illumination requirements in TABLE 130.1-A; and

iv. Spaces that are non-habitable shall not be used to comply with this requirement, and spaces with a lighting power density of less than 0.5 watts per square foot shall not be counted toward the building’s total lighting power.

~~L. To qualify for the PAF for Combined Manual Dimming plus Partial-ON Occupant Sensing Control in TABLE 140.6-A, (i) the lighting controls shall comply with the applicable requirements in Section 140.6(a)2J; and (ii) the lighting shall be controlled with a dimmer control that can be manually operated, or with a multi-scene programmable control that can be manually operated.~~

Table 140.6-A will be revised in the following manner:

TABLE 140.6-A LIGHTING POWER DENSITY ADJUSTMENT FACTORS (PAF)

TYPE OF CONTROL		TYPE OF AREA		FACTOR
a. To qualify for any of the Power Adjustment Factors in this table, the installation shall comply with the applicable requirements in Section 140.6(a)2 b. Only one PAF may be used for each qualifying luminaire unless combined below. c. Lighting controls that are required for compliance with Part 6 shall not be eligible for a PAF				
~~1. Partial-ON Occupant Sensing Control~~		~~Any area ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, conference or waiting room.~~		~~0.20~~
1. Daylight Dimming plus OFF Control		Luminaires in skylit daylit zone or primary sidelit daylit zone		0.10
2. Occupant Sensing Controls in Large Open Plan Offices		In open plan offices > 250 square feet: One sensor controlling an area that is:	No larger than 125 square feet	0.40
			From 126 to 250 square feet	0.30
			From 251 to 500 square feet	0.20
~~3. Dimming System~~	~~Manual Dimming~~	~~Hotels/motels, restaurants, auditoriums, theaters~~		~~0.10~~
	~~Multiscene Programmable~~			~~0.20~~
3 Manual Dimming Controls with High End Trim Tuning.		Luminaires in non-daylit areas. PAF is additive with other control PAFs.		0.10
4. Demand Responsive Control		All building types less than 10,000 square feet. Luminaires that qualify for other PAFs in this table may also qualify for this demand responsive control PAF		0.05
~~5. Combined Manual Dimming plus Partial-ON Occupant Sensing Control~~		~~Any area ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, conference or waiting room~~		~~0.25~~

4.2 Reference Appendices

Appendix JA1 – Glossary

ANSI C82.2 is the American National Standard for Lamp Ballasts –Method of Measurement for Fluorescent Lamp Ballasts (ANSI C82.2:2002)

CIE 53 is the International Commission on Illumination (Commission Internationale de l'Eclairage) document titled "Methods of characterizing the performance of radiometers and photometers," Publication CIE 53:1982.

10 CFR 430 Subpart B, Appendix Q is a section from the Code of Federal Regulations entitled 10 CFR Part 430, Subpart B – Test Procedures, with Appendix Q entitled, "Fluorescent Lamp Ballasts."

10 CFR 430 Subpart B, Appendix R is a section from the Code of Federal Regulations entitled 10 CFR Part 430, Subpart B - Test Procedures, with Appendix R entitled, "Uniform Test Method for Measuring Average Lamp Efficacy (LE), Color Rendering Index (CRI), and Correlated Color Temperature (CCT) of Electric Lamps."

10 CFR 430 Subpart B, Appendix W is a section from the Code of Federal Regulations entitled 10 CFR Part 430, Subpart B – Test Procedures, with Appendix W entitled, "Uniform Test Method for Measuring the Energy Consumption of Medium Base Compact Fluorescent Lamps."

10 CFR 430 Subpart B, Appendix BB is a forthcoming section from the Code of Federal Regulations (expected DOE adoption in late Fall 2014) entitled 10 CFR Part 430, Subpart B – Test Procedures, with Appendix BB entitled, "Uniform Test Method for Measuring the Input Power, Lumen Output, Lamp Efficacy, Correlated Color Temperature (CCT), Color Rendering Index (CRI), Time to Failure, and Standby Mode Power of Integrated Light-Emitting Diode (LED) Lamps."

IES TM-15~~-11~~ is the Illuminating Engineering Society document titled, "Luminaire Classification Systems for Outdoor Luminaires." (IES TM-15-11)

IES LM-9 is the Illuminating Engineering Society document titled, "Electrical and Photometric Measurements of Fluorescent Lamps." (IES LM-9-2009)

IES LM-20 is the Illuminating Engineering Society document titled "Photometric Testing of Reflector-Type Lamps – Incandescent Lamps." (IES LM-20-13)

IES LM-45, is the Illuminating Engineering Society document titled, "Electrical and Photometric Measurements of General Service Incandescent Filament Lamps." (IES LM-45-09)

IES LM-46, is the Illuminating Engineering Society document titled, "Photometric Testing of Indoor Luminaires Using High Intensity Discharge or Incandescent Filament Lamps." 2004. (IES-LM-46-12)

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IES LM-66, is the Illuminating Engineering Society document titled, "Electrical and Photometric Measurements of Single-Ended Compact Fluorescent Lamps." (IES LM66-11)

IES LM-79~~-08~~ is the Illuminating Engineering Society document titled, "IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products." (IES LM 79-08)

IES LM-82~~-08~~ is the Illuminating Engineering Society document titled, "LED Light Engines and LED Lamps for Electrical and Photometric Properties as a Function of Temperature." (IES LM 82-12)

Appendix JA10 Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements

This test method quantifies flicker from lighting systems which may include all of the following components: lamps, ballasts or drivers and dimming controls. This test method measures the fluctuation of light from lighting systems and processes this signal to quantify flicker as a percent amplitude modulation (percent flicker) below a given cut-off frequency. High frequency components of the signal above the cut-off frequency are filtered out. Since this test method is measuring the relative fluctuation of light, the test can be performed using either absolute photometry or relative photometry. The flicker of lighting components shall be tested according to this method, or by a method approved by the Executive Director.

JA10.1 Equipment Combinations

Flicker measurements of a phase cut dimmer controlling an incandescent line voltage lamp shall be considered representative of that dimmer with any line voltage incandescent lamp.

Flicker measurements of a phase cut dimmer controlling a transformer for low voltage incandescent lamps shall be considered representative of only that combination of dimmer and transformer with any incandescent lamp.

Flicker measurements of all non-incandescent lamp sources controlled by a phase cut dimmer shall be considered representative of only the specific combination of phase cut dimmer, ballast or driver, and lamp. These results cannot be applied to other combinations of dimmer, ballast, driver or lamp.

Flicker measurements of light sources controlled by a 0-10 volt control, a DALI control, other powerline carrier, wired, or wireless control protocol shall be considered representative of that combination of control protocol and ballast or driver and lamp. These results of the lamp and ballast or driver combination can be applied to other controls that utilize the same control protocol. If a proprietary protocol is used to control dimming, the results for the lamp and ballast or driver combination will be specific to that proprietary protocol only.

JA10.2 Test Equipment Requirements

Test Enclosure: The test enclosure does not admit stray light to ensure the light measured comes only from the unit under test (UUT). Provisions shall be made so that ambient air temperature and air flow rate in the test enclosure are maintained as described in JA 10.3 Test Conditions.

Photodetector: The photodetector fits the International Commission on Illumination (CIE) spectral luminous efficiency curve, V(λ)within 5% (f1'<5%) in accordance with CIE 53. The maximum deviation from linearity of response over the measurement range shall be less than 1%. The rise time of the sensor shall be 10 microseconds or less. Rise time is the time span required for the output signal to rise from a 10% to a 90% level of the maximum value when a steady input at the maximum value is instantaneously applied.

Signal amplifier: If a signal amplifier is used to increase the voltage to a range appropriate for the signal recording device, the bandwidth of the signal amplifier shall be at least 10 kHz at the amplification gain used to conduct the test and the maximum deviation from linearity of the amplifier gain over the measurement range shall be less than 3%.

Analog-to-digital converter and data storage: Digital oscilloscope with data storage capability or similar equipment able to store high frequency data from the photodetector, at a sample rate greater than or equal to 100 kHz for a minimum data record duration of greater than or equal to 2 seconds (e.g. at least 200,000 samples at 100 kHz).

JA 10.3 Flicker Test Conditions

Product wiring setup: Fluorescent ballasts shall be wired in accordance to the guidelines provided in the DOE ballast luminous efficiency test procedure in 10 CFR 430 Subpart B Appendix Q.

Product pre-conditioning: All fluorescent lamps shall be seasoned (operated at full light output) at least 100 hours before initiation of the test. Seasoning of other lamp types is not required.

Input power: Input power to the UUT shall be provided in accordance with the relevant test procedure for the UUT, as listed in JA 10.7. For technologies not listed in Section 10.7, input power to the UUT shall be provided at the rated primary voltage and frequency within 0.5% for both voltage and frequency. For technologies not listed in Section 10.7, the AC power supply while operating the UUT, shall have a sinusoidal wave shape at the prescribed frequency (typically 60 Hz or 50 Hz) such that the RMS summation of the harmonic components does not exceed 3% of the fundamental, i.e. less than 3% total harmonic distortion (THD).

Temperature: Temperature shall be maintained at a constant temperature in accordance with the relevant test procedure for the UUT, as listed in JA 10.7. For any technologies not listed in JA 10.7 temperature shall be maintained at a constant temperature of 25°C ±5°C.

Air Movement: Airflow rate shall be maintained in accordance with the relevant test procedure for the UUT, as listed in Section 10.7. For any technologies not listed in JA 10.7, airflow rate should be such that normal convective air flow induced by the UUT is not affected.

Dimming levels: Flicker measurements shall be taken within 2% of the following increments of full light output: 100%, 80%, 50%, and 20%, where 100% full light output is defined as the measured light output when operating the light source at the maximum setting provided by the control. Since this test method is interested in the relative fluctuation of light, these measurements are relative and do not require the measurement of absolute illuminance values. When the minimum light output of the systems is greater than 20% of full light output, then the flicker measurements are taken at the minimum light output. For harmonization with ENERGY STAR flicker tests, if a test lab wishes to use the labeled minimum output instead of 20% of full light output, this data can be used in lieu of the 20% light output data. For dimming fluorescent ballasts, lamp arc power may be used as a proxy for light output for the purpose of setting dimming levels for collecting test measurements.

JA10.4 Test Procedure

Light source stabilization: Light source stabilization for the initial flicker measurement of the UUT for a given equipment combination shall be determined in accordance with test procedures applicable to the UUT as referenced in JA 10.7. For any lighting technologies not listed in JA 10.7, light source output shall be considered stabilized for the initial flicker measurement of the UUT for a given equipment combination by using a test method in JA 10.7 that is applicable to a lighting technology that is most similar to the UUT. If the similar test method does not have a stabilization methodology, the light source output shall be considered stabilized for the initial flicker measurement by taking light output measurements once every fifteen minutes until three consecutive measurements over 30 minutes deviate by no more than 0.5% from the average of the three measurements.

For subsequent measurements, light source output shall be considered stabilized by taking light output measurements every minute until three consecutive measurements deviate by no more than 0.5% from the average of the three measurements.

Recording interval: Measured data shall be recorded to a digital file with an interval between each measurement no greater than 0.00005 sec (50 microseconds) corresponding to an equipment measurement rate of no less than 20kHz.

Equipment measurement period: shall be greater than or equal to 2 seconds.

For each dimming level after the lamps have stabilized, record lighting measurements from test equipment with readings taken at intervals of no greater than 50 microseconds. These readings are compiled for an equipment measurement period of no less than two seconds into a comma separated data file (*.csv) having the format specified in JA10.6.

JA 10.5 Calculations

The CEC Flicker Data Analysis Tool shall be used to perform the following data analysis on data collected at each relative dimming level (100%, 80%, 50%, 20% or minimum dimming). No calculations are required by the applicant, the CEC Flicker Data Analysis Tool will conduct the following calculations:

1. Calculate percent amplitude modulation (percent flicker) of unfiltered data over the duration of the test for a given dimming level using the following equation:

$$\text{Percent Amplitude Modulation} = \frac{(\text{Max} - \text{Min})}{(\text{Max} + \text{Min})} \times 100$$

Where,

Max is the maximum recorded light level or voltage from the test apparatus during the duration of the test for a given dimming level.

Min is the minimum recorded light level or voltage from the test apparatus during the duration of the test for a given dimming level.

2. Transform the time-domain data into frequency-domain data via Fast Fourier Transform (FFT) techniques.
3. Filter frequency-domain data to create five additional data sets with the following cut-off frequencies: 40 Hz, 90 Hz, 200 Hz, 400 Hz and 1,000 Hz. For each cut-off frequency listed, all frequency domain terms above the cut-off frequency will be set to zero, effectively truncating the Fourier series.[5]
4. Transform the filtered frequency-domain data back into the time-domain using an inverse Fourier transform technique.[6]
5. Calculate percent amplitude modulation on resulting time domain data for each filtered dataset over at least half of the full sampling duration (at least one second of filtered data in the time domain).

JA 10.6 Test Report and Data Format

For all systems where reporting of flicker data is required, the data shall be submitted to the California Energy Commission in a comma separated data file (*.csv) having the format specified in Table JA-10. Applicants can submit the file with the rows for amplitude modulation information left blank. The CEC Flicker Data Analysis Tool will take the file, process the raw data, and return the same file but with the amplitude modulation filled in based on calculations performed on the raw data.

TABLE JA-10. FLICKER DATA TO BE RECORDED AND SUBMITTED TO THE CALIFORNIA ENERGY COMMISSION

Description	Content
Test Date (2 comma separated text strings)	Date, (mm)/(dd)/(yyyy)
Contact Type Header (5 comma separated text strings)	Contact type, (Company), (Contact Name), (Phone Number), (e-mail address)
Test Operator (5 comma separated text strings)	Test Operator, (Company), (Contact Name), (Phone Number), (e-mail address)
Entity submitting results (5 comma separated text strings)	Entity submitting results, (Company), (Contact Name), (Phone Number), (e-mail address)
Product submitted for certification (5 comma separated text strings)	Product for certification, (Product type – dimmer, ballast or driver, etc.), (manufacturer), (model number), (other description)

[5] This filtering technique is described in Lehman, B.; Wilkins, A; Berman, S.; Poplawski, M.; Miller, N.J., "Proposing measures of flicker in the low frequencies for lighting applications," *Energy Conversion Congress and Exposition (ECCE), 2011 IEEE* , vol., no., pp.2865,2872, 17-22 Sept. 2011.

[6] Ibid, the paper above calculates “low frequency percent flicker” (filtered amplitude modulation) by a summation of the truncated Fourier series for each time step; this can more compactly be evaluated using the inverse Fourier transform.

TABLE JA-10. FLICKER DATA TO BE RECORDED AND SUBMITTED TO THE CALIFORNIA ENERGY COMMISSION	
Description	Content
Tested lighting system component: Dimmer (4 comma separated text strings)	Dimmer, (manufacturer), (model number), (other description)
Tested lighting system component: light source (4 comma separated text strings)	Light source**,** (manufacturer), (model number), (other description)
Tested lighting system component: Ballast or Driver (4 comma separated text strings)	Ballast or Driver**,** (manufacturer), (model number), (other description)
Recording interval (1 text string and 1 number)	Recording interval (secs), (value in sec – no greater than 0.00005 seconds)
Count of data points (1 text string and 1 number)	Count of data points, (number of measurements, no less than 40,000)
Equipment Measurement Period (1 text string and 1 number)	Equipment measurement period (secs), (value in sec – no less than 2 seconds)
Nominal Percent of Max Output Header (5 comma separated text strings)	Nominal percent of maximum output, 100%, 80%, 50%, (20% or minimum)
Fraction of rated light output at 100%, 80%, 50% and the greater of 20% or minimum fraction of light output. (1 text string and 4 comma separated numbers)	Measured fraction of max output, 100%, (measured fraction of max light output at 80%), (measured fraction of max light output at 50%), (measured fraction of max light output at the greater of 20% or minimum light output).
Amplitude modulation separator (1 text string and 4 comma separated numbers)	Cut-off Frequency Hz for dimming fractions, (same 4 values from line above)
Amplitude modulation with 40 Hz cut-off for each nominal dimming level (5 comma separated numbers)	40, (calculated percent amplitude modulation with 40 Hz cut-off for 100%, 80%, 50%, and the greater of 20% or minimum fraction of light output)
Amplitude modulation with 90 Hz cut-off for each nominal dimming level (5 comma separated numbers)	90, (calculated percent amplitude modulation with 90 Hz cut-off for 100%, 80%, 50%, and the greater of 20% or minimum fraction of light output)
Amplitude modulation with 200 Hz cut-off for each nominal dimming level (5 comma separated numbers)	200, (calculated percent amplitude modulation with 200 Hz cut-off for 100%, 80%, 50%, and the greater of 20% or minimum fraction of light output)
Amplitude modulation with 400 Hz cut-off for each nominal dimming level (5 comma separated numbers)	400, (calculated percent amplitude modulation with 400 Hz cut-off for 100%, 80%, 50%, and the greater of 20% or minimum fraction of light output)
Amplitude modulation with 1,000 Hz cut-off for each nominal dimming level (5 comma separated numbers)	1,000, (calculated percent amplitude modulation with 1,000 Hz cut-off for 100%, 80%, 50%, and the greater of 20% or minimum fraction of light output)
Amplitude modulation of unfiltered data for each nominal dimming level (1 text string and 4 numbers)	Unfiltered Percent Amp Mod, (calculated percent amplitude modulation with 1,000 Hz cut-off for 100%, 80%, 50%, and the greater of 20% or minimum fraction of light output)

TABLE JA-10. FLICKER DATA TO BE RECORDED AND SUBMITTED TO THE CALIFORNIA ENERGY COMMISSION	
Description	Content
Raw data separator (5 comma separated text strings)	Unfiltered raw photometric data for the following fractions of full light output:, 100%, 80%, 50%, (20% or minimum)
Raw data column headers (5 comma separated text strings)	Time stamp (sec), 100% data, 80% data, 50% data, (20% or minimum)
Raw Photometric Flicker Waveform (unfiltered) at 100%, 80%, 50% and the greater of 20% or minimum fraction of light output. (5 comma separated data values per row, with the number of rows being the number of data points taken during the test duration)	(time stamp), (flicker waveform data at 100%, 80%, 50%, and the greater of 20% or minimum fraction of light output)

JA 10.7 Reference Test Procedures

As described in Sections JA 10.2, JA 10.3 and JA 10.4, the criteria for input voltage, ambient temperature, ambient airflow rate, and light source stabilization for the initial flicker shall be based upon criteria in the test procedure specific to the lighting technology listed in Table JA-10.7. For those technologies where the test procedure listed in Table JA-10.7 does not contain a given criteria, the tests shall use the default criteria listed in Sections JA10.2 though JA 10.4.

TABLE JA-10.7 REFERENCE TEST PROCEDURES FOR UUT-SPECIFIC TEST CONDITIONS AND LIGHT SOURCE STABILIZATION	
Technology	**Test Procedure**
Incandescent and halogen reflector lamps, Incandescent non-reflector lamps, General service fluorescent lamps	10 CFR 430 Subpart B, Appendix R
Medium base compact fluorescent lamps	10 CFR 430 Subpart B, Appendix W
Fluorescent ballasts	10 CFR 430 Subpart B, Appendix Q
Fluorescent sources that are not medium base compact fluorescent lamps or general service fluorescent lamps	IES LM-9
Induction lamps	IES LM-66
LED integral lamps, LED light engines and integral LED luminaires	IES LM-79
High intensity discharge lamps	IES LM-51

Nonresidential Appendix NA7

Appendix NA7 – Installation and Acceptance Requirements for Nonresidential Buildings and Covered Processes

NA7.7.6 Lighting Controls Installed to Earn a Power Adjustment Factor (PAF) in Accordance with Section 140.6(a)2

NA7.7.6.1 Construction Inspection for all PAFs except High End Trim of Dimmable Lighting

Verify and document the following:

(a) Separately list all requirements for each PAF that is claimed in accordance with Sections 110.9, and 140.6(a)2, and Table 140.6-A.

(b) Verify the installation complies with all applicable requirements in accordance with Sections 110.9, and 140.6(a)2, and Table 140.6-A.

(c) If all of the above in not true for a specific PAF, the installation fails, and that specific PAF cannot be used.

NA7.7.6.2 Acceptance Tests for High End Trim Tuning of Dimmable Lighting.

NA7.7.6.2.1 Construction Inspection

Prior to Functional testing, verify and document the following:

(a) All systems receiving the PAF credit for tuning has their initial design illuminance on the construction documents. Missing design illuminance values are obtained from building designer or building owner before proceeding with rest of test.

(b)The controlled lighting is not within any daylight zone.

(c) The manual dimming control or the controlled luminaires have high end trim control capability. The control or controlled luminaires able to be adjusted so that their maximum light output can be adjusted and that normal operation of the manual dimming control does not override the maximum light output.

(d) The wattage of controlled lighting on receiving the PAF credit for tuning matches the controlled lighting power.

NA7.7.6.2.1 Functional testing of High End Trim Tuning of Dimmable Lighting

For buildings with up to seven (7) enclosed areas claiming the Manual Dimming Controls with High End Trim and Tuning PAF (power adjustment factor), all areas shall be tested. For buildings with more than seven (7) areas claiming this PAF, sampling may be done on the seven largest enclosed areas with tuned dimming systems. If any of the areas in the sample group of seven areas fails the acceptance test another group of seven areas must be tested. If any tested system fails it shall be tuned until it passes the test.

For each area to be tested do the following:

(a) Identify initial design illuminance for the areas illuminated by dimmable electric lighting receiving High End Trim and Tuning PAF from construction documents.

(b) Set dimmable electric lighting receiving High End Trim and Tuning PAF at normal maximum output allowed (e.g. manual dimmer at full output, occupant controlled dimming sensing occupancy etc).

(c) Measure and calculate average illuminance of the test areas in accordance with Chapter 9 of the IES Lighting Handbook 10th Edition.

(d) Document that measured average illuminance due to controlled electric lighting does not exceed the Initial Design Illuminance by more than 10%.

4.3 ACM Reference Manual

3.2.2.2 Indoor Lighting Power (see 5.4.4)

Compliance software shall print all applicable lighting forms and report the lighting energy use and the lighting level (Watts/ft2) for the entire project. Compliance software shall report "No Lighting Installed" for nonresidential spaces with no installed lighting. Compliance software shall report "Default Residential Lighting" for residential units of high rise residential buildings and hotel/motel guest rooms. If the modeled Lighting Power Density (LPD) is different than the actual LPD calculated from the fixture schedule for the building, Compliance software shall model the larger of the two values for sizing the mechanical systems and for the compliance run. Compliance software shall report the larger value on PERF-1. Lighting levels schedules shall be adjusted by any lighting Control Credit Watts, if input by the user.

Lighting power is not modeled in unconditioned spaces that are modeled, but lighting in those spaces is required to meet the prescriptive requirements for regulated unconditioned spaces such as commercial and industrial storage spaces and parking garages. When these types of spaces are entered the compliance software must report in the Special Features section that these spaces must comply with the prescriptive requirements for such spaces.

…

3.2.2.4 Design Illumination Setpoint

Spaces that have low design illuminance levels, below the ranges specified in Appendix 5.4A, shall provide documentation that show the design illuminance to be used as the daylight illumination setpoint.

Spaces with lighting systems which are making use of the high end trim tuning power adjustment factor shall provide documentation that show the initial design illuminance.

….

5.4.4 Interior Lighting

The building descriptors in this section are provided for each lighting system. Typically a space will have only one lighting system, but in some cases, it could have two or more. Examples include a general and task lighting system in offices or hotel multi-purpose rooms that have lighting systems for different functions. It may also be desirable to define different lighting systems for areas that are daylit and those that are not.

….

Power Adjustment Factors (PAF)	
Applicability	All projects
Definition	Automatic controls that are not already required by the baseline standard and which reduce lighting power more or less uniformly over the day can be modeled as power adjustment factors. Power adjustment factors represent the percent reduction in lighting power that will approximate the effect of the control. Models account for such controls by multiplying the controlled watts by (1 – PAF). except for the daylighting control PAF which is modelled directly in the daylighting model. When Power Adjustment Factors are used this shall be specified in the model inputs and reported in the compliance documents as an exceptional condition. Eligible California power adjustment factors are defined in Table 140.6-A. Reduction in lighting power using the PAF method can be used only for non-residential controlled general lights. Only one PAF can be used for a qualifying lighting system unless additions are allowed in Table 140.6.A of the standards. Controls for which PAFs are eligible are listed in Table 140.6-A of the California energy efficiency standards and include: • Occupancy Sensing Controls for qualifying ~~enclosed spaces and~~ open offices • Demand Control – Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal for qualifying building types where the control is not required by Section 130.1(e) (buildings less than 10,000 square feet).. • Manual ~~and multiscene programmable~~ dimming combined with high level trim tuning as verified by NA7.6.4 Acceptance Tests for High End Trim Tuning of Dimmable Lighting for qualifying area types. • Continuous dimming plus OFF daylighting control – the PAF shall not be used but the continuous dimming plus OFF control type shall be used when modeling the control. For more information see the subsection on “Daylighting Control Type” in Section 5.4.5 “Daylighting Control.” • ~~Manual Dimming plus multi-level occupancy sensor for qualifying area types.~~
Units	List: eligible control types (see above) linked to PAFs
Input Restrictions	PAF shall be fixed for a given control and area type
Standard Design	PAF is zero
Standard Design, Existing Buildings	PAF is zero

5.4.5 Daylighting Control

This group of building descriptors is applicable for spaces that have daylighting controls or daylighting control requirements.

California prescribes a modified version of the split flux daylighting methods to be used for compliance. This is an internal daylighting method because the calculations are automatically performed by the simulation engine. For top-lighted or sidelit daylighted areas, California Compliance prescribes an internal daylighting model consistent with the split flux algorithms used in many simulation programs. With this method the simulation model has the capability to model the daylighting contribution for each hour of the simulation and make an adjustment to the lighting power for each hour, taking into account factors such as daylighting availability, geometry of the space, daylighting aperture, control type and the lighting system. The assumption is that the geometry of the space, the reflectance of surfaces, the size and configuration of the daylight apertures, and the light transmission of the glazing are taken from other building descriptors.

Daylighting Control Type

Applicability	Daylighted spaces.
Definition	The type of control that is used to control the electric lighting in response to daylight available at the reference point. The options are:

.

- Stepped Switching Controls vary the electric input power and lighting output power in discrete equally spaced steps. See At each step, the fraction of light output is equal to the fraction of rated power.
- Continuous Dimming controls have a fraction to rated power to fraction of rated output that is a linear interpolation of the *minimum power fraction* at the *minimum diming light fraction* to rated power (power fraction = 1.0) at full light output. See Figure 9
- Continuous Dimming + Off controls are the same as continuous dimming controls except that these controls can turn all the way off when none of the controlled light output is needed. See Figure 10. When continuous dimming plus off control is used, this shall be reported in the compliance documentation as an exceptional condition.

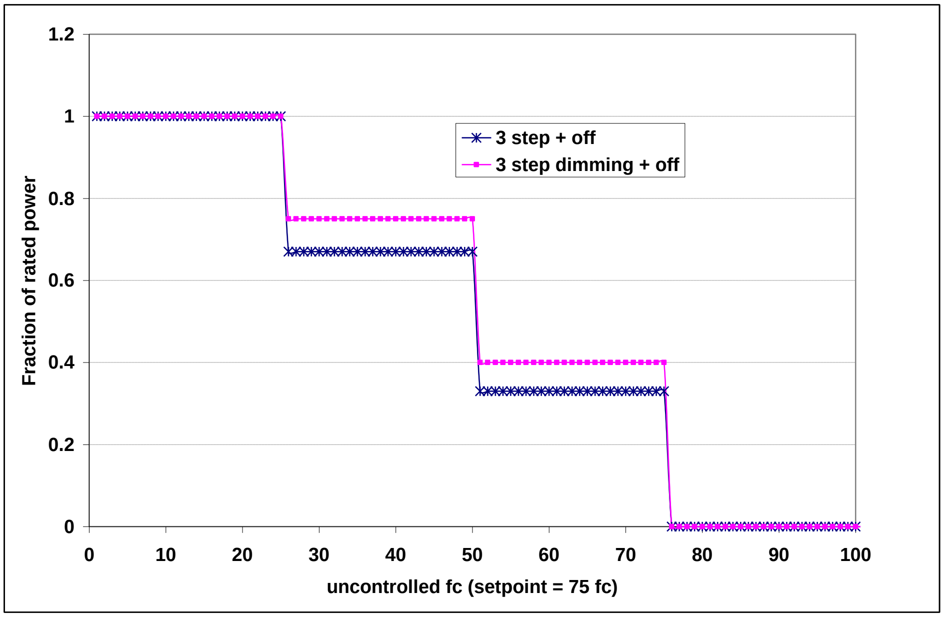

Figure 9 – Example Stepped Daylight Control

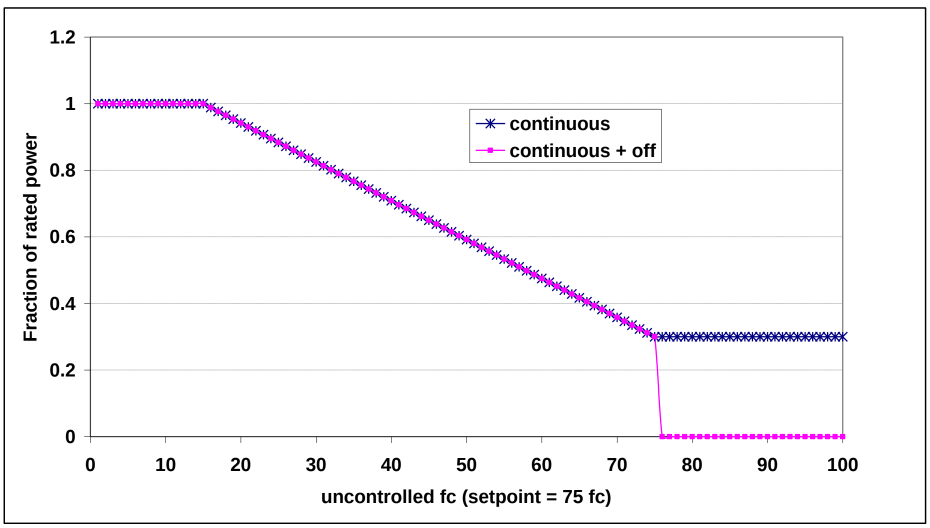

Figure 10 – Example Dimming Daylight Control.

Units	List (see above)
Input Restrictions	As designed .
Standard Design	<u>when general lighting in primary sidelit daylight zone or skylit daylight zone is greater than 120 Watts, otherwise no daylighting control.</u>
Standard Design, Existing Buildings	Same as for new construction, when skylights are added, replaced and general lighting altered.

4.4 Compliance Manuals and Forms

Chapter 5 (Lighting) of the Nonresidential Compliance Manual will need to be revised. The existing compliance form NRCC-LTI-02-E will be modified to be clear that continuously dimmable lighting systems must be comply with the low flicker operation requirements in Section 110.9 as tested in accordance with Reference Joint Appendix JA-10. Acceptance testing form NRCA-LTI-03-A (daylighting control acceptance), will need to be revised to check for lights being turned all the way off when applying for the daylight dimming plus OFF PAF. A new form NRCA-LTI-04-A (high end trim tuning of dimmable lighting) will need to be created.

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APPENDIX A SAMPLE FOURIER FILTERING COMMAND LANGUAGE FOR MATLAB

This CASE report has proposed that high frequency light data be filtered before calculating percent amplitude modulation (same as percent flicker). As proposed, the California Energy Commission would receive data from equipment manufacturers in a csv (comma separated variables) format as described in TABLE JA-10. *Flicker Data to be Recorded and Submitted to the California Energy Commission*. This data would be processed by the CEC Flicker Data Analysis Tool based on the raw photometric data submitted by the manufacturer. The data processing in the CEC Flicker Data Analysis Tool is based upon the use of Fourier transforms to filter out high frequency amplitude modulation that apparently does not impact people. Manufacturers would not have to develop their own filtering tools or even use the command language below. This command language is provided for use by stakeholders who wish to evaluate what impact filtering out high frequency components of the raw photometric data has on percent amplitude modulation of different light sources. Since the 2008 Title 24 standards California has had a requirement for dimming systems that they comply with requirements for "low flicker operation" which is defined as less than 30 percent amplitude modulation for frequencies less than 200 Hz. In 2013 this requirement was moved into the California Title 20 appliance standards which require dimming controls to comply with requirements for "low flicker operation."

Disclaimer: *While the authors have made every attempt to make this command language accurate and useful, we cannot be responsible for its use or application to specific products. The authors and sponsors of disclaim any responsibility or liability of any kind associated with the material contained here and make no warrantees, expressed or implied, of any kind, regarding the information or methods contained herein. Furthermore none of the contents of this tool shall be construed as a recommendation of any patented or proprietary product or application. By using this command language, the user agrees to hold harmless the authors and sponsors from any damages that might result from the use of information contained herein.*

```
%
% This MATLAB command file is public domain evaluated files compatible with reporting format for
% 2016 Title 24 JA-10 "Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements"
%
% Copy into MATLAB command window and press return
% This program will process photometric data in JA 10 format and return the identical file with
% calculated amplitude modulation of the data after it has been filtered
% for the following cut-off frequencies: 40, 90, 200, 400, 1,000 Hz
%
% This file is for processing raw relative photometric data and using Fourier transforms to
```

```
% provide low pass filtering of data for various key frequencies similar that described in:
% B. Lehman, A. Wilkins, S. Berman, M. Poplawski, and N. J. Miller,
% “Proposing measures of flicker in the low frequencies for lighting applications,”
% in 2011 IEEE Energy Conversion Congress and Exposition (ECCE), Phoenix, AZ, 2011, pp. 2865 –2872.

% READING FILE DATA INTO ARRAYS
[filename, pathname] = uigetfile('*.csv', 'Select JA-10 csv file with photometric data');
source = strcat(pathname, filename)
 destination = strcat(pathname,'modified-',filename)
cd(pathname)

fileIn = source
fileOut = destination

fidIn = fopen(fileIn);
fidOut = fopen(fileOut);

%  The row and column arguments are zero based, so that row = 0 and col = 0 specify the first value in the file
%  M = csvread(filename,row,col,csvRange) reads only the range specified by csvRange
%  M = csvread('csvlist.dat',1,0,[1,0,2,2]) once in M the index of the array starts with 1

% Reading in variables
Interval = csvread(fileIn,9,1,[9,1,9,1]) % Time period between each recoded measurement (8th row 2nd column)
N = csvread(fileIn,10,1,[10,1,10,1]) % Number of data points (9th row 2nd column)
Duration = csvread(fileIn,11,1,[11,1,11,1]) % Length of total measurement duration (10th row 2nd column)
fS = (1/Interval) % sampling frequency of recorded data
Nz = floor(Duration/Interval)  % Nz should equal N
FracMeas = csvread(fileIn,13,1,[13,1,13,4])  % fraction of full light output for each measurement

% fopen - Open file and overwrite 'w' – only applies to output file
fidOut = fopen(fileOut, 'w');

% Writing first 13 lines from source (input) file to destination (output) file
for Nline = 1:13
    tline = fgets(fidIn)
```

```
        fprintf(fidOut, '%s', tline);
end

% Line 14 echo back Measured fraction from input file into output file
DimmingText = 'Measured fraction of max output'
myformat = '%s,%f, %f, %f, %f\r\n';
fprintf(fidOut, myformat, DimmingText, FracMeas);

% Line 15 Header for amplitude modulation values
AMHeader = 'Cut-off Frequency Hz for dimming fractions'
fprintf(fidOut, myformat, AMHeader, FracMeas);

% Vectors with 5 elements, CutOffHz - cut off frequencies, and
% FilterIndex - Fourier coefficient number that corresponds to Cut-off frequency

% Cut-off frequency*Duration = Fourier element number corresponding to cut-off frequency

CutOffHz = [40 90 200 400 1000]
FilterIndex = round(CutOffHz*Duration)



% PD - percent dimming 1 = 100%, 2 = 85%,  3 = 50%, 4 = 20% or minimum
for PD = 1:4     % 4 columns of data corresponding to 4 increments of percent dimming

   M=csvread(fileIn,23,PD,[23,PD,N+22,PD]);  % reading starting on line 24 (csvread uses 0 index for first value)
   F = fft(M);

for Hz = 1:5     % 5 cut-off frequencies. See CutOffHz
        % filterindex - how many transform terms allowed before truncation
        % format of MATLAB transform frequency bins ( 0, 1, …N/2, -N/2+1, -N/2+2, …-2, -1)
        % filter array has 1's for low frequencies below cut-off frequency term,
        % 0's in middle of array to cut-off high frequencies and
        % 1's at end of end of array for low negative frequency terms
        FilterArray(:,Hz) = vertcat(ones(FilterIndex(Hz),1), zeros(N-2*FilterIndex(Hz),1),
ones(FilterIndex(Hz),1));
```

```
        FilteredFourier = FilterArray(:,Hz).*F;

        FF(:,Hz) = FilteredFourier;
        InvFF = abs(ifft(FilteredFourier));

        FFI(:,Hz) = InvFF;
        AM(Hz,PD) = (max(InvFF) - min(InvFF)) /(max(InvFF) + min(InvFF))*100;
  end

% Unfiltered Fourier and inverse transform, could also evaluate M directly
        Hz = 6;
        InvFF = abs(ifft(F));

        FFI(:,Hz) = InvFF;
        AM(Hz,PD) = (max(InvFF) - min(InvFF)) /(max(InvFF) + min(InvFF))*100;
end

% Display to screen
display(N)
display(FilterIndex)
display(CutOffHz)
display(FracMeas)
display(AM)

myformat = '%6.0f, %6.1f, %6.1f, %6.1f, %6.1f\r\n';

for n = 1:5;      % Prints filtered amplitude modulation data to output file

        newData = [CutOffHz(n), AM(n,1), AM(n,2),AM(n,3),AM(n,4)];
        fprintf(fidOut, myformat, newData);

end;

        % print unfiltered amplitude modulation data to file
        UnfilText = 'Unfiltered Percent Amp Mod';
```

```
    myformat = '%s, %6.1f, %6.1f, %6.1f, %6.1f\r\n';
    newData = [AM(6,1), AM(6,2),AM(6,3),AM(6,4)];
    fprintf(fidOut, myformat, UnfilText, newData);


for Nline = 14:21           % Moves input file ahead to line 22
    tline = fgets(fidIn);
end

for Nline = 22:23   % print header lines from rows 22 and 23
    tline = fgets(fidIn);
    strformat = '%s, %s, %s, %s, %s\r\n';
    fprintf(fidOut, '%s', tline);
end

% read in high frequency photometric data (flicker data)
RawData=csvread(fileIn,23,0,[23,0,N+22,4]);

% transpose and write high frequency photometric data (flicker data) to output file
RawDataT = transpose(RawData);
myformat = '%f, %f, %f, %f, %f \r\n';
    fprintf(fidOut, myformat, RawDataT);

fclose(fidOut);
fclose(fidIn);
```