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Residential Lighting

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Residential Lighting

2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team October 2014

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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 Residential Lighting. 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);
- Methodology and assumption used in the analyses energy and electricity demand impacts, cost-effectiveness, and environmental impacts (Section 4);
- Results of energy and electricity demand impacts analysis, Cost-effectiveness Analysis, and environmental impacts analysis (Section 5); and
- Proposed code change language (Section 6).

Scope of Code Change Proposal

The proposed Residential Lighting measure will affect the following code documents listed in Table 1.

Table 1: Scope of Code Change Proposal

Standards Requirements (see note below)	Compliance Option	Appendix	Modeling Algorithms	Simulation Engine	Forms
10-103 (M) 100.1 150.0(k) (M)	N/A	JA1 JA8 JA10	N/A	N/A	CF2R-LTG-01-E, CF2R-LTG-02-E

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

Measure Description

This Residential Lighting proposal would update Section 150.0(k) to require the use of high efficacy lighting in all residential new construction applications (single family residential, and low rise multifamily residential buildings and dwelling units within high rise multifamily buildings), and eliminate exceptions which allow low efficacy lighting in combination with controls. To accommodate this change, the definition of "high efficacy luminaire" for residential lighting is revised to include any fixture installed with high quality, high efficacy lamps, regardless of base type (including screw base lamps) as long as they comply with quality and high efficacy requirements in the revised Reference Joint Appendix 8 (JA8) (see sections 2.2.3 and 6.2 for more details on the revised JA8).

Recessed luminaires, currently the primary low efficacy luminaire type, would not be allowed to contain screw based lamps, and would be required to contain a JA8 compliant source.

High efficacy lighting has been required in the Standards since the adoption of the 2005 Standards, but low efficacy lighting has also been allowed in most room types in combination with certain controls. As a result, the majority of lighting wattage in new homes is low efficacy; something this proposal would change. The current structure of the Standards classifies fixtures as high efficacy or low efficacy regardless of the lamp installed the fixture. The proposed revision allows any fixture, other than screw based recessed luminaires, to qualify as a high efficacy fixture, as long as the fixture is installed with a qualifying JA8 compliant lamp. This proposal still considers legacy high efficacy sources (GU24 sockets containing CFLs, linear fluorescents, HID and induction lighting) as high efficacy without these sources having to comply with Appendix JA8 as revised by this proposal.

The mandatory controls in this proposal continue to require vacancy sensors in utility rooms, laundry rooms, and garages, as required by the current Standards and add a requirement that at least one bathroom luminaire be controlled by a vacancy sensor. Dimmers or vacancy controls are required on all luminaires except those that contain the legacy high efficacy light sources. Thus, outside of the bathroom lighting control requirements, the proposed lighting controls requirements are mostly the same.

The proposal allows for greater flexibility and choice for consumers, while delivering substantial energy savings. The life cycle cost benefit ratio is 6.6 due to the lower cost of screw based LED lamps. We estimate approximately 85 GWH/yr of savings for each year's new construction after adoption.

The trade-off with this approach is the risk that homeowners will remove high efficacy sources and replace them with low efficacy sources. Key to addressing this risk is the safeguards placed in JA8. The specifications in the revised JA8 require that light sources have the following characteristics:

- Color temperature and color rendering index similar to incandescent
- Dimmable and low flicker similar to incandescent
- Start time similar to incandescent
- Life of at least 15,000 operating hours, much better than most incandescent but achievable by most high efficacy sources

- For light sources placed in enclosed or recessed luminaires, long lamp life at high temperatures, has historically been a problem for CFLs and recently LEDs
- The lamps are labeled as being JA8 compliant and lamps that cannot pass an elevated temperature test are labeled as such.

Thus designers and homebuilders can benefit from greater design flexibility and the lower luminaire cost associated with screw based luminaires as long as they put Appendix JA8 compliant lamps in these luminaires. The consumer receives a high quality light source that does not need new lamps for time periods in excess of 10 years that is extremely cost-effective. In addition, this approach increases the market demand for approximately 3 million additional high efficacy, high quality lamps per year. This will likely increase economies of scale and downward price pressure on these light sources.

Starting in the 2005 Title 24 standards, up to 50% of the calculated wattage in the kitchen was allowed to be low efficacy. Starting in the 2008 standards an additional low efficacy wattage credit was added to increase allowable wattage of low efficacy lighting in the kitchen. The calculation of installed wattage of low efficacy sources is not straight forward as it includes not only the wattage of the source but potentially the diameter of recessed cans etc. This proposal removes all these calculation procedures and requires that all sources are either the traditional high efficacy sources (pin-based fluorescent, induction, HID, etc.) or the sources are labeled "T-24 JA8 compliant." This makes inspection and compliance much easier.

Since more expensive screw based high efficacy lamps complying with JA8 can be easily replaced with less expensive low efficacy lamps, one worst case scenario is that between the time of inspection and the time that the first homeowner takes possession of the house, the high efficacy lamps are replaced with low efficacy lamps. This proposal addresses this concern by requiring that the designer include a luminaire and lamp schedule with the construction documents that are to be left at the home and given to the buyer so the new homeowner is aware of the light sources they are legally entitled to upon receipt of the new home. This luminaire schedule is less onerous to fill out than the existing wattage calculations.

Section 2 of this report provides detailed information about the code change proposal including Section 2.2, which 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 6: Scope of Code Change Proposal
- Table 7: Sections of Standards Impacted by Proposed Code Change
- Table 8: Appendices Impacted by Proposed Code Change

Detailed proposed changes to the text of the building efficiency standards, the reference appendices, and forms are given in ***Section 6 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.

Market Analysis and Regulatory Impact Assessment

Under the proposed revision to allow JA8 compliant sources to qualify as high efficacy luminaires, any fixture type, other than screw based recessed luminaires, would be considered high efficacy if it is installed with a source that meets the requirements established in the revised JA8. This would effectively allow any fixture on the market, other than screw based recessed luminaires, to qualify as high efficacy, greatly expanding the choices available to consumers.

Residential measures are considered to have a 30-year life. Although fixtures may last 30 years, fixture components and lamps have shorter life. For the purpose of this analysis, lamp life and ballast life are based on industry standards, and typical product warranties. There is a chance that some JA8 compliant sources installed in otherwise low efficacy fixtures could be replaced with low efficacy sources. However, the long life and high quality of the installed lamps is expected to discourage early replacement in all but a few isolated cases.

This proposal is cost effective over the 30-year period of analysis.

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

- **Impact on Voluntary Energy Efficiency Programs:** There should be none because this proposal only applies to new construction. The required labelling could be used by EE programs to incentivize LED lamps. But the proposal could be the misinterpretation by the CPUC ED consultants that this proposal establishes a new "to code" baseline. This would incorrectly eliminate all of the savings claimed by EE programs for screw based LED lamps. The CEC will need to communicate with CPUC the exact scope of this proposed change to Title 24.
- **Impact on builders:** This proposal is expected to have little impact on builders. Rather than having multiple room type requirements, the Standards will have a single overarching requirement for all rooms. The luminaire and lamp schedule required to with the construction documents will need to be left with the dwelling.
- **Impact on building designers:** The proposal simplifies the standards by eliminating most room type requirements, and the addition of the JA8 compliant sources as high efficacy fixtures will allow for greater flexibility in specifications to meet the requirements.
- **Impact on occupational safety and health:** The proposed code change is not expected to have an impact on occupational safety and health.
- **Impact on building owners and occupants:** The proposal provides high efficiency lighting for residential owners and occupants, while preserving variety and choice in the fixtures available for residential applications.
- **Impact on equipment retailers (including manufacturers and distributors):** The proposal is expected to have minimal impact on fixture sales. High efficacy fixtures are already available on the market, and the proposal will essentially allow the installation of any fixture currently on the market, other than screw based recessed luminaires, as long as that fixture is installed with JA8 compliant sources. The proposal will dramatically reduce sales of screw based recessed luminaires for new construction, which are no

longer allowed under the proposal. The proposed measures may also accelerate market adoption of longer life high efficacy lamps, resulting in slowing sales for incandescent and other low efficacy lamp sources. Revised JA8 requirements may also increase the product testing and labeling burden on manufacturers, but manufacturers are already routinely testing their products to meet various standards, and the proposed measures primarily reference existing testing protocols. Most of the testing requirements match those in the ENERGY STAR Product Specification for Lamps (Version 1.0) that take effect in September 2014.

- **Impact on energy consultants:** The proposal is not expected to have a significant impact on energy consultants but is expected to slightly reduce work load as lighting wattage is no longer calculated and requirements are streamlined.
- **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 but the code changes is expected to slightly reduce work load as lighting wattage is no longer calculated and requirements are streamlined..
- **Statewide Employment Impacts:** slight increase in employment due to wealth generation. Incremental cost is substantially less than energy cost savings resulting in added disposable income to California homeowners. This added income allows residents to purchase more goods and services.
- **Impacts on the creation or elimination of businesses in California:** Slight positive impact, see discussion of employment impacts above.
- **Impacts on the potential advantages or disadvantages to California businesses:** Negligible outside employment impacts described above.
- **Impacts on the potential increase or decrease of investments in California:** Potential to increase investments in California related to LED (light emitting diode) technology as this standard accelerates the uptake of this technology.
- **Impacts on incentives for innovations in products, materials or processes:** Increased flexibility of the energy code while requiring a significant expansion in high efficacy technologies creates a market opportunity for innovative products.
- **Impacts on the State General Fund, Special Funds and local government:** No impacts outside of reduced enforcement costs (see below).
- **Cost of enforcement to State Government and local governments:** Slight reduction in enforcement costs as proposal is easier to enforce and eliminates wattage calculations required by the current code.
- **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 Homeowners (including potential first time home owners):** This proposal is cost effective for the homeowner. As a result the combined mortgage costs and utility bill payment for the homeowner are less if the measure is incorporated into all new homes.

- **Impact on Renters:** This proposal is advantageous to renters as it reduces the cost of utilities which are typically paid 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

Table 2 shows the estimated energy savings over the first twelve months of implementation of the Residential Lighting proposal.

Table 2: Estimated First Year Energy Savings

	Electricity Savings (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	TDV Electricity Savings (Million kBTU)	TDV Natural Gas Savings (Million kBTU)
Residential Lighting	85.0	-	N/A	1,839.7	N/A

Section 4.6.1 discusses the methodology and Section 5.1.1 shows the results for the per unit energy impact analysis.

Cost-effectiveness

Results per unit Cost-effectiveness Analyses are presented in Table 3. The TDV Energy Costs Savings are the present valued energy cost savings over the 30-year period of analysis using CEC's TDV methodology. The Total Incremental Cost represents the incremental initial construction and maintenance costs of the proposed measure relative to existing conditions (current minimally compliant construction practice when there are existing Title 24 Standards). Costs incurred in the future (such as periodic maintenance costs or replacement costs) are discounted by a 3 percent real discount rate, per CEC's LCC Methodology. The Benefit to Cost (B/C) Ratio is the incremental TDV Energy Costs Savings divided by the Total Incremental Costs. When the B/C ratio is greater than 1.0, the added cost of the measure is more than offset by the discounted energy cost savings and the measure is deemed to be cost effective. For a detailed description of the Cost-effectiveness Methodology see Section 4.7 of this report.

The change in Lifecycle Cost is negative (present valued costs are reduced) and the benefit to cost ratio is at least 6.6 for all climate zones.

Table 3: Cost-effectiveness Summary per Home[1]

Climate Zone	Benefit: TDV Energy Cost Savings[2] (2017 PV$)	Benefit: Present Valued Net Maintenance Cost Savings[3] (2017 PV$)	Cost: Incremental First Cost[4] (2017 PV$)	Change in Lifecycle Cost[5] (2017 PV$)	Planned Benefit to Cost (B/C) Ratio[6]
Climate Zone 1	$2,381	$132	$365	-$2,148	6.9
Climate Zone 2	$2,379	$132	$365	-$2,146	6.9
Climate Zone 3	$2,373	$132	$365	-$2,140	6.9
Climate Zone 4	$2,378	$132	$365	-$2,145	6.9
Climate Zone 5	$2,370	$132	$365	-$2,137	6.9
Climate Zone 6	$2,308	$132	$365	-$2,075	6.7
Climate Zone 7	$2,416	$132	$365	-$2,183	7.0
Climate Zone 8	$2,323	$132	$365	-$2,090	6.7
Climate Zone 9	$2,293	$132	$365	-$2,060	6.6
Climate Zone 10	$2,284	$132	$365	-$2,051	6.6
Climate Zone 11	$2,394	$132	$365	-$2,161	6.9
Climate Zone 12	$2,396	$132	$365	-$2,163	6.9
Climate Zone 13	$2,384	$132	$365	-$2,151	6.9
Climate Zone 14	$2,290	$132	$365	-$2,057	6.6
Climate Zone 15	$2,301	$132	$365	-$2,068	6.7
Climate Zone 16	$2,279	$132	$365	-$2,046	6.6

1. Relative to existing conditions. All cost values presented in 2017 dollars.
2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta TDV\$ = \Delta TDV\$E + \Delta TDV\$G$.
3. Because the proposed measure results in present valued maintenance savings, maintenance costs are part of the benefits side of the B/C ratio calculation; MS = - ΔMC. Maintenance savings is the negative value of the increase in present valued maintenance costs.
4. Total incremental cost equals only the incremental construction cost (post adoption); $\Delta C = \Delta CI_{PA}$.
5. Negative values indicate the measure is cost effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta LCC = \Delta C - \Delta TDV\$$
6. The benefit to cost ratio is the TDV energy costs savings and the present valued maintenance cost savings divided by the total incremental costs; $B/C = (\Delta TDV\$ + MS) \div \Delta C$. The measure is cost effective if the B/C ratio is greater than 1.0.

Section 4.7 discusses the methodology and Section 5.2 shows the results of the Cost Effectiveness Analysis.

Greenhouse Gas and Water Related Impacts

For more a detailed and extensive analysis of the possible environmental impacts from the implementation of the proposed measure, please refer to Section 5.3 of this report.

Greenhouse Gas Impacts

Table 4 presents the estimated avoided greenhouse gas (GHG) emissions of the proposed code change for the first year the standards are in effect. Assumptions used in developing the GHG savings are provided in Section 4.8.1 on page 43 of this report.

The monetary value of avoided GHG emissions is included in TDV cost factors (TDV $) and is thus included in the Cost-effectiveness Analysis prepared for this report.

Table 4: Estimated Statewide Greenhouse Gas Emissions Impacts

	Avoided GHG Emissions ($MTCO_2e/yr$)
Residential Lighting	29,970

Section 4.8.1 discusses the methodology and Section 5.3.1 shows the results of the greenhouse gas emission impacts analysis.

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.

Field Verification and Diagnostic Testing

As with the existing residential lighting Standards, this measure will require field verification to confirm that the installed lighting equipment complies with the requirements. This measure will require modifications to the existing field verification, to include verification of JA8 compliant sources in fixtures that do not already qualify as high efficacy. JA8 compliant lamps will be required to be labeled as meeting the JA8 requirements in order to ease verification by building inspectors.

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 a code change proposal for Residential Lighting. 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 summarizes key issues that the Statewide CASE Team addressed during the CASE development process, including issues discussed during a public stakeholder meeting that the Statewide CASE Team hosted in May 2014.

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.

Section 4 describes the methodology and approach the Statewide CASE Team used to estimate energy, demand, costs, and environmental impacts. Key assumptions used in the analyses can be also found in Section 4.

Results from the energy, demand, costs, and environmental impacts analysis are presented in Section 5. The Statewide CASE Team calculated energy, demand, and environmental impacts using two metrics: (1) per unit, and (2) statewide impacts during the first year buildings complying with the 2016 Title 24 Standards are in operation. Time Dependent Valuation (TDV) energy impacts, which accounts for the higher value of peak savings, are presented for the first year both per unit and statewide. The incremental costs, relative to existing conditions are presented as are present value of year TDV energy cost savings and the overall cost impacts over the year period of analysis.

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

2.1.1 Measure Description

The Residential Lighting measure is intended to update Section 150.0(k) to require the use of high efficacy lighting in all residential new construction applications, eliminating exceptions allowing low efficacy lighting in combination with controls.

Details of the proposed revisions include the following:

- Expand the definition of "high efficacy luminaire" to include all light fixtures, other than screw based recessed luminaires, that have a high quality high efficacy lamp (that meets the requirements of the revised JA8) installed at the time of new construction. This expanded definition of high efficacy luminaire would include those light fixtures that contain lamp bases previously defined as "low efficacy," and that are traditionally associated with incandescent lighting (Edison screw base, candelabra screw base, bi-pin base for multi-faceted reflector (MR) lamps, etc.). At time of inspection, these fixtures must contain a labeled JA8 compliant lamp. The high quality lamps would meet revised JA8 requirements that address color rendering, color temperature, dimmability, lifetime, warranty, and low flicker operation at full and low output, power factor, start time, and audible noise. The high quality lamp specification is required to ensure that most homeowners will want to keep the high quality high efficacy lamps.
- The home builder must provide to the new homeowner a luminaire schedule including lamp specifications that identify the luminaires and lamps that the homeowner is entitled to receive with their new home.
- Recessed luminaires shall not have a screw base, and shall have a JA8 compliant source. Recessed luminaires with any base other than screw base will still be allowed as long the source installed meets the requirements in JA8.
- Require vacancy sensor control for at least one luminaire in each bathroom, laundry room, utility room, and garage, to maintain consistency with current control requirements.
- All screw based fixtures will be required to be controlled by a dimmer or vacancy sensor, and all phase cut dimmers shall comply with NEMA SSL 7A to ensure compatibility with LED lamps.

2.1.2 Measure History

Residential lighting measures are well established in the Standards. Although residential lighting is already covered by the Standards, advances in lighting technology and performance provide opportunities for additional energy savings. Several proposed measures in the 2013 CASE process were not adopted in the Standards, providing even greater opportunity for energy savings potential with the 2016 Standards.

For the sake of simplicity, the residential lighting standards define residential luminaires as either "high efficacy" or "low efficacy." High efficacy luminaires are those that are manufactured, designed and rated for use with lighting technologies defined by the Commission as high efficacy sources. Examples of high efficacy sources include pin-based linear or compact fluorescent fixtures, GU-24 sockets rated for CFL or LED lamps, and LED fixtures that have been certified to the Commission to comply with the revised JA8. Low efficacy luminaires include any standard screw base fixtures, line-voltage or low-voltage lamp holders capable of operating incandescent lamps, or LED fixtures that have not been certified to the Commission. High efficacy lighting, as defined in the Standards, has been determined to be cost effective in all residential applications since the adoption of the 2005 Standards. At the same time, typical costs of high efficacy lighting products have decreased, while the variety of high efficacy products available and the quality of high efficacy lighting has increased.

Under the current 2013 Title 24, part 6 Building Efficiency Standards, any fixture that is categorized as "low efficacy" will always be considered a low efficacy fixture, no matter what type of lamp is installed in the fixture, despite the availability of CFL and LED replacement lamps for most low efficacy fixture types. This is due to the risk of "snap back," where consumers revert to low efficacy sources at end of life or due to dissatisfaction with the high efficacy products. However, the long life of LED lamps raises the possibility that individual lamps could last for decades in residential applications. Similarly, quality improvements make LED lamp performance more similar to traditional incandescent lamps than most CFL products. If JA8 compliant products, such as LED, provide high quality illumination that consumers expect, it is unlikely that they will revert to less efficient technologies.

Appendix JA8 has been upgraded to cover more features of customer amenity so that the State has greater assurance that high efficacy lamps placed in traditionally low efficacy sockets stay in place. Thus testing and performance requirements have been added for start time, high temperature light output, flicker, longevity, lumen maintenance, etc. Many of the requirements and test methods proposed in this CASE Report are based on requirements that already exist in the ENERGY STAR Version 1 Lamps Specification adopted by the Environmental Protection Agency in 2013 (EPA 2013). Several other proposed requirements are based on the Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification,[1] approved by the CEC in December 2012 for use by California's residential rebate programs (CEC). The requirements proposed in this CASE initiative closely mirror another CASE initiative developed by the Statewide CASE Team in 2013 in support of Title 20 appliance standards for LED replacement lamps (PG&E and SDG&E). These three proceedings (ENERGY STAR Lamps Specification, CEC Voluntary Specification, and the Title 20 LED Lamp CASE Proposal) contain much of the background information behind the requirements proposed here. Specifically, much of the analysis and rationale behind the proposed requirements in this CASE initiative can be found in Section 5 of the Title 20 LED Lamp Quality CASE Initiative (PG&E and SDG&E).

In addition, existing Federal and Title 20 general service lamp (GSL) standards will phase-out standard incandescent lamps shortly after the next version of these Standards go into effect (currently scheduled for Jan. 2017). In most typical residential applications, current low

[1] http://www.energy.ca.gov/2012publications/CEC-400-2012-016/CEC-400-2012-016-SF.pdf

efficacy A-lamp technologies will no longer be available, further reducing the likelihood of low efficacy products replacing high efficacy lamps.

2.1.3 Existing Standards

Residential lighting is already regulated in the Standards. Although the existing Standards contain many details pertaining to residential lighting, there are two primary features that regulate interior lighting in residential units:

- Definitions of "high efficacy" and "low efficacy" luminaires for residential lighting
- Room type requirements for permanently installed lighting in residential units

The definitions of "high efficacy" and "low efficacy" sources, as established in Table 150.0-A of the Standards, are summarized below in Table 5.

Table 5: Existing High Efficacy and Low Efficacy Light Source Definitions

High Efficacy Light Sources	Low Efficacy Light Sources
1. Pin-based linear or compact fluorescent lamps 2. Pulse-start metal halide lamps 3. High pressure sodium lamps 4. GU-24 sockets rated for LED lamps 5. GU-24 sockets rated for compact fluorescent lamps 6. LED light sources that have been certified to the Commission as high efficacy in accordance with Reference Joint Appendix JA8. 7. Luminaire housings rated by the manufacturer for use with only LED light engines 8. Induction lamps	1. Line-voltage lamp holders for incandescent lamps of any type 2. Low voltage lamp holders for incandescent lamps of any type 3. High efficacy lamps installed in low efficacy luminaires 4. Mercury vapor lamps 5. Track lighting or other similar flexible lighting systems 6. LED light sources that have not been certified to the Commission as high efficacy 7. Modular lighting systems that allow conversion between high efficacy and low efficacy sources 8. Electrical boxes finished with a blank cover

Using these "high efficacy" and "low efficacy" definitions, the Standards establish mandatory requirements for hardwired lighting in residential room types. The room type requirements, in Section 150.0(k), are summarized as follows:

- Kitchens: At least 50% of the total rated wattage of permanently installed lighting must be high efficacy. Up to 50 watts for homes less than or equal to 2,500 square feet, or 100 watts for homes greater than 2,500 square feet may be exempt from the 50% high efficacy requirement if they are controlled by either vacancy sensors or dimmers.
- Bathrooms: Each bathroom must have at least one high efficacy luminaire. All other luminaires must be high efficacy, or controlled by vacancy sensor.
- Garages, Laundry Rooms, and Utility Rooms: All permanently installed lighting in these spaces must be high efficacy and controlled by vacancy sensors.
- All other space types: Lighting in spaces other than those listed above must be high efficacy, or controlled by either dimmers or vacancy sensors.

2.1.4 Alignment with Zero Net Energy Goals

Increasing energy efficiency in residential construction is crucial to meeting the zero net energy goals. Requiring all permanently installed residential lighting to be high efficacy has the potential to reduce residential lighting energy use (kWh/year) by an average of 51% per home.

2.1.5 Relationship to Other Title 24 Measures

The proposed residential lighting measure does not directly impact any other measures.

2.2 Summary of Changes to Code Documents

The sections below provide a summary of how each Title 24 document will be modified by the proposed change. See Section 6 of this report for detailed proposed revisions to code language.

2.2.1 Catalogue of Proposed Changes

Scope

Table 6 identifies the scope of the code change proposal. This measure will impact the following areas (marked by a "Yes").

Table 6: Scope of Code Change Proposal

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

Standards

The proposed code change will apply only to new low-rise residential construction and additions to low-rise residential construction by modifying the sections of the California Building Energy Efficiency Standards (Title 24, Part 6) identified in Table 7.

Table 7: Sections of Standards Impacted by Proposed Code Change

Title 24, Part 6 Section Number	Section Title	Mandatory (M) Prescriptive (Ps) Performance (Pm)	Modify Existing (E) New Section (N)
10-103(b)1	Compliance Information	M	E
100.1	Definitions and Rules of Construction	M	E
150.0(k)	Residential Lighting	M	E
Appendix 1-A	Standards and Documents Referenced in the Energy Efficiency Regulations	M	E

Appendices

The proposed code change will modify the sections of the indicated appendices presented in Table 8. If an appendix is not listed, then the proposed code change is not expected to have an effect on that appendix.

Table 8: Appendices Impacted by Proposed Code Change

APPENDIX NAME		
Section Number	**Section Title**	**Modify Existing (E) New Section (N)**
JA1	Glossary	E
JA8	Qualification Requirements for Residential Luminaires Using LED Light Source	E
JA10	Test Method for Measuring Flicker of Lighting Systems and Reporting Requirements	N

Residential Alternative Calculation Method (ACM) Reference Manual

Since the proposed code change modifies a mandatory requirement, it will not require any modifications to the Residential Alternative Calculation Method References.

Simulation Engine Adaptations

Residential Lighting requirements are modeled as fixed values in the current simulation engine. Changes to the lighting defaults in simulation engine are required as these defaults impact the HERS rating and more importantly impact the HERS score or the Design Rating used to mark progress towards the ZNE (zero net energy) goal.

2.2.2 Standards Change Summary

This proposal would modify the following sections of the Building Energy Efficiency standards as shown below. See Section 6.1 of this report for the detailed proposed revisions to the standards language.

Changes in Mandatory Requirements [Section 150.0(k)]

Section 150.0 is for any newly constructed low-rise residential building or addition to an existing building. The residential lighting requirements are contained Section 150.0(k) “Residential Lighting”. Currently these lighting requirements require the calculation of lighting power to assess compliance with residential lighting code requirements, and this calculation references Section 130.0(c). If the current proposal is adopted, the residential lighting requirements would no longer calculate lighting wattage and thus no longer reference Section 130.0(c). However the nonresidential lighting standards would still be referencing Section 130.0.

This proposal recommends the following changes to Section 150.0(k):

- High efficacy lighting is required in all room types, eliminating allowances for low efficacy lighting combined with certain controls and removing allowances for a percentage of kitchen lighting power being low efficacy and an additional kitchen wattage credit based on lighting controls in the kitchen.
- Eliminate cabinet lighting wattage requirements per linear foot of illuminated cabinet length.

- The definition of "high efficacy" luminaire for residential use is expanded to include any luminaire, other than screw based recessed luminaires, installed with a high quality high efficacy lamp meeting the revised JA8 requirements.
- Light sources in recessed luminaires must meet the elevated temperature light output ratio and lumen maintenance requirements.
- Phase cut dimmers are required to comply with NEMA SSL 7A so the dimmers are more likely compatible with solid state lighting.
- At least one luminaire in each bathroom must be controlled by a vacancy sensor
- Vacancy sensors or dimmers are required for all luminaires containing JA8 compliant light sources except those in hallways or in closets less than 70 square feet.

2.2.3 Standards Reference Appendices Change Summary

This proposal would modify the following sections of the Standards Appendices as shown below. See ***Section 6.2*** of this report for the detailed proposed revisions to the text of the reference appendices.

Reference Joint Appendix JA1

Primary proposed changes to this appendix are to call out the full reference, including publication or adoption year, of the test methods cited in the modified Appendix JA8 and the newly added Appendix JA10. Many of these test methods are developed by the Illuminating Engineering Society (IES) and ENERGY STAR. Definitions were also added for CCT and CRI.

Reference Joint Appendix JA8

Originally, Appendix JA8 was developed to define the efficacy and quality requirements for LED sources only. The proposal would substantially modify JA8 such that it will be technology neutral and specify the requirements for any light source that can comply with the requirements as a "high quality, high efficacy" light source. Thus it is retitled and reformatted to be technology neutral; the proposal would change the title from "Qualification Requirements for Residential Luminaires Using LED Light Sources" to "Qualification Requirements for Residential Luminaires Using High Quality, High Efficacy Light Sources." Sources would be eligible to comply with JA8 regardless of base type or source technology. The proposal reformats JA8 to include coverage of replacement lamps in addition to light sources that are integral to luminaires and light engines.

Some of the JA8 requirements in this proposal are identical to the existing 2013 Title 24 Reference Joint Appendix JA8 requirements, including the following:

- Minimum CRI of 90
- Laboratories conducting the testing must be accredited by the National Voluntary Laboratory Accreditation Program (NVLAP)
- Complying products are labeled with a permanent marking on the light source or light source housing with their: watts, lumens, CCT, and CRI.

The proposal references industry-standard test methods such those published by the Illuminating Engineering Society and the U.S. Department of Energy (DOE), wherever possible. The Statewide CASE Team is also aware that DOE is currently developing a Federal Test Procedure for LED lamps that will include measurement protocol for luminous flux, input power, efficacy, correlated color temperature, color rendering index, and lamp life. The Federal Test Procedure may be finalized in late 2014 or early 2015. The Title 24 proposal may choose to reference some of the Federal Test Procedure if it is completed before the end of the Title 24 rulemaking.

This proposal also leverages the ENERGY STAR program requirements for lamps, which are primarily focused on LED and CFL integral lamps. This proposal references several ENERGY STAR test methods and adds the phrase "notwithstanding scope" to indicate that other light sources can use these test methods even if these sources are not included in the scope of the test method. In this manner the high efficacy, high quality light source standard is technology agnostic; one could comply with an advanced incandescent or other technology as long as it meets the performance requirements of the JA8 Qualification Requirements. Using the ENERGY STAR test methods and many of the ENERGY STAR criteria allows many manufacturers to comply using their ENERGY STAR certified products. It also minimizes testing burden for manufacturers. Though many of the proposed JA8 requirements are based on the ENERGY STAR Lamps V1.0 Specification (which was recently modified slightly to V1.1), in some cases they differ from the ENERGY STAR requirements. All of these metrics and the specifics of the proposed requirements are illustrated in Table 9 and explained in greater detail below.

Table 9: Comparison of ENERGY STAR Lamp Spec v1.1 and Proposed 2016 Title 24 JA-8

Metric	ENERGY STAR Lamps Spec v1.1	Proposed JA8
Applicable sources	Integral LED lamps. Excluded: light engines, luminaire integrated sources all other sources The scope is limited to lamps with integrated ballasts and drivers intended to be connected to the electric power grid with the following ANSI standard base types: E26, E26d, E17, E11, E12, GU10, GU24, GU5.3, and GX5.3. Lamps with rated nominal operating voltages of 120, 240 or 277 VAC, or 12 or 24 VAC or VDC.	Any source certified to the Commission to be a high efficacy, high quality source
Efficacy (lm/W)	Varies at least 45 – 60 lm/W depending upon lamp type and wattage.	≥45 lm/W for all light sources
Power Factor	≥0.7	≥0.9
Color Appearance (CCT / Duv)	2700 - 6500K allowed, 0.006 Duv (7 MacAdam Step Bins)	Must be capable of providing ≤3,000K, with .0033 Duv (~4 step color bins). Lamps with GU-24 bases exempted
Color Rendering (CRI / R9)	≥80 / ≥0	≥90 / ≥50
Dimmability	Not Required	Required

Metric	ENERGY STAR Lamps Spec v1.1	Proposed JA8
Dimmer Compatibility	No Requirement	NEMA SSL7A required for sources designed for phase control
Flicker	All lamps must operate at 120Hz or greater. Additional testing only required for dimming lamps. Data not filtered with respect to frequency.	Low flicker performance required. Data filtered (200 Hz low-pass)
Noise	Lamps marketed as dimmable only: ≤ 24 dBA at 1 meter or less	All sources: ≤ 24 dBA at 1 meter or less
Start Time	≤1 sec	≤0.3 sec.
Rated life	Decorative lamps ≥ 15,000 hours All other ≥ 25,000	All sources ≥ 15,000 hours
Lumen maintenance	Decorative lamps ≥86.7%@6,000 hr All other ≥91.8%@6,000 hr	Omni directional sources < 10 W, light sources integral to the luminaire and sources labelled "not for use in recessed fixtures" or "not for use in enclosed fixtures" lumen maintenance ≥86.7%@6,000 hr Integral fixtures must have 12" of R-38 fiberglass insulation on sides and top of fixture
Warranty	≥3 yrs	≥5 yrs
Elevated temperature light output ratio	Required for directional lamps: ≥ 90% of initial light output at 25°C	No requirement
Elevated temperature Lumen maintenance	Required for lamps in recessed and enclosed fixtures rated ≥ 10 Watts: Decorative lamps ≥86.7%@6,000 hr All other ≥91.8%@6,000 hr	Required for lamps in recessed and enclosed fixtures (except omni-directional lamps under 10W: All sources ≥86.7%@6,000 hr Test A for recessed fixtures must have 12" of R-38 fiberglass insulation on sides and top of fixture
Product labelling	Manufacturer or brand, Model No or SKU, CCT, Watts, lumens, beam angle (as applicable), exception language: "not for use in enclosed fixtures" or "not for use in recessed fixtures"	"CA T-24 JA8 Compliant," CCT, Watts, lumens, CRI, Date of Manufacture, exception language: "not for use in enclosed fixtures" or "not for use in recessed fixtures"

This proposal largely builds upon the Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification which is designed to provide guidance on *"the appropriate level of performance necessary to achieve a light-emitting diode (LED) lighting product that would meet or exceed customer expectations for general purpose lighting in residences"* (CEC 2012a). This voluntary quality specification exceeds the stringency of the ENERGY STAR lamp specifications in some areas including color accuracy, color consistency with traditional light sources in residences, and other performance related features such as dimmability and power factor. The California Public Utilities Commission has directed the California investor-owned utilities to propose rebates for screw-based LEDs products that meet the Voluntary CA Quality LED Specification.[2] Thus there is an effort underway by the IOU energy efficiency programs to transform the market for LED screw based lamps to meet these performance specifications. The rationale for this quality specification is that sources with higher color quality and improved performance in residential applications will be more likely to be retained in residential sockets over the long term which is also a goal of this proposal.

The quality elements of this Title 24 proposal are also closely aligned with many of the requirements in the Title 20 appliance standards proposal currently being considered by the CEC for integral LED replacement lamps. That proposal, originally submitted to the CEC as a Title 20 CASE Report in July 2013 (PG&E/SDG&E 2013), contains significant research and analysis of the quality and performance metrics proposed, including assessments of consumer preference research where available and analysis of product performance test data and the feasibility of each requirement. Specifically, this Title 24 proposal leans heavily on the content developed in Section 5, Energy Usage and Product Quality, of that 2013 Title 20 CASE Report.

To complement the Title 20 2013 CASE Report, the following section also provides explanations and background for all of the quality parameters being proposed for the revised JA8:

- **Color Temperature:** Correlated color temperature and Duv (deviation from black body locus): Source must be capable of providing warm white light with a color point that is near the black body locus in the 1976 CIE color space. Specifically, the source must be capable of providing light at a correlated color temperature (CCT) of 3000 Kelvin or lower, and with Duv values within 0.0033 of the black body locus (roughly a 4 MacAdam Step distance) (areas inside of dotted lines in Figure 1). GU-24 lamps are exempted from the CCT requirement.

  The existing JA8 standard allows a CCT between 2,700K and 4,000K for indoor sources and a CCT between 2,700K and 5,000K for outdoor sources. The change to require all sources to be *capable* of providing CCT at 3,000 Kelvin or lower allowed manufacturers to certify color changing lamps (e.g. those that offer a range of color temperatures at full output, and/or those that drop their color temperature when they dim) and to better align with the CA LED Quality Specification that is the basis of utility LED incentive programs. These color temperatures were selected to match incandescent light sources, which typically provide CCT of 2,700-2,800K and which have been the predominant light source in residential applications for many decades.

[2] CPUC Decision 12-05-015

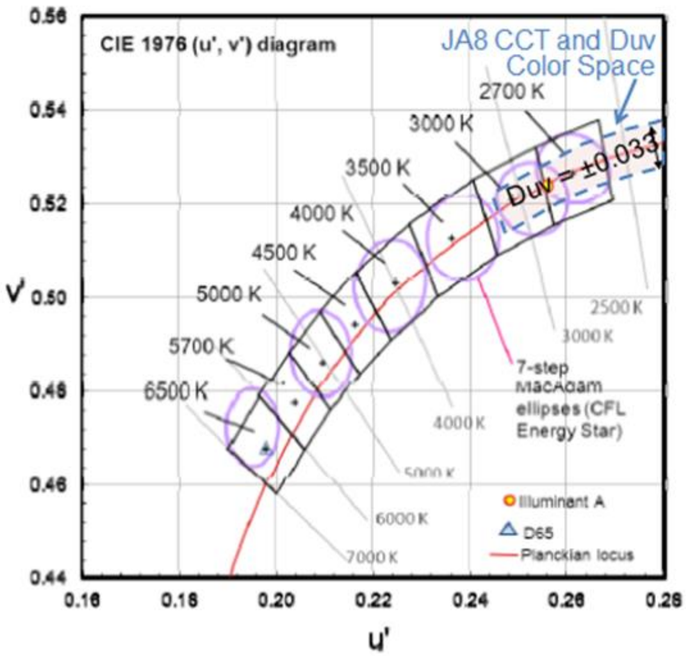

Figure 1: JA8 CCT and Duv Chromaticity Proposal Plotted on CIE (u'v') chromaticity diagram

Source: Original Image from ANSI C78.377-2008, edited by Statewide CASE Team for illustrative purposes.

However, this proposal recognizes the need for light sources of other color temperatures, whether it is to accommodate the limitations of some light sources or for personal preference. Legacy high efficacy sources (linear fluorescent, pin-based CFL, induction, HID, etc.) do not have to comply with JA8 at all so high CCT products are acceptable with any of these technologies (as are product with larger Duv values). This proposal also allows GU-24 lamps to be any color temperature and be certified as compliant with JA8; it also allows color changing lamps provided they're *capable* of providing 2,700K light. This exception for GU-24 lamps and the allowance for color changing lamps provide alternatives for designers who want to use different color temperatures (e.g. 4,000K-5,000K). In addition, since this proposal allows all base types, if the consumer wants a different color they can choose a different color by purchasing a new lamp without having to replace an entire luminaire. Thus there are many color options within this proposal while creating a framework for most JA8 qualified lamps to be of a familiar, warm, incandescent-like color temperature.

In terms of color consistency and deviation from the black body locus the Voluntary California LED Quality Specification requires that *"LED lamps shall fall within a 4-step Macadam ellipse of the 2700K or 3000K points on the Planckian Locus."* The Voluntary Quality Specification selected the 4-step ellipse as that was readily achievable with LED sources at the time of the study. Additionally, the ANSI specification that has historically defined color targets for fluorescent and LED products (ANSI C78.377) introduced 4-step target color bins in its last revision and is continuing in that direction for its next (upcoming) revision. An LRC (2004) study on white LED sources found that light sources within a four-step MacAdam ellipse were perceived as being the same color sources when looking at reflected light from these sources. If one is directly looking at the sources, instead of reflected light, then sources within a two-step MacAdam ellipse were perceived as being the same color. This proposal recommends limiting Duv deviations from the black body locus to no more than 0.0033 Duv (~4 MAcAdam steps). (This requirement will only apply to lamps providing CCT of 3000K or lower.) However, if future research and discussions with stakeholders reveal that a tighter color tolerance (for example a 2-step tolerance) is appropriate, this should be considered for Title 24. Additionally, the CEC is currently considering this aspect of the requirement in the upcoming Title 20 rulemaking for LED lamps, and we recommend alignment with the Title 20 LED quality standard. Feedback from stakeholders in both the Title 20 and Title 24 proceedings will be instrumental in informing decisions on this metric.

- **Color Rendering:** Color rendering index must be at least 90 CRI and R9 value (deep red hues) must be at least 50. This responds to complaints of high efficacy sources having poor color rendering. The CRI metric does not capture rendering of red well so the addition of the R9 requirement helps assure that sources will provide sufficient red content and that consumers will be satisfied with the light sources. High CRI and high R9 are important for accurately rendering skin tones, wood, food, and other natural materials. In addition to the justification provided in previous CEC reports and the Title 20 CASE report submitted to the CEC on this topic, a more recent study led by the Pennsylvania State University compared lower CRI to high CRI LED lighting among test subjects and found that there is a strong preference for the improved CRI spectrum in terms of rendering colors, especially for neutral and warm tones (e.g., reds, skin) and in terms of rendering white objects such as white shirts and teeth (LRT 2014). (CFLs, many of which provide 80 CRI, have been perceived historically as providing distorted, harsh, or "unfriendly" light that makes people and foods appear sickly. Though consumers are not able to define this as a deficiency in CRI (because they don't know what CRI is), inadequate color rendering is a big part of the reason CFLs have this reputation. This requirement is also in the Voluntary CA LED Quality Specification and the Title 20 LED lamps CASE proposal.
- **Dimmability:** All JA8 sources must be dimmable. This addresses the concern of lamp failure, flicker, and/or otherwise poor performance when non-dimmable lamps are installed on dimmers, and also responds to significant consumer dissatisfaction that resulted from non-dimmable CFLs. As proposed, Section 150.0(k)2K would require that all JA8 sources be placed on vacancy sensors or dimmers; as a result there is a high likelihood that the sources will be paired with dimmers, so it is imperative that they be dimmable.
- **Low-end Dimming:** Light sources must be able to dim to 10% of full light output. ENERGY STAR requires that lamps that are labeled as dimmable be able to dim down to at least 20% of light output. The 10% minimum dimming level in JA8 is consistent with the nonresidential mandatory dimming requirements for LED and incandescent sources as required by Section 130.1(b) and specified in Table 130.1-A "Multi-Level Lighting Controls and Uniformity Requirements" in the 2013 version of Title 24. (Other sources in this table, such as linear fluorescent, have other minimum dimmed level requirements identified; however, these other sources are defined as high efficacy sources so they do not need to meet JA8. The proposed JA8 requirement to dim to 10% has been set

specifically to be consistent with the sources in Table 130.1-A that *would* have to meet JA-8 if installed in residential new construction.)

- **Flicker:** Must provide "reduced flicker operation" between 100% and 20% light output when tested according to test method in JA10. Reduced flicker operation is defined as less than 30% amplitude modulation (percent flicker) at frequencies less than 200 Hz. This test method and the rationale for specifying reduced flicker operation will be discussed in more detail in the description of Joint Appendix JA10 below. An even more stringent requirement would be to test for flicker at minimum light output and perhaps allowed even less depth of amplitude modulation (percent flicker), but the current proposal would eliminate the worst flicker and collect product data for consideration in the next code cycle.
- **Power Factor:** Must have Power Factor ≥ 0.90 at full rated power. High power factor results in less current (amps) flow for a given wattage and thus reduces voltage drop losses in house wiring. In addition, high power factor reduces transformer losses and thus increases grid efficiency. Though power factor is not directly billed to residential customers, to the extent that all costs are passed through to customers this saves on energy costs. This is identical to the power factor requirement in the Voluntary LED Lamp Quality Specification.
- **Start Time:** Must have start time ≤ 0.3 seconds. This prevents a time delay between switching the light on and the illumination of the source. This responds to complaints about CFLs historically having too slow of a start time, and increases acceptance of high efficacy sources. The study Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market (PNNL 2006) explained that "some consumers still indicate dissatisfaction with CFLs for various reasons: not bright enough, size, color consistency, and slow start-up time." Also, "several utility surveys and consumer focus group studies pointed to performance issues such as the humming, buzzing, and flickering…, [and] delayed start." Incandescent lamps have very short start times (below 0.3 seconds), and several manufacturers and industry stakeholders have indicated that products with 0.3 second start times are currently widely available. This is a test procedure already required by the ENERGY STAR lamps specification so it should not be a significant additional burden.
- **Audible Noise:** Light source shall not emit noise above 24dBA measured at 1 meter or less from the light source, when tested at 100% and 20% (or lower) of full light output in accordance with ENERGY STAR Product Specification for Lamp Noise, Recommended Practice. This requirement is in response to complaints from consumers that high efficacy sources have historically hummed or buzzed, particularly when dimmed. This is also consistent with requirements in ENERGY STAR, and in the CEC Voluntary Specification. Note that the ENERGY STAR program is currently working on some modifications to its test method to make it less onerous without losing functionality (Fall 2014). The Statewide CASE Team will monitor ENERGY STAR's progress and if the test method is updated in time, we recommend that Title 24 reference the revised ENERGY STAR test method for consistency.
- **Rated Life**: Minimum rated lifetime for all sources: 15,000 hrs. This matches the lowest rated life allowed for ENERGY STAR LED lamps.

- **Lumen Maintenance**: For all lamps, minimum percentage of 0-hour light output after 6,000 hour test must be 86.7%. ENERGY STAR uses this as a proxy for a rated life of 15,000 hours (assuming rated life is defined as a lumen maintenance of 70%) and DOE has included a similar proxy for rated life in the most recent stage of it test procedure rulemaking (the June Supplemental Notice of Proposed Rule).
- **Early Failure**: 9 out of 10 tested units shall be operational at 6,000 hours. One of the most common complaints about CFLs was their propensity to burn out prematurely and not meet consumer expectations. This requirement is designed to limit early failures by ensuring that products are designed with quality components not likely to experience catastrophic failure long before the projected 15,000 hour rated life (which is based on lumen maintenance projections).
- **Elevated Temperature Testing:** Requirements for sources installed in Recessed or Enclosed Fixtures:
  - Lumen depreciation down to no less than 86.7% of 0 hour output after elevated temperature operation for 6,000 hours. This test requirement is to assure that the high efficacy, high quality sources do not suffer early failure like so many CFLs placed in enclosed or recessed luminaires where elevated operating temperatures are common. LED lamps and luminaires also contain electronic components so heat build-up may prove to be an issue for LEDs as well. This requirement is consistent with ENERGY STAR requirements for directional lamps and omni-directional lamps 10W and above that do not have a label stating “not for use in recessed or enclosed fixtures.”
  - These tests are required only for sources that are used in enclosed or recessed fixtures. Products installed in recessed or enclosed luminaires must meet these requirements and be labeled “rated for use in enclosed or recessed fixtures.”
  - The proposal references ENERGY STAR’s test method for elevated life testing, with two minor modifications. The ENERGY STAR test method provides three options, the first of which is that manufacturers test products in a specified 6” ICAT can, unless they get approval from EPA to test in a different can. “Testing shall be conducted using the Halo® model H7UICAT incandescent downlight housing or EPA-approved substitute.” The Statewide CASE Team has proposed modifications to this language so that sources of different sizes would not be tested in the same 6” can but rather would be tested in a can of the appropriate size. Additionally, the ENERGY STAR test method allows for the ambient temperature immediately outside the can to be 25°C, which is not representative of most recessed cans installed in ceilings where temperatures generally climb much higher than 25°C. The Statewide CASE Team therefore proposes that the ICAT can be sealed on the top and the sides be in direct contact of least 12" of R-38 fiberglass insulation.
- **Warranty:** 5 year manufacturer warranty (based on 1,200 h/yr) from date of manufacture. This helps assure the manufacturer stands behind their product, and similar to the early life requirement, helps ensure that products are designed with quality components not likely to experience catastrophic failure long before the projected 15,000 hour rated life.
- **Compatibility:** LED lamps designed to be dimmed by phase cut dimmers must meet NEMA SSL7A as Type 1 or Type 2 products. This helps ensure that the entire lighting

system works together to minimize flicker and other problems resulting from component incompatibility. Similarly in Section 150(k)2A, when phase cut dimmers are installed, they must also be NEMA SSL 7A compliant.

Subsections JA 8.10 and JA8.11 address certification and labeling requirements, including the following:

- **Marking:** Product must contain a permanent marking indicating "CA JA8 Compliant." This is so the requirements in Section 150.0(k) and Table 150.0-A that require JA8 light sources can be enforced merely by looking in the luminaire and seeing if the light source does indeed have the "JA8 compliant" label. If not the builder must get different light sources to comply with the proposed energy code.
- **Certification:** Product must be certified in the CA appliance efficiency database. This is to ensure that the product does indeed comply with Appendix JA8. This creates a paper trail for the product and gives designers and code officials information about the products being specified. Manufacturers also have access to the information if they think another manufacturer is unfairly competing by not meeting all of the requirements in JA8.
- **Date of Manufacture:** Product must contain a marking that indicates the date of manufacture in the following format: "Date of Manufacture: MM/YYYY." This allows a consumer to exercise the manufacturer warranty provisions if the product does not last as long as warrantied.

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.[3] 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:

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[3] 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.

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

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 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.

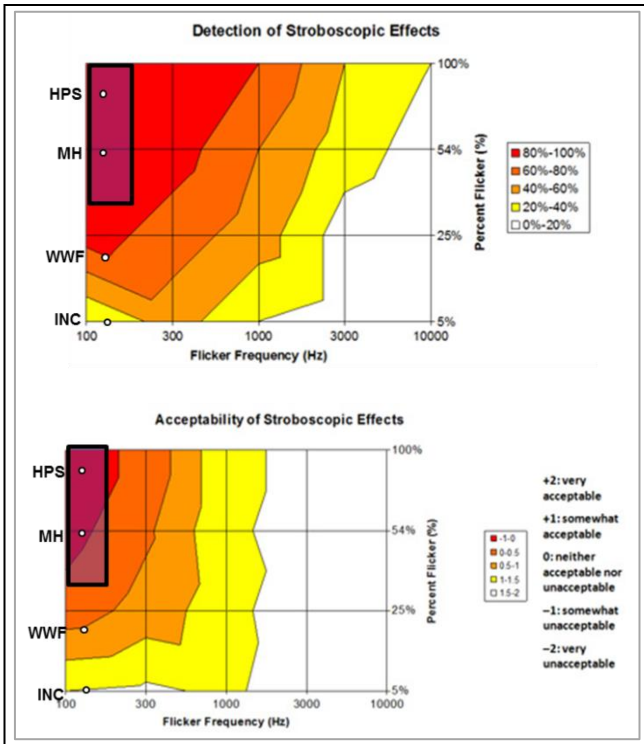

Figure 2: Detection and Acceptability of Stroboscopic Effects (LRC 2012)

The "reduced flicker operation" requirements in the current Title 20 appliance standards and proposed for Reference Joint Appendix JA8 are: "<u>reduced flicker operation is defined as having percent amplitude modulation (percent flicker) less than 30% at frequencies less than 200Hz.</u>" 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.

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.

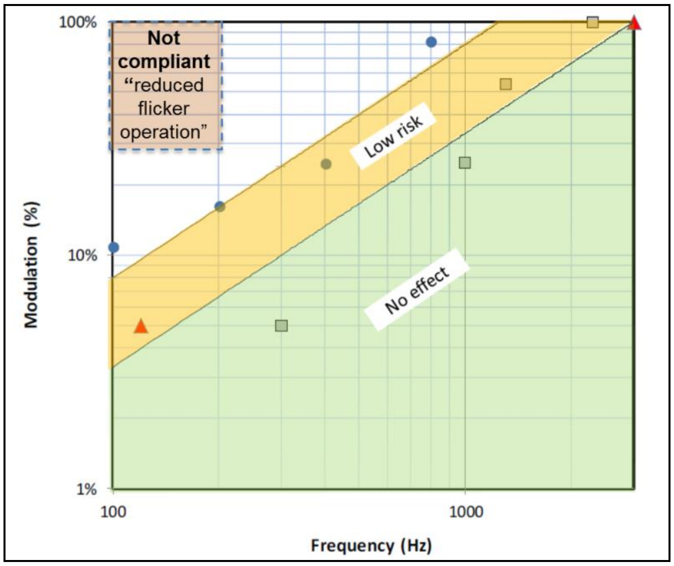

Figure 3: Low risk and no observable effect regions for flicker (Lehman et .a 2014) overlaid with region of graph not compliant with "reduced flicker operation" requirement

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 2. 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.

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 3 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. Early tests of filtered amplitude modulation measurements of LED A lamps indicates that at least 40% 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 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 4, 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 4, 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 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 a few are failing badly.

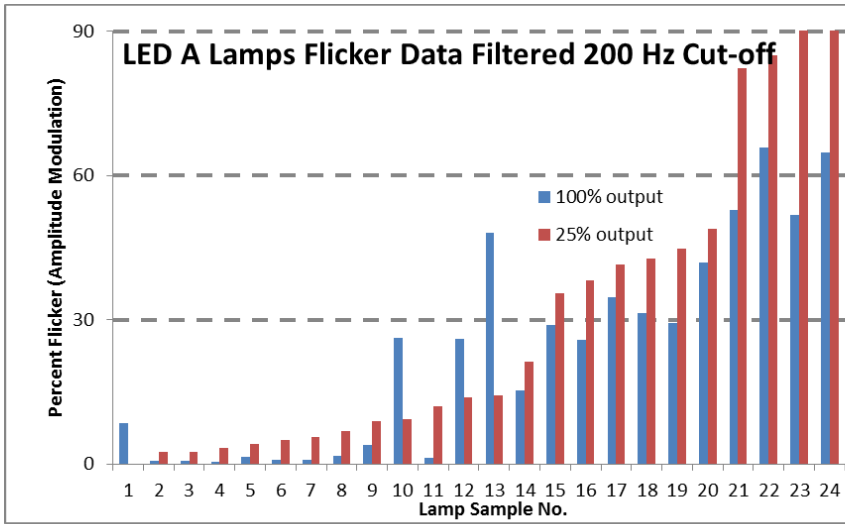

Figure 4: Filtered Flicker Test Data for 25 LED A-lamps (filtered flicker proposed for CA standards)

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 5 illustrates what happens if the high frequency photometric data for the same A-lamps is not filtered; only one product is able achieve 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.

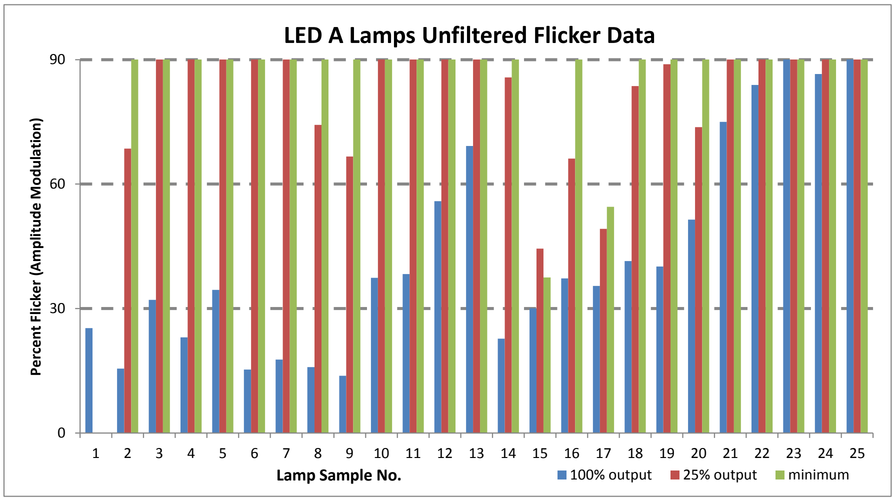

Figure 5: Unfiltered Flicker Test Data for 25 LED A-Lamps (unfiltered flicker not proposed for CA standards)

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 C. If test data is placed in the data format as outlined in TABLE JA-10 (see the JA 10 code language in Section 6.2) 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 raised about flicker testing.

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.

Repeatability of Flicker Test Procedure

In addition to the flicker testing performed at CLTC, "round robin" testing was also completed by the Statewide CASE Team in collaboration with Pacific Northwest National Laboratory (PNNL) to compare raw, unfiltered flicker test data taken in different labs. In the winter of 2013/2014, four of the LED replacement lamps that were tested for flicker at CLTC, were also sent to PNNL for flicker testing. The four samples tested in this round robin testing were from four different manufacturers, and included two products with very high Percent Flicker (at or near 100%), one product with Percent Flicker near the proposed cut-off (~30%), and one product with low Percent Flicker (~10%), to represent a range of performance. The results collected at PNNL were consistent with the results collected at CLTC. The largest measured difference between labs was 1.98%, while the average difference was 0.81%. While limited in scope to four products, this initial round robin testing indicated strong repeatability of the flicker test procedure. It should be noted that the test procedure requires a maximum interval of 50 microseconds between data points (data recording rate no less than 20,000 Hz). CLTC conducted their test at a data recording rate of 125,000 Hz and PNNL used a data recording rate of 1 Megahertz. The data recording rates were both well in excess of the minimum required and though they used different data recording rates, the results from both labs closely matched each other. We anticipate that with the relatively low frequency of the virtual low pass filter associated with Fourier filtering of the data for "reduced flicker operation" (200 Hz) this will reduce error associated with high frequency noise that might be present in some test apparatus. We welcome additional round robin testing with other test labs.

Table 10: 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%

Detailed description of rationale behind JA 10 test procedure

JA 10.1 Equipment Combinations

The primary focus of this section is to clarify that flicker results are specific to the combination of lamp, ballast or driver and in the case of phase cut dimmers, the dimmer. For incandescent lamps the main influence of flicker is the dimmer and transformer (if low any). For fluorescent systems past experience has indicated that flicker can be influenced by lamp/ballast combination, lead length and dimmer selection (if phase cut). LED flicker performance is expected to be a function of primarily driver selection and dimmer (if phase cut). The rules on equipment selections are designed to assure the test results are not overgeneralized to equipment combinations that might still have flicker problems.

JA 10.2 Test Equipment Requirements

Test enclosure. Similar to the ENERGY STAR flicker testing requirements the JA10 test method can use either absolute photometry or relative photometry. If one is conducting this method using absolute photometry then one would be using an integrating sphere and to make sure the data is accurate the integrating sphere has to be light tight so that it does not let in any light not generated by the unit under test. Even the relative photometry device within cannot let in stray light as this would reduce the measured amplitude modulation as the stray light would increase the value of the minimum light level.

Photodetector. We are requiring that the photodetector be photometrically corrected so that the response of the photodetector reflects the light levels in lumens. In addition the electrical output has to be linear so that the measurement of light output does not have to be mathematically corrected depending upon the intensity of light measured. Having a photodetector with high levels of linearity reduces the potential for measurement error as no further manipulation of the data is required with respect to the value of the measurement.

Signal amplifier and bandwidth. As described earlier, flicker can potentially have human impacts all the way up to 1,000 Hz with extremely high amplitude modulation. As a result we want to make sure the equipment has a bandwidth that can characterize a signal well by having a sampling rate that is at least 10 times as great as the frequency of the signal we want to capture. In this case we have called for a sampling rate that is at a frequency 20 times greater than the signal we want to measure so we have a good representation of the waveform. The signal amplifier bandwidth can be a function of the level of amplification used (gain setting), so this bandwidth specification is a function not only of the equipment but the level of amplification required for a given test. One can reduce the amplification required by placing the photodetector closer to the source.

Device for Data Collection. A digital oscilloscope will likely be the most commonly used device for this test. The relatively inexpensive model used for collecting flicker data at PNNL and CLTC was able to collect data at the 100,000 Hz level. Having a high frequency data collection device allows us to have confidence in the results when lower frequency flicker is present in the signal. It was desirable that the equipment be able to collect at last 2 seconds of data so that if desired, there would be enough data to conduct a Fourier analysis all the way down to 1 Hz frequency incremental after truncating the data to satisfy the 2^N length of data set for high speed calculation of the discrete Fourier transform. When truncating the data the maximum loss of data is one half of the data set, thus at least one second of data will be available for transforming into the frequency domain to frequencies as low as one Hertz.

JA 10.3 Flicker Test Conditions

This test method recognizes that fluorescent lamp seasoning is required by many manufacturers to make sure that impurities have been removed from lamp gases which could lead to a spurious flicker measurement that represents operation of a dimming ballast in a format not recommended by the manufacturer. Other lamp sources do not require the same lamp seasoning. Input power requirements reflect the requirements for many other lighting measurement tests and assure that flicker is not induced by overly “dirty” power with harmonics, peaks, sags etc. Relatively steady surrounding air temperature around the unit under test assures that measured flicker reflects stable temperature conditions and reflects the temperature conditions for many of the other photometric tests. We are proposing that the tests be conducted at 100%, 80%, 50% and 20% of the light output of the product when the dimmer is set to maximum output. Often the 100% light output when the dimmer is set to its maximum setting is a few percent less than the output of the device when directly connected to line voltage.

JA 10.4 Test Procedure

Lamps are stabilized according the test methods set by the Department of Energy, or where no Federal test procedure exists, to the industry standard test methods applicable to each source type. In this manner manufacturers can test their products for flicker at the same time they are conducting tests to show compliance with the federal efficiency regulations or for showing compliance with ENERGY STAR specifications and thereby reduce testing costs.

The recording interval (which can be different from the sampling rate) identifies the time between the relatively high speed lighting measurements that are being recorded in a digital file. The maximum length of the interval between measurements is 50 microseconds which is a measurement rate of 20 kHz or approximately 10 to 20 times faster than the higher frequency of concern for flicker.

As described earlier we are interested in 2 seconds worth of high frequency relative light intensity data. This allows us to truncate the data if need be and still have at least 1 second of data for converting into a Fourier series for frequency filtering.

Data is stored in a commonly applied and easily machine readable format that is Comma Separated (ASCII)[4] Values, also known as CSV format. This data can then be easily manipulated using spreadsheets or other mathematical software.

JA 10.5 Calculations

Calculate percent amplitude modulation of the unfiltered data over the time period of data collected using the equation in this section. The percent amplitude modulation is identical to percent flicker equation that ENERGY STAR uses. The only difference between the ENERGY STAR calculation of unfiltered data is that the ENERGY STAR data can be taken at an data recording frequency of as little as 2,000 Hz and for a duration as short as 100 msec. The data collected for JA 10 must be taken at a minimum data recording frequency of 20,000 Hz and for duration of at least 2 seconds. ENERGY STAR only requires collecting data for light output at maximum output of the dimmer and at 20% of the output of the dimmer. The JA10 protocol requires that this data be collected at 100%, 80% 50% and 20% of the output of the dimmer at its maximum setting.

As described earlier, the impact of flicker on humans is a function of both the depth of light (amplitude) modulation and the frequency at which the modulation occurs. The ENERGY STAR method qualitatively captures this with a screen capture image of the waveform. The JA10 protocol quantitatively describes this interaction of frequency and depth of modulation by conducting a Fourier analysis to filter data with various numerical low pass filters having cut-off frequencies of 40, 90, 200, 400 and 1,000 Hz. With increasing frequency are humans are less sensitive to depth of modulation of light. At frequencies less than 70 Hz several seconds of highly modulated light is extremely annoying for most people, and can even induce serious photosensitive epilepsy in 1 out of 4,000 people (IEEE 2010). The JA10 flicker measurement standard collects flicker data at different dimming levels and filtered for different cut-off frequencies. The data from this test method is used at only two levels of dimming 100% and 20% and at one cut off-frequency, 200 Hz to enforce the requirement in JA8 that complying products are able to provide "reduced flicker operation" i.e.no greater than 30% amplitude modulation for frequencies less than 200 Hz.

JA 10.6 Test Report and Data Format

Test data is stored in very specific format for easy retrieval, machine reading for process and verification of results and with raw data to validate the claimed percent flicker at various frequencies. This data will be processed using a California Energy Commission CEC Flicker Data Analysis Tool so that the results are consistent, the calculations are transparent and an even playing field is maintained for all manufacturers. The CEC maintains a publicly available database so that all market participants can compare the performance of products that are sold in California. This feedback to the market differentiates high flicker and low flicker products and everything in between and provides a market signal for manufacturers to develop light sources that are low flicker.

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[4] American Standard Code for Information Interchange

2.2.4 Compliance Forms Change Summary

The proposed code change will require some modifications to the residential lighting compliance forms to accommodate the changes in high efficacy requirements and definitions. Additional details on the revised forms are presented in Section 6.4 of this report.

2.2.5 Simulation Engine Adaptations

As a default measure, lighting power is not traded off against other measures. Lighting is not directly modeled in the residential simulation tool, so the only modification needed is to change the default lighting power assumptions in the simulation model. This will affect the total energy consumption in the building as used for providing a HERS score or a design rating. The HERS score and design rating is used to define whether a home can be considered Zero Net Energy (ZNE) for efficiency programs or local government reach codes.

2.2.6 Other Areas Affected

No other areas are affected.

2.3 Code Implementation

2.3.1 Verifying Code Compliance

The baseline high efficacy requirement will not necessitate any new compliance practices other than those already in place. Compliance practices used to confirm high efficacy lighting under the current Standards will continue to be used under the proposed measure.

However, inspectors will need to be able to identify and verify JA8 compliant sources installed in fixtures that would otherwise not qualify as high efficacy.

2.3.2 Code Implementation

Residential lighting is already regulated in the Standards, and the structure of the proposed measure requirements will be familiar in the industry. Furthermore, the proposal greatly simplifies the Standards, making fixture requirements consistent across all space types. The main addition to the structure from the current Standards is the requirement to provide home buyers with a schedule of lighting equipment installed in the home.

Although all high efficacy lighting for both indoor and outdoor hardwired fixtures is not common practice, high efficacy lighting has been required in the Standards in some form since 2005. By allowing any fixture with a JA8 compliant source to qualify as a high efficacy fixture, it will provide more options for complying with the Standards and will simplify compliance for designers and builders.

2.3.3 Field Verification and Diagnostic Testing

As with the existing residential lighting Standards, this measure will require field verification by a local building inspector to confirm that the installed lighting equipment complies with the requirements. This measure will require modifications to the existing field verification, to include verification of JA8 compliant sources in fixtures that do not already qualify as high efficacy. Qualifying light sources will be required to be labeled as meeting the JA8 requirements in order to ease verification by building inspectors.

2.4 Issues Addressed During 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 conducted a public stakeholder meeting to discuss the proposals. The issues that were addressed during development of the code change proposal are summarized below.

The Statewide CASE Team coordinated with various stakeholders in both lighting equipment manufacturing, and lighting design. Several key concerns expressed by stakeholders included the following:

- Uncertainty in the quality and variety of currently available high efficacy products
- Uncertainty in the quality of LED fixtures and lamps
- Difficulty in producing fixtures that meet the current high efficacy requirements

The Statewide CASE Team developed the proposal to allow JA8 compliant lamps to qualify any fixture as high efficacy as a means to address these initial concerns while still achieving significant energy savings. The proposal allows any fixture to qualify as high efficacy as long as it is equipped with a qualifying lamp, addressing the difficulty of meeting the current high efficacy requirements, and limited quantity and variety of currently available high efficacy fixtures. The rigorous quality requirements proposed in the revised JA8 address concerns about quality, and if consumers are unhappy with the high efficacy lamps installed, they will have the flexibility to choose a different type of lamp. This proposal was vetted with several key stakeholders who were all generally happy with level of flexibility afforded, as well as the quality requirements.

In addition, the Statewide CASE Team held a public stakeholder meeting on May 15, 2014, where the proposed requirements were presented to a broader audience. Attendees who provided feedback at the meeting were generally supportive, and provided useful feedback on the proposed requirements. Some concerns raised by stakeholders included:

- The importance of establishing effective flicker requirements
- Questions regarding the stringency of the color temperature requirements

All feedback from stakeholders was taken into consideration in developing this proposal.

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. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with key stakeholders including utility program staff, CEC, and a wide range of industry players who were invited to participate in a public stakeholder meeting that the Statewide CASE Team hosted in May 2014.

3.1 Market Structure

Residential light fixtures and lamps are available from a wide variety of manufacturers, retailers, and distributors.

Many residential lighting manufacturers produce light fixtures that meet the current definition of high efficacy in the 2013 Title 24 Standards. Requirements for high efficacy lighting have been in effect since the 2005 Title 24 Standards, and the market has responded to these requirements. These fixtures are available from various distribution paths, including retailers, and lighting distributors who sell directly to builders. High efficacy lamps and sources are also available from a wide variety of manufacturers through both retail and distributor channels.

Under the proposed revision to allow JA8 compliant sources to qualify as high efficacy luminaires, any fixture type would be considered high efficacy if it is installed with a JA8 compliant source that meets the requirements established in the revised JA8. This would effectively allow any fixture on the market, other than screw based recessed luminaires, to qualify as high efficacy, greatly expanding the choices available to consumers.

3.2 Market Availability and Current Practices

High efficacy lighting equipment for residential applications is widely available on the market. High efficacy lighting has been required in residential lighting since the 2005 Title 24 Standards, and is a well-established practice in residential construction. In addition, lamps meeting the necessary "high quality" criteria are already available on the market from manufacturers such as Cree, Feit, LEDnovation, and Green Creative, with more manufacturers likely to provide JA8 compliant sources in the near future. This measure seeks to expand the use of high efficacy lighting in more residential applications, and to expand the number of choices available to consumers to meet the high efficacy requirements.

3.3 Useful Life, Persistence, and Maintenance

Residential measures are considered to have a 30-year life. Although fixtures may last 30 years, fixture components and lamps have shorter life.

For the purpose of this analysis, lamp life and ballast life are based on industry standards, and typical product warranties. These assumptions are outlined in section 4.7.1.

There is a chance that some JA8 compliant sources installed in otherwise low efficacy fixtures could be replaced with low efficacy sources. However, the long life and high quality of the installed lamps is expected to discourage early replacement in all but a few isolated cases.

The methodology the Statewide CASE Team used to determine the costs associated with incremental maintenance costs, relative to existing conditions, is presented in Section 4.7.1. The incremental maintenance costs of the proposed code change are presented in Section 5.2.1.

3.4 Market Impacts and Economic Assessments

3.4.1 Impact on Builders

This proposal is expected to have little impact on builders. The proposal simplifies the residential lighting requirements in the Standards. Rather than having multiple room type requirements, the Standards will have a single overarching requirement for all rooms. The proposal to allow JA8 compliant sources as high efficacy fixtures will also allow more flexibility in fixture choices, and may also reduce the need to install certain control types in some spaces.

Builders will need to ensure that JA8 compliant sources used to qualify as high efficacy fixtures meet the quality requirements established in the revised JA8, and are labeled as such. They will need to provide homeowners with documentation of the high efficacy fixtures and lamps installed at the time of possession.

3.4.2 Impact on Building Designers

Similar to the impact on builders, described above, the proposed measure is expected to have minimal impact on building designers. The proposal simplifies the standards by eliminating most room type requirements, and the addition of the JA8 compliant sources as high efficacy in luminaires other than screw based recessed luminaires will allow for greater flexibility in specifications to meet the requirements.

Building designers will need to specify JA8 compliant sources for any fixture that does not currently qualify as a high efficacy fixture in the Standards.

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 ongoing maintenance of the building.

3.4.4 Impact on Building Owners and Occupants

The proposal provides high efficiency lighting for residential owners and occupants, while preserving variety and choice in the fixtures available for residential applications. Allowing JA8 compliant sources to qualify any fixture as a high efficacy fixture provides added flexibility for consumers to choose any fixture currently available on the market, other than screw based recessed luminaires.

If owners and occupants are not satisfied with the lighting provided by the JA8 compliant sources, they will have the flexibility to replace those lamps with another source.

3.4.5 Impact on Retailers (including manufacturers and distributors)

The proposal is expected to have minimal impact on fixture sales. High efficacy fixtures are already available on the market, and the proposal will essentially allow the installation of any fixture currently on the market, other than screw based recessed luminaires, as long as that fixture is installed with JA8 compliant sources.

The proposal will result in a reduction in sales of screw based recessed luminaires, which will no longer be allowed. The proposal is also expected to result in a reduction in sales of low efficacy sources for the new construction market. However, state and federal appliance standards are expected to phase out many low efficacy sources shortly after these new Standards go into effect.

The proposed revisions to JA8 are expected to result in a slight increased testing burden for manufacturers, but manufacturers are already routinely testing their products to meet various standards, and the proposed measures primarily reference existing testing protocols.

3.4.6 Impact on Energy Consultants

The proposal is not expected to have a significant impact on energy consultants but is expected to slightly reduce work load as lighting wattage is no longer calculated and requirements are streamlined.

3.4.7 Impact on Building Inspectors

The proposal will not significantly change practices for building inspectors. The proposal will require building inspectors to verify that high efficacy sources installed in otherwise low efficacy fixtures meet the criteria established in the revised JA8. JA8 compliant lamps shall be labeled as such to ease verification for building inspectors. Overall, but the code changes is expected to slightly reduce work load as lighting wattage is no longer calculated and requirements are streamlined.

3.4.8 Impact on Statewide Employment

This change is expected to result in a slight increase in employment due to wealth generation. Incremental cost is substantially less than energy cost savings resulting in added disposable income to California homeowners. This added income allows residents to purchase more goods and services.

3.5 Economic Impacts

The proposed Title 24 code changes, including this measure, are expected to increase job creation, income, and investment in California. As a result of the proposed code changes, it is anticipated that less money will be sent out of state to fund energy imports, and local spending is expected to increase due to higher disposable incomes due to reduced energy costs.[5] For instance, the statewide life cycle net present value of this measure is $201.2 million over the 30 year period of analysis. In other words, utility customers will have $201.2 million to spend

[5] Energy efficiency measures may result in reduced power plant construction, both in-state and out-of-state. These plants tend to be highly capital-intensive and often rely on equipment produced out of state, thus we expect that displaced power plant spending will be more than off-set from job growth in other sectors in California.

elsewhere in the economy. In addition, more dollars will be spent in state on improving the energy efficient of new buildings.

These economic impacts of energy efficiency are documented in several resources including the California Air Resources Board's (CARB) Updated Economic Analysis of California's Climate Change Scoping Plan, which compares the economic impacts of several scenario cases (CARB, 2010b). CARB include one case (Case 1) with a 33% renewable portfolio standard (RPS) and higher levels of energy efficiency compared to an alternative case (Case 4) with a 20% RPS and lower levels of energy efficiency. Gross state production (GSP)[6], personal income, and labor demand were between 0.6% and 1.1% higher in the case with the higher RPS and more energy efficiency (CARB 2010b, Table 26). While CARB's analysis does not report the benefits of energy efficiency and the RPS separately, we expect that the benefits of the package of measures are primarily due to energy efficiency. Energy efficiency measures are expected to reduce costs by $2,133 million annually (CARB 2008, pC-117) whereas the RPS implementation is expected to cost $1,782 million annually, not including the benefits of GHG and air pollution reduction (CARB 2008, pC-130).

Macro-economic analysis of past energy efficiency programs and forward-looking analysis of energy efficiency policies and investments similarly show the benefits to California's economy of investments in energy efficiency (Roland-Holst 2008; UC Berkeley 2011).

3.5.1 Creation or Elimination of Jobs

The proposed measure is expected to result in a slight increase in employment due to wealth generation. Incremental cost is substantially less than energy cost savings resulting in added disposable income to California homeowners. This added income allows residents to purchase more goods and services.

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation estimates that this scenario would result in a 1.1% increase in statewide labor demand in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Tables 26 and 27). CARB's economic analysis also estimates a 1.3% increase in small business employment levels in 2020 (CARB 2010b, Table 32).

3.5.2 Creation or Elimination of Businesses within California

The proposal is expected to have a slight positive impact on the creation of businesses within California, as a result of increased wealth generation discussed above in section 3.5.1.

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation (as described above) estimates that this scenario would result in 0.6% additional GSP in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Table ES-2). We expect that higher GSP will drive additional business creation in California. In particular, local small businesses that spend a much larger proportion of revenue on energy than other businesses (CARB 2010b, Figures 13 and 14) should disproportionately benefit from lower

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[6] GSP is the sum of all value added by industries within the state plus taxes on production and imports.

energy costs due to energy efficiency standards. Increased labor demand, as noted earlier, is another indication of business creation.

Table 11 below shows California industries that are expected to receive the economic benefit of the proposed Title 24 code changes. It is anticipated that these industries will expand due to an increase in funding as a result of energy efficiency improvements. The list of industries is based on the industries that the University of California, Berkeley identified as being impacted by energy efficiency programs (UC Berkeley 2011 Table 3.8).[7] This list provided below is not specific to one individual code change proposal; rather it is an approximation of the industries that may receive benefit from the 2016 Title 24 code changes. A table listing total expected job creation by industry that is expected in 2015 and 2020 from all investments in California energy efficiency and renewable energy is presented in Appendix B: Job Creation by Industry of this CASE Report.

Table 11: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code

Industry	NAICS Code
Residential Building Construction	2361
Electrical Contractors	23821
Manufacturing	32412
Electric Lighting Equipment Manufacturing	3351
Engineering Services	541330
Building Inspection Services	541350
Environmental Consulting Services	541620

3.5.3 Competitive Advantages or Disadvantages for Businesses within California

The impact of this measure is expected to be negligible outside of the employment impacts described above in section 3.5.1. California businesses would benefit from an overall reduction in energy costs. This could help California businesses gain competitive advantage over businesses operating in other states or countries and an increase in investment in California, as noted below

3.5.4 Increase or Decrease of Investments in the State of California

The proposal is expected to results in a potential to increase investments in California related to LED (light emitting diode) technology as this standard accelerates the uptake of this technology. CARB's economic analysis indicate that higher levels of energy efficiency and

[7] Table 3.8 of the UC Berkeley report includes industries that will receive benefits of a wide variety of efficiency interventions, including Title 24 standards and efficiency programs. The authors of the UC Berkeley report did not know in 2011 which Title 24 measures would be considered for the 2016 adoption cycle, so the UC Berkeley report was likely conservative in their approximations of industries impacted by Title 24. Statewide CASE Team believes that industries impacted by utilities efficiency programs is a more realistic and reasonable proxy for industries potentially affected by upcoming Title 24 standards. Therefore, the table provided in this CASE Report includes the industries that are listed as benefiting from Title 24 and utility energy efficiency programs.

33% RPS will increase investment in California by about 3% in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b Figures 7a and 10a).

3.5.5 Incentives for Innovation in Products, Materials, or Processes

Updating Title 24 standards will encourage innovation through the adoption of new technologies to better manage energy usage and achieve energy savings. Increased flexibility of the energy code while requiring a significant expansion in high efficacy technologies creates a market opportunity for innovative products. These mandatory requirements do not impact the sale of replacement lamps and thus do not impact ratepayer funded Energy Efficiency programs. Rather the changes in JA8 support the efforts of voluntary to transform the market for replacement lamps.

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

The proposal is expected to have minimal impacts outside of reduced enforcement costs (see below).The Statewide CASE Team expects positive overall impacts on state and local government revenues due to higher GSP and personal income resulting in higher tax revenues, as noted earlier. Higher property valuations due to energy efficiency enhancements may also result in positive local property tax revenues. The Statewide CASE Team has not obtained specific data to quantify potential revenue benefits for this measure.

Cost of Enforcement

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24 standards, including updating education and compliance materials and responding to questions about the revised standards, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.

Cost to Local Governments

The proposal is expected to result in a slight reduction in enforcement costs as the proposal is easier to enforce and eliminates wattage calculations required by the current code. All revisions to Title 24 will result in changes to Title 24 compliance determinations. Local governments will need to train permitting staff on the revised Title 24 standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2016 code change cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining. For example, utilities offer compliance training such as “Decoding” talks to provide training and materials to local permitting departments. As noted earlier, although retraining is a cost of the revised standards, Title 24 energy efficiency standards are expected to increase economic growth and income with positive impacts on local revenue.

Impacts on Specific Persons

The proposed changes to Title 24 are not expected to have a differential impact on any of the following groups relative to the state population as a whole:

- Migrant Workers
- Persons by age
- Persons by race
- Persons by religion
- Commuters

We expect that the proposed code changes for the 2016 Title 24 code change cycle would reduce energy costs and could put potential first-time homeowners in a better position to afford mortgage payments. On the other hand, homeowners may experience higher first costs to the extent that builders pass-through the increased costs of Title 24 compliance to home buyers. Some financial institutions have progressive policies that recognize that home buyers can better afford energy efficiency homes (even with a higher first cost) due to lower energy costs.[8]

Renters will typically benefit from lower energy bills if they pay energy bills directly. These savings should more than offset any capital costs passed-through from landlords. Renters who do not pay directly for energy costs may see more of less of the net savings based on how much landlords pass the energy cost savings on to renters.

On average, low-income families spend less on energy than higher income families, however lower income families spend a much larger portion of their incomes on energy (Roland-Holst 2008). Thus it seems reasonable that low-income families would disproportionately benefit from Title 24 standards that reduce residential energy costs.

4. METHODOLOGY

This section describes the methodology and approach the Statewide CASE Team used to estimate energy, demand, costs, and environmental impacts. The Statewide CASE Team calculated the impacts of the proposed code change by comparing existing conditions to the conditions if the proposed code change is adopted. This section of the CASE Report goes into more detail on the assumptions about the existing and proposed conditions, prototype buildings, and the methodology used to estimate energy, demand, cost, and environmental impacts.

4.1 Existing Conditions

To assess the energy, demand, costs, and environmental impacts, the Statewide CASE Team compared current design practices to design practices that would comply with the proposed

[8] For example, see US EPA's Energy Star website for examples: http://www.energystar.gov/index.cfm?fuseaction=new_homes_partners.showStateResults&s_code=CA.

requirements. There is an existing Title 24 standard that covers the building system in question, so the existing conditions assume a building complies with the 2013 Title 24 Standards.

As outlined above in Section 2.1.2, the existing Standards require some combination of high efficacy lighting and/or controls, depending on the room type. These requirements are summarized as follows:

- At least 50% of the total installed load in kitchens must be high efficacy lighting.
- Lighting in internally illuminated cabinets must not exceed 20 watts per linear foot.
- Bathrooms require at least one high efficacy luminaire. All other lighting must be high efficacy or controlled by vacancy sensor.
- Lighting in garages, laundry rooms, and utility rooms must be high efficacy and controlled by vacancy sensors.
- Lighting in spaces types other than those listed above must be either high efficacy or controlled by dimmer or vacancy sensor.

Although the requirements are “mandatory,” they are structured to allow flexibility, and they result in a wide range of current practice and only apply to new construction and additions.

The Statewide CASE Team used lighting data from the *Efficiency Characteristics and Opportunities for New California Homes* (ECO) (Proctor, Chitwood, and Wilcox, 2011) study to establish current practice in installed lighting load, and the “Final Evaluation Report: Upstream Lighting Program” (KEMA 2010) for hours of use data. The authors of the ECO study provided the Statewide CASE Team with a detailed inventory of all fixtures and lamps installed in each of the 80 homes surveyed in the study. This data formed the basis of the current residential lighting practice assumptions. Both of these sources provide data for both single family homes, and multifamily units. All data presented here reflect average practice across all housing units, including both single family and multifamily. These data sets primarily reflect practices under the 2008 Standards or earlier. The Statewide CASE Team made modifications to data that is inconsistent with the 2013 Standards to better reflect the current Standards.

Permanently installed lighting wattage in bathrooms was modified to estimate the impact of the 2013 Standards, which require at least one high efficacy fixture in each bathroom. Using the lighting inventory data from the ECO study, the Statewide CASE Team was able to assess how many homes and bathroom spaces were already complying with the 2013 Standards, and then estimated the reduction in wattage that would result from the 2013 Standards in the remaining bathroom spaces in the study sample. In addition, current practice calculations and all energy savings calculations do not consider garages, laundry rooms, or utility rooms, which already require all high efficacy lighting. The table below summarizes existing permanently installed residential lighting conditions. The information in the table is taken from a database of lighting inventory data collected as part of the ECO study (Proctor, Chitwood, and Wilcox, 2011). Current practice is described in both watts and sockets. The watts values indicate the potential for energy savings from switching to all high efficacy lighting, while the socket values will determine the incremental cost of switching to all high efficacy lighting. As the table shows, the vast majority of both watts and sockets are low efficacy in current residential new construction practice. Only kitchens have higher efficacy lighting than lower efficacy, due to the 50% minimum requirement.

Table 12: Current Residential Lighting Practice

Room	Average Permanently Installed Watts	Average Percent High Efficacy Watts	Average Percent Low Efficacy Watts	Average High Efficacy Sockets	Average Low Efficacy Sockets
Whole Home	1965	19%	81%	13.3	31.2
Kitchen	202	68%	32%	5.5	1.3
Bathroom (est. 2013 practice)	215	21%	79%	1.7	3.3
Bedroom	98	11%	89%	0.2	1.9
Hallway/Stair	248	12%	88%	0.7	4.1
Living Room	201	4%	96%	0.2	3.6
Dining Room	235	6%	94%	0.1	4.5

Current residential practice includes 15.9 recessed luminaires per average home. Many of these recessed luminaires use low efficacy sources, or inefficient fixture designs.

4.2 Proposed Conditions

The proposed conditions are defined as the design conditions that will comply with the proposed code change. Specifically, the proposed code change will require high efficacy lighting in all residential lighting applications, and revise the definition of "high efficacy fixture" to include any fixture that is installed with JA8 compliant light sources. The proposed change will also require all recessed luminaires shall not use screw bases.

In order to estimate energy savings from the proposed measure, the Statewide CASE Team calculated the reduction in wattage from the lighting inventory data from the ECO study (Proctor, Chitwood, and Wilcox, 2011), modified to reflect the 2013 Standards as summarized in Table 12, assuming all permanently installed sources were changed to a high efficacy source.

Hours of use data for the proposed conditions were taken from the "Final Evaluation Report: Upstream Lighting Program" (KEMA 2010). Hours of use data are summarized in Table 13. Energy savings calculations use the whole house average hours of use (1.7 hr/day), as the proposed revisions to the Standards apply across all room types.

Table 13: Average Hours of Use (KEMA 2010)

Room	Hours of Use
Bedroom	1.7
Bathroom	1.4
Hallway	1.2
Dining Room	1.9
Living Room	2.3
Kitchen	2.5
Exterior	3.9
Other	1.4
Whole Home Average	1.7

4.3 Prototype Building

CEC provided guidance on the type of prototype buildings that must be modeled. According to CEC guidelines, the recommended prototype buildings for this analysis are residential prototype D and prototype E as defined in the Residential ACM Manual (Section 4.2). However, the existing residential lighting requirements and the proposed measure are based on room types, and the prototype buildings do not define room types.

As a result, prototype analysis for the Residential Lighting measure was based on the average room type composition and lighting inventory information in the ECO study (Proctor, Chitwood, and Wilcox, 2011).

Table 14 outlines the average permanently installed watts in each room type, and average number of occurrences of each room types in the average home.

Table 14: Average Home Data used in Analysis

Room Type	Average Permanently Installed Watts per Room	Average Number of Rooms per Home
Kitchens	202	1.00
Bathrooms (est. 2013 practice)	215	2.45
Bedrooms	98	2.84
Hallways/Stairs	248	0.85
Living Rooms	201	1.26
Dining Rooms	235	0.80

The estimated schedule of hours of operation are presented in Figure 6.

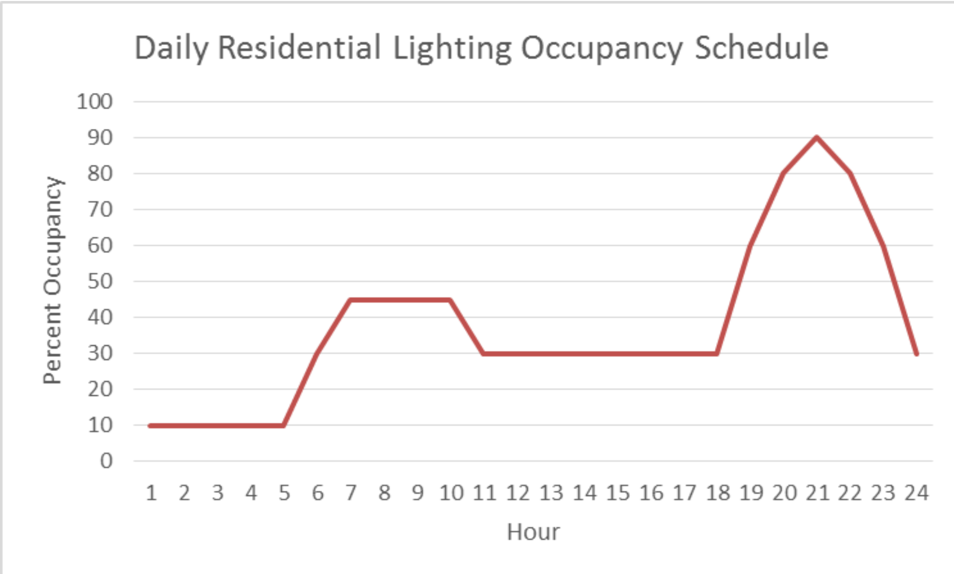

Figure 6: Residential Lighting Occupancy Schedule (CEC, 2008)

When this schedule is applied across all days of the year, and multiplied by the TDV factors the average 30 year present value of current energy consumption is $4439, or $3.64 per kWh.

4.4 Climate Dependent

The impacts of the Residential Lighting measure are not climate specific, so statewide average TDV factors were used in the energy and cost analysis.

4.5 Time Dependent Valuation

The TDV of savings is a normalized format for comparing electricity and natural gas savings that takes into account the cost of electricity and natural gas consumed during different times of the day and year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 30 years. The TDV cost impacts are presented in 2017 present value dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of "TDV kBTUs" so that the savings are evaluated in terms of energy units and measures with different periods of analysis can be combined into a single value.

CEC derived the 2016 TDV values that were used in the analyses for this report (CEC 2014). The TDV energy impacts are presented in Section 5.1 of this report, and the statewide TDV cost impacts are presented in Section 5.2 of this report.

4.6 Energy Impacts Methodology

The Statewide CASE Team calculated per unit impacts and statewide impacts associated with all new construction during the first year buildings begin complying with the 2016 Title 24 Standards (effective 2017).

4.6.1 Per Unit Energy Impacts Methodology

The Statewide CASE Team estimated the electricity savings associated with the proposed code change. The energy savings were calculated on a per building basis.

Per unit energy impacts were determined based on the following parameters:

- Baseline residential lighting energy use was calculated based on lighting inventory data from the ECO study (Proctor, Chitwood, and Wilcox, 2011), and hours of use data for each room from "Final Evaluation Report: Upstream Lighting Program" (KEMA 2010).
- Reductions in lighting wattage resulting from the all high efficacy requirement were calculated based on the average low efficacy lighting wattage for each room from the ECO study (Proctor, Chitwood, and Wilcox, 2011). To accommodate the wide range of lighting technologies and applications, the Statewide CASE Team assumed that the all high efficacy requirement would reduce the installed lighting load of current low efficacy fixtures by 60%. This is considered a conservative estimate, as most high efficacy technologies use more than 60% fewer watts than comparable low efficacy options. Hours of use data for the proposed condition were equal to the baseline condition.
- Reductions in lighting wattage resulting from the recessed luminaire requirement were calculated based on the average wattage of the current recessed luminaires installed from the ECO study (Proctor, Chitwood, and Wilcox, 2011), and the average wattage of dedicated LED downlight products available on the market now. The average recessed luminaire in the ECO study was 45W, and the average dedicated LED downlight is 12W, resulting in an average reduction of 73% per luminaire.
- Per unit energy savings were calculated based on the average whole home lighting inventory from the ECO study (Proctor, Chitwood, and Wilcox, 2011). Energy savings were also calculated for the following common room types: kitchens, bathrooms, bedrooms, hallways/stairs, living rooms, and dining rooms.

Analysis Tools

Energy impacts were calculated using a Microsoft Excel® spreadsheet analysis of existing conditions, and estimated savings from the proposed measure, as described above.

Key Assumptions

As mentioned, CEC provided a number of key assumptions to be used in the energy impacts analysis. Some of the assumptions included in CEC's Lifecycle Cost Methodology Guidelines (LCC Methodology) include hours of operation, weather data, and prototype building design (CEC 2011). The key assumptions used in the per unit energy impacts analysis that are not already included in the assumptions provided in the LCC Methodology are presented in Table 15.

Table 15: Key assumptions for per unit Energy Impacts Analysis

Parameter	Assumption	Source	Notes
Current Residential Lighting Practice	Whole home and room type lighting inventory data from ECO study	Proctor, Chitwood, and Wilcox, 2011	See Table 12 and Table 14 for detailed data
Building Composition	Average of data from ECO study	Proctor, Chitwood, and Wilcox, 2011	See Table 14 for detailed room type and quantity data
Hours of Use	Whole home and space values from Final Evaluation Report: Upstream Lighting Program	KEMA, 2010	See Table 13 for detailed data
Recessed Luminaire Watts Reduction	Assumed 73% watt reduction	Proctor, Chitwood, and Wilcox, 2011; and retail price survey	Average of recessed luminaires from ECO study, and available dedicated LED downlights
All Other Lighting Watts Reduction	Assumed 60% watt reduction	Conservative assumption based on watt reduction from current incandescent to current CFL or LED	

4.6.2 Statewide Energy Impacts Methodology

First Year Statewide Impacts

The Statewide CASE Team estimated statewide impacts for the first year that new dwellings comply with the 2016 Title 24 Standards by multiplying per unit savings estimates by statewide construction forecasts.

The CEC Demand Analysis office provided the projected annual residential dwelling starts for the single family and multifamily sectors. CEC provided three projections: low, mid and high estimates with each case broken out by forecast climate zones (FCZ). The Statewide CASE Team translated this data to building climate zones (BCZ) using the same weighting of FCZ to BCZ as the previous code update cycle (2013), as presented in in Table 15.

The Statewide CASE Team used the mid scenario of forecasted residential new construction for statewide savings estimates. The projected new residential construction forecast, presented by BCZ is presented below in Table 16.

The proposed code change will apply to all residential new construction, additions, and alterations, and is not climate dependent. Statewide impacts were determined by multiplying the per unit energy impacts by statewide new residential construction estimates.

Section 100.1(b) of the 2013 Title 24 Part 6 defines additions and alterations as follows (CEC 2012b):

> **ADDITION** is any change to a building that increases conditioned floor area and conditioned volume. See also “newly conditioned space.” Addition is also any change that increases the floor area and volume of an unconditioned building of an occupancy group or type regulated by Part 6. Addition is also any change that increases the illuminated area of an outdoor lighting application regulated by Part 6.

ALTERATION is any change to a building's water-heating system, space-conditioning system, lighting system, or envelope that is not an addition. Alteration is also any change that is regulated by Part 6 to an outdoor lighting system that is not an addition. Alteration is also any change that is regulated by Part 6 to signs located either indoors or outdoors.

In the definition of "Alteration" the phrase "outdoor lighting system" refers to the wiring, controls, and fixtures that comprise a "system" and does not refer to replacement lamps that are contained in the fixtures.

Table 16: Translation from FCZ to BCZ

		Building Standards Climate Zones (BCZ)																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Grand Total
Forecast Climate Zones (FCZ)	1	22.51%	20.62%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	9.80%	33.14%	0.16%	0.00%	0.00%	13.77%	100.00%
	2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	22.00%	75.70%	0.00%	0.00%	0.00%	2.30%	100.00%
	3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	20.95%	22.76%	54.50%	0.00%	0.00%	1.79%	100.00%
	4	0.15%	13.73%	8.36%	46.03%	8.94%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	22.81%	0.00%	0.00%	0.00%	0.00%	100.02%
	5	0.00%	4.23%	89.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.64%	0.00%	0.00%	0.00%	0.00%	100.00%
	6	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	7	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	75.80%	7.08%	0.00%	17.12%	100.00%
	8	0.00%	0.00%	0.00%	0.00%	0.00%	40.37%	0.00%	51.08%	8.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.46%	100.00%
	9	0.00%	0.00%	0.00%	0.00%	0.00%	6.97%	0.00%	24.54%	57.85%	0.00%	0.00%	0.00%	0.00%	6.68%	0.00%	3.95%	99.99%
	10	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	74.90%	0.00%	0.00%	0.00%	12.27%	7.90%	4.93%	100.00%
	11	0.00%	0.00%	0.00%	0.00%	0.00%	33.04%	0.00%	24.75%	42.21%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	12	0.00%	0.00%	0.00%	0.00%	0.00%	0.92%	0.00%	20.20%	75.19%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.69%	100.00%
	13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	69.55%	0.00%	0.00%	28.77%	0.00%	0.00%	0.00%	1.56%	0.09%	0.00%	99.97%
	14	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	15	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.12%	99.88%	0.00%	100.00%
	16	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	17	2.95%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	97.05%	100.00%

Table 17: Projected New Residential Construction in 2017 by Climate Zone [1]

Source: CEC Demand Analysis Office

Building Climate Zone	Single Family Starts	Multifamily Starts[2]
Climate Zone 1	695	47
Climate Zone 2	2,602	507
Climate Zone 3	5,217	3,420
Climate Zone 4	5,992	1,053
Climate Zone 5	1,164	205
Climate Zone 6	4,142	2,151
Climate Zone 7	6,527	2,687
Climate Zone 8	7,110	3,903
Climate Zone 9	8,259	8,023
Climate Zone 10	16,620	1,868
Climate Zone 11	5,970	217
Climate Zone 12	19,465	1,498
Climate Zone 13	13,912	770
Climate Zone 14	3,338	492
Climate Zone 15	3,885	433
Climate Zone 16	3,135	508
Total	**108,032**	**27,784**

1. CEC provided a low, middle, and high forecast. The Statewide CASE Team used the middle forecast for the statewide savings estimates. Statewide savings estimates do not include savings from mobile homes.
2. Includes high-rise and low-rise multi-family construction.

4.7 Cost-effectiveness Methodology

This measure proposes a mandatory requirement. As such, a lifecycle cost analysis is required to demonstrate that the measure is cost effective over the 30-year period of analysis.

CEC's procedures for calculating lifecycle cost-effectiveness are documented in LCC Methodology. The Statewide CASE Team followed these guidelines when developing the Cost-effectiveness Analysis for this measure. CEC's guidance dictated which costs were included in the analysis. Incremental equipment and maintenance costs over the 30-year period of analysis were included. The TDV energy cost savings from electricity savings were considered. Each of these components is discussed in more detail below.

Design costs were not included nor will incremental cost of verification both of which are likely to be either none or very small.

4.7.1 Incremental Cost Methodology

Incremental costs for the proposal are based on the assumption that all sockets that are currently defined as "low efficacy" would be populated with JA8 compliant lamps, and all recessed luminaires would be populated with JA8 compliant non-screw based lamps or sources under the new Standards. Incremental costs are based on the additional cost of those lamps or sources, compared to current practice. The sections below detail the methodology used to determine incremental costs.

Incremental Construction Cost Methodology

As requested by CEC, the Statewide CASE Team estimated the Current Incremental Construction Costs and Post-adoption Incremental Construction Costs. The Current Incremental Construction Cost (ΔCI_C) represents the cost of the incremental cost of the measure if a building meeting the proposed standard were built today. The Post-adoption Incremental Construction Cost (ΔCI_{PA}) represents the anticipated cost assuming full market penetration of the measure as a result of the new Standards, resulting in possible reduction in unit costs as manufacturing practices improve over time and with increased production volume of qualifying products the year the Standard becomes effective.

Table 18: Key Assumptions for per unit Incremental Construction Cost

Parameter	Assumption	Source	Notes
Current JA8 compliant lamp costs	$14 per compliant lamp	Retail price survey, and manufacturer provided data for 90+ CRI LED A-lamp	Prices expected to continue to decrease going forward
Current recessed luminaire costs	$35 per compliant downlight	Retail price survey, and manufacturer provided data for 90+ CRI LED downlight products	Prices expected to continue to decrease going forward
Future LED cost projections	38% reduction in cost between current costs and 2017 costs	LED Lamp Quality CASE report, PG&E/SDG&E 2013	Prices expected to continue to decrease following the implementation of the Standards
Number of sockets converted	Averages based on ECO study	Proctor, Chitwood, and Wilcox, 2011	See Table 12 and Table 14 for detailed data
Lamp life	15,000 hours	Minimum rated lamp life proposed for revised JA-8	

As noted above, the incremental cost of this proposal is based primarily on the incremental cost of JA8 compliant sources. Due to rapidly decreasing costs of LED products, incremental construction costs were estimated using current price data for JA8 compliant sources, as well as projections of future LED costs at the time the Standards go into effect. Current prices for JA8 compliant lamps and downlight products were determined using retail surveys, and input from manufacturers. Although the proposed Standards would allow a variety of compliant luminaire types and lamp sources, incremental cost estimates were determined assuming JA8 compliant integral LED downlights to meet the recessed luminaire requirements, and JA8 compliant LED A-lamps for all other lighting. Key assumptions used to derive cost are presented in Table 18.

The proposed controls requirements maintain consistency with the current Standards, requiring at least one vacancy sensor in bathrooms, garages, laundry, and utility rooms, and dimmers or vacancy sensors in other rooms. Because these requirements are consistent with current residential construction practice, the analysis assumes no change in incremental construction cost for lighting controls.

Compliant lamps and sources will have to undergo a number of testing protocols to comply with JA8, however the testing is very similar to the testing already required by ENERGY STAR (in most cases the testing requirements proposed here are based entirely on ENERGY STAR test methods). Because the products that meet this specification are primarily ENERGY STAR certified products, the cost to perform this testing is already included in their sale prices, so any costs to perform testing is already included in this analysis.

Incremental Maintenance Cost Methodology

Maintenance cost is included in the lifecycle cost analysis. The present value (PV) of maintenance costs (savings) was calculated using a 3 percent discount rate (d) as directed in the LCC Methodology. The PV of maintenance costs that occurs in the nth year is calculated as follows (where d is the discount rate of 3 percent):

$$\text{PV Maintenance Cost} = \text{Maintenance Cost} \times \left\lfloor \frac{1}{1 + \text{d}} \right\rfloor^{\text{n}}$$

4.7.2 Cost Savings Methodology

Energy Cost Savings Methodology

The present value (PV) of the energy savings were calculated using the method described in the LCC Methodology (CEC 2011). In short, the hourly energy savings estimates for the first year of building operation were multiplied by the 2016 TDV cost values to arrive at the PV of the cost savings over the period of analysis. This measure is not climate sensitive, so the energy cost savings were calculated using the population-weighted TDV values.

4.7.3 Cost-effectiveness Methodology

The Statewide CASE Team calculated the cost-effectiveness using the LCC Methodology. According to CEC's definitions, a measure is cost effective if it reduces overall lifecycle cost from the current base case (existing conditions). The LCC Methodology clarifies that absolute lifecycle cost of the proposed measure does not need to be calculated. Rather, it is necessary to calculate the change in lifecycle cost from the existing conditions to the proposed conditions.

If the change in lifecycle cost is negative then the measure is cost-effective, meaning that the present value of TDV energy savings is greater than the cost premium, or the proposed measure reduces the total lifecycle cost as compared to the existing conditions. Propane TDV costs are not used in the evaluation of energy efficiency measures.

The Planning Benefit to Cost (B/C) Ratio is another metric that can be used to evaluate cost-effectiveness. The B/C Ratio is calculated by dividing the total present value TDV energy cost savings (the benefit) by the present value of the total incremental cost (the cost). If the B/C Ratio is greater than 1.0 (i.e. the present valued benefits are greater than the present valued costs over the period of analysis), then the measure is cost effective.

4.8 Environmental Impacts Methodology

4.8.1 Greenhouse Gas Emissions Impacts Methodology

Greenhouse Gas Emissions Impacts Methodology

The Statewide CASE Team calculated avoided GHG emissions assuming an emission factor of 353 metric tons of carbon dioxide equivalents ($MTCO_2e$) per GWh of electricity savings. As described in more detail in Appendix A, the electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts if the state meets the Renewable Portfolio Standard (RPS) goal of 33 percent renewable electricity generation by 2020. Avoided GHG emissions from natural gas savings were calculated using an emission factor of 5,303 $MTCO_2e$/million therms (U.S. EPA 2011).

5. ANALYSIS AND RESULTS

Results from the energy, demand, cost, and environmental impacts analyses are presented in this section.

As described above, the analysis assumes that transitioning low efficacy lighting to high efficacy sources represents at least a 60% reduction in installed watts, and recessed luminaire requirements result in a 73% reduction. By extension, converting all residential low efficacy lighting in current practice to high efficacy sources results in a 51% energy use savings. The sections below describe the energy savings results in more detail.

5.1 Energy Impacts Results

Table 19 summarizes current residential lighting energy use conditions, as discussed in Section 4.1 of this report. Average permanently installed wattage figures are taken from the lighting inventory from the ECO study. The average annual hours of use figure was determined by multiplying the daily hours of use number reported above by 365 days in a year.

Table 19: Current Residential Lighting Conditions

Room	Average Permanently Installed Watts per Home	Average Hours of Use per year	Average Annual Energy Use (kWh/year) per Home
Recessed Luminaires	711	621	441
All Other Lighting	1,254	621	778
TOTAL	**1,965**	**621**	**1,219**

Table 20 summarizes the energy savings results from requiring all permanently installed lighting to be high efficacy. The analysis assumes that energy use from all current low efficacy lamps is reduced by 60%, and energy use from current recessed luminaire practice is reduced by 73%. Note that although the proposed requirements for recessed luminaires will impact all recessed luminaires in residential new construction, the requirements for all other lighting would only apply to those sockets currently classified as low efficacy. As the table shows, 65%

of non-recessed luminaire wattage in current practices is impacted by the proposed measure, based on lighting inventory data from the ECO study. As shown in Table 20, the proposed measures result in an annual savings of 625 kWh/year, or a 51% reduction in total lighting energy use per home.

Table 20: Energy Impacts Results

Room	Average Annual Energy Use (kWh/year) per Home	% Lighting Watts Impacted by Proposed Measure	Impacted Energy Use (kWh/year) per Home	Savings from Proposed Measures (kWh/year)	% Savings from All High Efficacy Lighting
Recessed Luminaires	441	100%	441	322	73%
All Other Lighting	778	65%	506	303	24%
TOTAL	**1,219**	**78%**	**947**	**625**	**51%**

5.1.1 Per Unit Energy Impacts Results

Per unit energy and demand impacts of the proposed measure are presented in Table 21. Per unit savings for the first year are expected to be 625 kilowatt-hours per year (kWh/yr). Due to the lack of reliable data on residential lighting schedules, the Statewide CASE Team did not calculate demand savings. As noted above, the TDV energy savings was calculated based on the lighting use schedule shown in

Figure 3, multiplied by the associated hourly TDV factors for each climate zone.

It is estimated that the TDV electricity savings over the 30-year period of analysis will be between 13,160 and 13,947 kBTU per unit. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Table 21: First Year[1] Energy Impacts per Home

Climate Zone	Electricity Savings[2] (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings[3] (kBTU)	TDV Natural Gas Savings[3] (kBTU)
Climate Zone 1	625	-	N/A	13,746	N/A
Climate Zone 2	625	-	N/A	13,736	N/A
Climate Zone 3	625	-	N/A	13,701	N/A
Climate Zone 4	625	-	N/A	13,728	N/A
Climate Zone 5	625	-	N/A	13,686	N/A
Climate Zone 6	625	-	N/A	13,327	N/A
Climate Zone 7	625	-	N/A	13,947	N/A
Climate Zone 8	625	-	N/A	13,411	N/A
Climate Zone 9	625	-	N/A	13,240	N/A
Climate Zone 10	625	-	N/A	13,185	N/A
Climate Zone 11	625	-	N/A	13,823	N/A
Climate Zone 12	625	-	N/A	13,833	N/A
Climate Zone 13	625	-	N/A	13,767	N/A
Climate Zone 14	625	-	N/A	13,220	N/A
Climate Zone 15	625	-	N/A	13,285	N/A
Climate Zone 16	625	-	N/A	13,160	N/A

1. Energy savings from one home for the first year the building is in operation.
2. Site electricity savings. Does not include TDV of electricity savings.
3. Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity.

5.1.2 Statewide Energy Impacts Results

First Year Statewide Energy Impacts

The statewide energy impacts of the proposed measure are presented in Table 22. Per unit electricity and TDV savings was multiplied by the total projected number of housing unit (both single family and multifamily) starts in 2017, as described above, to determine the statewide impacts. During the first year buildings complying with the 2016 Title 24 Standards are in operation, the proposed measure is expected to reduce annual statewide electricity use by 85.0 GWh. As noted above, demand savings was not calculated.

Table 22: Statewide First Year[1] Energy Impacts

Measure	Electricity Savings[2] (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	TDV Electricity Savings[3] (Million kBTU)	TDV Natural Gas Savings[3] (Million kBTU)
Recessed Luminaires	43.7	-	N/A	945.6	N/A
All Other Lighting	41.3	-	N/A	894.1	N/A
TOTAL	**85.0**	**-**	**N/A**	**1,839.7**	**N/A**

1. First year savings from all buildings built statewide during the first year the 2016 Standards are in effect.
2. Site electricity savings.
3. Calculated using CEC's 2016 TDV factors and methodology.

All assumptions and calculations used to derive per unit and statewide energy and demand savings are presented in Section 4 of this report.

5.2 Cost-effectiveness Results

The proposal to require all high efficacy results in significant energy savings, at relatively low incremental cost. As described in detail in the sections below, the proposal is cost effective.

5.2.1 Incremental Cost Results

The incremental cost of the proposed measure, relative to existing conditions, is presented in Table 24. The total incremental cost includes the incremental cost during initial construction and the present value of the incremental maintenance cost over the 30-year period of analysis. Each of these components of the incremental cost is discussed below.

As described in section 4.7.1, using a CRI of at least 90 as a proxy for compliance with the revised JA8 requirements, the current cost of compliant A-lamps is assumed to be $14, and the average cost of compliant downlight products is assumed to be $35. Note that these costs may be higher than the overall average for LED products because of the higher CRI requirement.

Projected future LED costs are based on findings in the LED Lamp Quality CASE report (PG&E/SDG&E, 2013). To determine price points for high quality LED lamps, the study reviewed price projection and cost trend data from U.S. DOE studies, and conducted an independent statistical study of LED lamp prices and characteristics in order to determine future costs for high quality LED products.

Figure 7 reproduces U.S. DOE's LED replacement lamp price projections in dollars per kilolumen, as published in the 2014 Solid-State Lighting Research and Development Multi-Year Program Plan (U.S. DOE, 2014).

The LED Lamp Quality CASE report projects that in 2016, just prior to the proposed Standards going into effect, compliant LED A-lamps will have an average cost of $8.64. The Statewide CASE Team used this value as the projected cost for LED A-lamps when the standards go into effect. This cost projection represents a 38% reduction from current prices. Using the same percentage reduction, the Statewide CASE Team assumes that compliant LED downlight products will have an average cost of $21.60 when the proposed Standards go into effect.

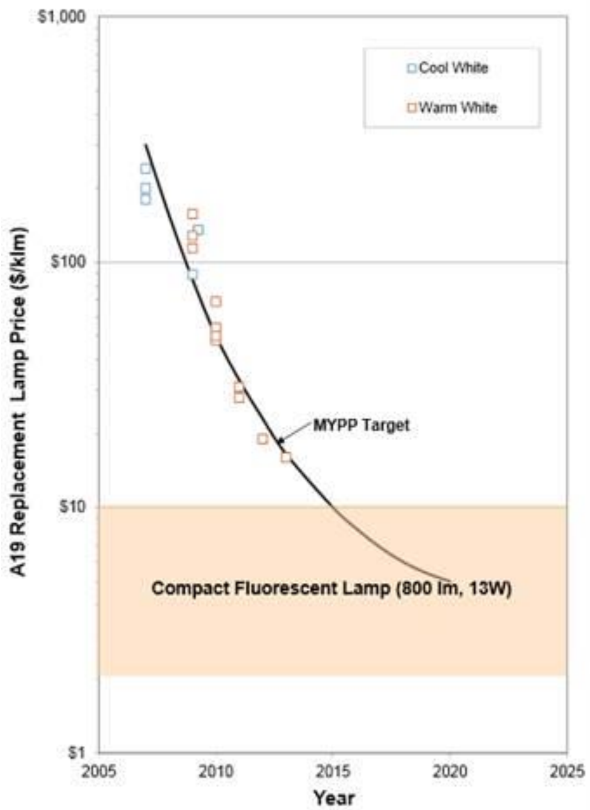

Figure 7: US DOE LED A19 Replacement Lamp Price Projection, May 2014

Incremental costs were determined based on the difference between current practice, and the proposed Standards. Current practice costs were also determined using current retail prices. LED downlight products are assumed to replace a standard trim ring and a halogen PAR lamp (fixture housing costs are expected to remain unchanged), at a combined cost of $9.09 per downlight. LED A-lamps are assumed to replace incandescent A-lamps at a cost of $0.73 each. The Statewide CASE Team does not expect any change in cost for current practices between now and the implementation of the proposed standards in 2017.

As noted above, the average number of impacted sockets was determined based on the lighting inventory data in the ECO study (Proctor, Chitwood, and Wilcox, 2011).

Table 23 summarizes the incremental construction costs at both current prices, and projected 2017 prices when the proposed Standards go into effect. As noted in section 4.7.1, current cost for compliant LED A lamps is $14, and the cost of LED recessed luminaire products is $35. These costs are expected to decrease by 38% by the time the Standards go into effect in 2017. For the purpose of calculating incremental costs, LED recessed luminaire products are assumed to replace a PAR lamp (at $4.09), and a trim ring ($5), with a current total cost of $9.09. LED A lamps are assumed to replace incandescent A lamps, with a current cost of $0.73 per lamp. Labor costs are assumed to be equal in both cases. The total incremental construction cost of the proposed measures when the Standards go into effect in 2017 is estimated to be $365.

Table 23: Incremental Construction Costs

	Average Number of Lamps Affected per Home	Average Cost of Current Practice per Lamp	Average Cost of Proposed Measure per Lamp	Incremental Cost per Lamp	Total Incremental Construction Costs per Home
Recessed Luminaires – Current	15.9	$9.09	$35.00	$25.91	$412
All Other Lighting – Current	21.0	$0.73	$14.00	$13.27	$279
TOTAL – Current	36.9	-	-	-	$691
Recessed Luminaires – Projected	15.9	$9.09	$21.60	$12.51	$199
All Other Lighting – Projected	21.0	$0.73	$8.64	$7.91	$166
TOTAL – Projected	**36.9**	**-**	**-**	**-**	**$365**

Table 24: Incremental Cost of Proposed Measure 2017 Present Value Dollars[1]

Condition	Incremental Initial Construction Cost		Incremental Present Value of Maintenance Cost[4]
	Current[2]	Post Adoption[3]	
Existing Conditions	$160	$160	$390
Proposed Conditions	$851	$525	$258
Incremental[1]	$691	$365	-$132

1. Incremental costs equal the difference between existing conditions and proposed conditions. Negative values indicate the Proposed Conditions are less expensive than Existing Conditions.
2. Initial construction cost using current prices; ΔCI_C.
3. Initial construction cost using estimated prices after adoption; ΔCI_{PA}.
4. Present value of maintenance costs over 30-year period of analysis; ΔCM.
5. Total costs equals incremental cost (post adoption) plus present value of maintenance costs; $\Delta CI_{PA} + \Delta CM$.

Incremental Construction Cost Results

The incremental construction cost for the proposed measure is $365 per home. As described in Section 4.7.1 of this report, the incremental cost of the measure is based on the added cost JA8 compliant sources used to comply with the proposed measures. The incremental costs are based on the current price of a 90+ CRI LED A-lamp, or dedicated LED downlight. Although prices are expected to fall between now and January 2017, when the standards go into effect, the added quality requirements in the revised JA8 may result in less of a price reduction. As noted in Section 4.7.1 there is no change in construction costs for lighting controls. For this analysis, post adoption incremental construction costs remain equal to current costs.

Incremental Maintenance Cost Results

Although residential measure life is assumed to be 30 years, most lamp sources will not last the full 30-year life of the measure. To determine maintenance costs for the proposed measure, the Statewide CASE Team assumed that JA8 compliant sources are replaced every 15,000 hours of use, based on the minimum lifetime requirement proposed for the revised JA8. Based on the average 621 hours of use per year, a 15,000 hour life equates to one lamp replacement over the 30 year life of the measure, typically in the 24th year. By comparison, typical incandescent A-lamps were assumed to need replacement every 3 years, and halogen PAR lamps in recessed luminaires were assumed to need replacement every 4 years. Maintenance costs for current practice use the prices described above, minus the discount rate for each replacement year. Maintenance costs for the life of the measure were calculated using the projected 2017 cost data described above, with the discount rate determined for the corresponding year of replacement. Note that although LED costs are projected to continue decreasing, the fast-changing nature of the lighting industry makes it impossible to predict what the replacement technology for LED will be in 24 years. As a result, the 2017 LED costs, minus the discount rate, were used for the maintenance costs.

Lamp replacement costs were calculated on a per average home basis. Table 25 summarizes the incremental maintenance costs per home. Using the assumptions described above, the PV maintenance cost of the proposed measure is actually less than the maintenance cost of current practice. The change in maintenance costs over the 30 year life of the proposed measures results in a present value savings of $132 per average home.

Table 25: Incremental Maintenance Cost

	PV Maintenance Cost of Current Practice per Home	PV Maintenance Cost of Proposed Measures per Home	Incremental PV Maintenance Costs per Home
Recessed Luminaires	$293	$169	-$124
All Other Lighting	$97	$89	-$8
TOTAL	**$390**	**$258**	**-$132**

The incremental present value of maintenance costs for the proposed measure results in a savings of $132 over the life of the measure.

5.2.2 Cost Savings Results

Energy Cost Savings Results

The per unit TDV energy cost savings over the 30-year period of analysis are presented in Table 26. The total TDV electricity cost savings ranges from $2,279 to $2,416 per home. Residential lighting is not climate zone dependent, so the cost savings results apply to all climate zones.

Table 26: TDV Energy Cost Savings Over 30-Year Period of Analysis - Per Home

Climate Zone	TDV Electricity Cost Savings (2017 PV$)	TDV Natural Gas Cost Savings (2017 PV$)	Total TDV Energy Cost Savings (2017 PV$)
Climate Zone 1	$2,381	N/A	$2,381
Climate Zone 2	$2,379	N/A	$2,379
Climate Zone 3	$2,373	N/A	$2,373
Climate Zone 4	$2,378	N/A	$2,378
Climate Zone 5	$2,370	N/A	$2,370
Climate Zone 6	$2,308	N/A	$2,308
Climate Zone 7	$2,416	N/A	$2,416
Climate Zone 8	$2,323	N/A	$2,323
Climate Zone 9	$2,293	N/A	$2,293
Climate Zone 10	$2,284	N/A	$2,284
Climate Zone 11	$2,394	N/A	$2,394
Climate Zone 12	$2,396	N/A	$2,396
Climate Zone 13	$2,384	N/A	$2,384
Climate Zone 14	$2,290	N/A	$2,290
Climate Zone 15	$2,301	N/A	$2,301
Climate Zone 16	$2,279	N/A	$2,279

Given data regarding the new construction forecast for 2017, the Statewide CASE Team estimates that TDV energy cost savings (30-year period) of all buildings built during the first year the 2016 Standards are in effect will be $318.6 million.

Other Cost Savings Results

This measure does not have any non-energy cost savings.

5.2.3 Cost-effectiveness Results

Results per unit lifecycle Cost-effectiveness Analyses are presented in Table 27.

The proposed measure saves money over the 30-year period of analysis relative to the existing conditions. Because the residential lighting measure is not climate zone dependent, the proposed code change is cost effective in every climate zone. As shown in Table 27, the proposed measures result in a benefit-cost ratio of 6.6:1. Because the proposed measures result in maintenance savings, the incremental maintenance cost is included in the “benefit” column.

Table 27: Cost-effectiveness Summary[1]

	Benefit: TDV Energy Cost Savings[2] (2017 PV$)	Benefit: Present Valued Net Maintenance Cost Savings[3] (2017 PV$)	Cost: Incremental First Cost[4] (2017 PV$)	Change in Lifecycle Cost[5] (2017 PV$)	Planned Benefit to Cost (B/C) Ratio[6]
Climate Zone 1	$2,381	$132	$365	-$2,148	6.9
Climate Zone 2	$2,379	$132	$365	-$2,146	6.9
Climate Zone 3	$2,373	$132	$365	-$2,140	6.9
Climate Zone 4	$2,378	$132	$365	-$2,145	6.9
Climate Zone 5	$2,370	$132	$365	-$2,137	6.9
Climate Zone 6	$2,308	$132	$365	-$2,075	6.7
Climate Zone 7	$2,416	$132	$365	-$2,183	7.0
Climate Zone 8	$2,323	$132	$365	-$2,090	6.7
Climate Zone 9	$2,293	$132	$365	-$2,060	6.6
Climate Zone 10	$2,284	$132	$365	-$2,051	6.6
Climate Zone 11	$2,394	$132	$365	-$2,161	6.9
Climate Zone 12	$2,396	$132	$365	-$2,163	6.9
Climate Zone 13	$2,384	$132	$365	-$2,151	6.9
Climate Zone 14	$2,290	$132	$365	-$2,057	6.6
Climate Zone 15	$2,301	$132	$365	-$2,068	6.7
Climate Zone 16	$2,279	$132	$365	-$2,046	6.6

1. Relative to existing conditions. All cost values presented in 2017 dollars.
2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta TDV\$ = \Delta TDV\$E + \Delta TDV\$G$.
3. Because the proposed measure results in present valued maintenance savings, maintenance costs are part of the benefits side of the B/C ratio calculation; $MS = -\Delta MC$. Maintenance savings is the negative value of the increase in present valued maintenance costs.
4. Total incremental cost equals only the incremental construction cost (post adoption); $\Delta C = \Delta CI_{PA}$.
5. Negative values indicate the measure is cost effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta LCC = \Delta C - \Delta TDV\$$
6. The benefit to cost ratio is the TDV energy costs savings and the present valued maintenance cost savings divided by the total incremental costs; $B/C = (\Delta TDV\$ + MS) \div \Delta C$. The measure is cost effective if the B/C ratio is greater than 1.0.

Given data regarding the new construction forecast for 2017, the Statewide CASE Team estimates that that lifecycle cost savings (30-year period) of all buildings built during the first year the 2016 Standards are in effect will be $287.0 million.

5.3 Environmental Impacts Results

5.3.1 Greenhouse Gas Emissions Results

Table 28 presents the estimated first year avoided GHG emissions of the proposed code change. During the first year the 2016 Standards are in effect the proposed measure will result in avoided GHG emissions of 29,970 $MTCO_2e$. The monetary value of avoided GHG emissions is included in TDV cost factors (TDV $) for each hour of the year and thus included in the Cost-effectiveness Analysis presented in this report.

Table 28: Statewide Greenhouse Gas Emissions Impacts

	First Year Statewide Avoided GHG Emissions[1] ($MTCO_2e$/yr)
Recessed Luminaires	15,426
All Other Lighting	14,544
TOTAL	**29,970**

1. First year savings from buildings built in 2017; assumes 353 $MTCO_2e$/GWh and 5,303 $MTCO_2e$/MMTherms.

6. 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).

6.1 Standards

SECTION 10-103 – PERMIT, CERTIFICATE, INFORMATIONAL, AND ENFORCEMENT REQUIREMENTS FOR DESIGNERS, INSTALLERS, BUILDERS, MANUFACTURERS, AND SUPPLIERS

(b) **Compliance, Operating, Maintenance, and Ventilation Information to be provided by Builder.**

1. **Compliance information.**

   A. For low-rise residential buildings, at final inspection, the enforcement agency shall require the builder to leave in the building, copies of the completed, signed, and submitted compliance documents for the building owner at occupancy. For low-rise residential buildings, such information shall, at a minimum, include copies of all Certificate of Compliance, Certificate of Installation, and Certificate of Verification documentation submitted. The enforcement agency shall require the builder to produce a luminaire schedule complying with Section 150.0(k)1H that shall be part of the construction documents and left at the building at the time of final inspection for the building owner at occupancy. These documents shall be in paper or electronic format and shall conform to the applicable requirements of Section 10-103(a).

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

NEMA SSL 7A is the National Electrical Manufacturers Association document titled "Phase Cut Dimming for Solid State Lighting: Basic Compatibility," 2013. (NEMA SSL 7A-2013**)**

LIGHTING definitions:

…

Recessed Luminaire is a luminaire that is mounted above the ceiling or behind a wall or other surface with the opening of the luminaire level with the surface.

Section 150.0(k)

(k) **Residential Lighting.**

1. **Luminaire Requirements**

A. **Luminaire Efficacy:** All installed ~~Installed~~ luminaires shall be ~~classified as~~ high-efficacy ~~or low-efficacy~~ ~~for compliance with Section 150.0(k)~~ in accordance with TABLE 150.0-A ~~or TABLE 150.0-B, as applicable~~.

~~B. **Hybrid Luminaires:** When a high efficacy and low efficacy lighting system are combined together in a single luminaire, the high efficacy and low efficacy lighting systems shall separately comply with the applicable provisions of Section 150.0(k).~~

B.- **Blank Electrical Boxes.** ~~C. **Luminaire Wattage and Classification.** The Wattage and Classification of permanently installed luminaires in residential kitchens shall be determined in accordance with Section 130.0(c). In residential kitchens, the wattage of e~~ The number of electrical boxes that are more than 5 feet above the finish floor and do not contain a luminaire or other device shall be no greater than the number of bedrooms. These electrical boxes must be served by a dimmer or vacancy sensor control. ~~or where no electrical equipment has been installed, and where the electrical box can be used for a luminaire or a surface mounted ceiling fan, shall be calculated as 180 watts of low efficacy lighting per electrical box.~~

C. ~~8.~~ **Recessed Luminaires in Ceilings.** Luminaires recessed into ceilings shall meet all of the following requirements:

i. ~~A~~. Be Listed, as defined in Section 100.1, for zero clearance insulation contact (IC) by Underwriters Laboratories or other nationally recognized testing/rating laboratory; and

ii. ~~B~~. Have a label that certifies that the luminaire is airtight with air leakage less than 2.0 CFM at 75 Pascals when tested in accordance with ASTM E283. An exhaust fan housing shall not be required to be certified airtight; and

iii. ~~C~~. Be sealed with a gasket or caulk between the luminaire housing and ceiling, and shall have all air leak paths between conditioned and unconditioned spaces sealed with a gasket or caulk; and

~~D. For recessed compact fluorescent luminaires with ballasts to qualify as high efficacy for compliance with Section 150.0(k), the ballasts shall be certified to the Commission to comply with the applicable requirements in Section 110.9; and~~

iv. ~~E.~~ For luminaires with hardwired ballasts or drivers, ~~A~~allow ballast or driver maintenance and replacement to be readily accessible to building occupants from below the ceiling without requiring the cutting of holes in the ceiling.

v. Shall not contain screw based sockets.

vii. Shall contain light sources that comply with Reference Joint Appendix JA8 and shall not contain light sources that are labeled “not for use in enclosed fixtures” or “not for use in recessed fixtures.”

D. **Totally Enclosed Fixtures.** Light sources labeled "not for use in enclosed fixtures" or "not for use in recessed fixtures" shall not be installed in totally enclosed fixtures.

E. **Electronic Ballasts.** Ballasts for fluorescent lamps rated 13 watts or greater shall be electronic and shall have an output frequency no less than 20 kHz.

F. **Night Lights.** Permanently installed night lights and night lights integral to installed luminaires or exhaust fans shall be rated to consume no more than five watts of power per luminaire or exhaust fan as determined in accordance with Section 130.0(c). Night lights shall not be required to be controlled by vacancy sensors.

G. **Lighting Integral to Exhaust Fans.** Lighting integral to exhaust fans shall meet the applicable requirements of Section 150.0(k).

EXCEPTION to Section 150.0(k)1F: Lighting installed by the manufacturer in kitchen exhaust hoods.

H. **Screw based luminaires.** Screw based luminaires shall meet all the following requirements

i. the luminaires are not recessed luminaires

ii the luminaires contain lamps that comply with Reference Joint Appendix JA8 and

iii. the installed lamps are labeled as compliant with T-24 JA8 (Title 24, part 6 Reference Joint Appendix JA8).

EXCEPTION to Section 150.0(k)1G: Luminaires with hard-wired ballasts for high intensity discharge lamps.

H. **Fixture schedule.** Builder shall complete and sign a Certificate of Installation for Lighting including the fixture schedule of all interior and exterior luminaires and the required light sources in compliance with Section 150.0(k). In accordance with Section 10-103(b) at the time of final inspection, the enforcement agency shall require the builder to leave in the building copies of the completed, signed Certificate of Installation for Lighting including the fixture schedule for the use of the building owner.

2. **Interior Lighting Switching Devices and Controls.**

~~A. High efficacy luminaires shall be switched separately from low efficacy luminaires.~~

A. All phase cut dimmers shall comply with NEMA SSL 7A.

…….

J. In Bathrooms, Attached Garages, Detached Garages, Laundry Rooms, and Utility Rooms, at least one luminaire in each of these spaces shall be controlled by a vacancy sensor.

K. Dimmers or vacancy sensors shall control all luminaires required by Table 150.0-A to have light sources compliant with Reference Joint Appendix JA8.
EXCEPTION 1 to Section 150.0(k)2K: Luminaires in closets less than 70 square feet.
EXCEPTION 2 to Section 150.0(k)2K: Luminaires in hallways.

~~3. **Lighting in Kitchens.**~~

~~A. A minimum of 50 percent of the total rated wattage of permanently installed lighting in kitchens shall be high efficacy.~~

~~B. For the purpose of compliance with Section 150.0(k), kitchen lighting includes all permanently installed lighting in the kitchen except for lighting that is internal to cabinets for the purpose of illuminating only the inside of the cabinets. Lighting in areas adjacent to the kitchen, including but not limited to dining and nook areas, are considered kitchen lighting if they are not separately switched from kitchen lighting.~~

~~**EXCEPTION to Section 150.0(k)3:** Up to 50 watts for dwelling units less than or equal to 2,500 ft^2 or 100 watts for dwelling units larger than 2,500 ft^2 may be exempt from the 50 percent high efficacy requirement when all lighting in the kitchen is controlled in accordance with the applicable provisions in Section 150.0(k)2, and is also controlled by vacancy sensors or dimmers.~~

~~4. **Lighting Internal to Cabinets.** Permanently installed lighting that is internal to cabinets shall use no more than 20 watts of power per linear foot of illuminated cabinet. The length of an illuminated cabinet shall be determined using one of the following measurements, regardless of the number of shelves or the number of doors per cabinet section:~~

~~A. One horizontal length of illuminated cabinet; or~~

~~B. One vertical length, per illuminated cabinet section; or~~

~~C. No more than one vertical length per every 40 horizontal inches of illuminated cabinet.~~

~~5. **Lighting in Bathrooms.** Lighting installed in bathrooms shall meet the following requirements:~~

~~A. A minimum of one high efficacy luminaire shall be installed in each bathroom; and~~

~~B. All other lighting installed in each bathroom shall be high efficacy or controlled by vacancy sensors.~~

~~6. **Lighting in Garages, Laundry Rooms, and Utility Rooms.** Lighting installed in attached and detached garages, laundry rooms, and utility rooms shall be high efficacy luminaires and controlled by vacancy sensors.~~

~~7. **Lighting other than in Kitchens, Bathrooms, Garages, Laundry Rooms, and Utility Rooms.** Lighting installed in rooms or areas other than in kitchens, bathrooms, garages, laundry rooms, and utility rooms shall be high efficacy, or shall be controlled by either dimmers or vacancy sensors.~~

~~**EXCEPTION 1 to Section 150.0(k)7:** Luminaires in closets less than 70 square feet.~~

~~**EXCEPTION 2 to Section 150.0(k)7:** Lighting in detached storage buildings less than 1,000 square feet located on a residential site.~~

~~8. **Recessed Luminaires in Ceilings.** Luminaires recessed into ceilings shall meet all of the following requirements:~~

~~A. Be Listed, as defined in Section 100.1, for zero clearance insulation contact (IC) by Underwriters Laboratories or other nationally recognized testing/rating laboratory; and~~

~~B. Have a label that certifies that the luminaire is airtight with air leakage less than 2.0 CFM at 75 Pascals when tested in accordance with ASTM E283. An exhaust fan housing shall not be required to be certified airtight; and~~

~~C. Be sealed with a gasket or caulk between the luminaire housing and ceiling, and shall have all air leak paths between conditioned and unconditioned spaces sealed with a gasket or caulk; and~~

~~D. For recessed compact fluorescent luminaires with ballasts to qualify as high efficacy for compliance with Section 150.0(k), the ballasts shall be certified to the Commission to comply with the applicable requirements in Section 110.9; and~~

~~E. Allow ballast maintenance and replacement to be readily accessible to building occupants from below the ceiling without requiring the cutting of holes in the ceiling.~~

3. ~~9.~~ **Residential Outdoor Lighting.** In addition to meeting the requirements of Section 150.0(k)1, ~~Luminaires~~ luminaires providing residential outdoor lighting shall meet the following requirements, as applicable:

A. For single-family residential buildings, outdoor lighting permanently mounted to a residential building or other buildings on the same lot shall ~~be high efficacy, or may be low efficacy if it meets all of~~ comply with the ~~following~~ requirements in items (i), (ii) and (iii). The controls shall be configured so that controlled lighting is OFF unless all of the controls in items (i) through (iii) are calling for the controlled lights to be ON. An override control that turns lighting ON shall not be allowed unless the override automatically returns the lighting controls to their normal operation within 6 hours.

i. Controlled by a manual ON and OFF switch ~~that does not override to ON the automatic actions of items ii or iii below~~; and

ii. Controlled by a motion sensor. ~~not having an override or bypass switch that disables the motion sensor, or controlled by a motion sensor having a temporary override switch which temporarily bypasses the motion sensing function and automatically reactivates the motion sensor within 6 hours~~

iii. Controlled by one of the following methods:

a. Photocontrol. ~~not having an override or bypass switch that disables the photocontrol~~; or

b. Astronomical time clock. ~~not having an override or bypass switch that disables the astronomical time clock,~~ ~~and which~~ that is programmed to automatically turn the outdoor lighting OFF during daylight hours; or

c. Energy management control system which meets all of the following requirements:

~~At a minimum provides~~ Provides the functionality of an astronomical time clock in accordance with Section 110.9; meets the Installation Certification requirements in Section 130.4; meets the requirements for an EMCS in Section 130.5; ~~does not have an override or bypass switch that allows the luminaire to be always ON;~~ and, is programmed to automatically turn the outdoor lighting OFF during daylight hours.

B. For low-rise multi-family residential buildings, outdoor lighting for private patios, entrances, balconies, and porches; and outdoor lighting for residential parking lots and residential carports with less than eight vehicles per site shall comply with one of the following requirements:

i. Shall comply with Section ~~150.0(k)9A~~ 150.0(k)3A; or

ii. Shall comply with the applicable requirements in Sections 110.9, 130.0, 130.2, 130.4, 140.7, and 141.0.

C. For low-rise residential buildings with four or more dwelling units, outdoor lighting not regulated by Section ~~150.0(k)9B~~ 150.0(k)3B or Section ~~150.0(k)9D~~ 150.0(k)3D shall comply with the applicable requirements in Sections 110.9, 130.0, 130.2, 130.4, 140.7, and 141.0.

D. Outdoor lighting for residential parking lots and residential carports with a total of eight or more vehicles per site shall comply with the applicable requirements in Sections 110.9, 130.0, 130.2, 130.4, 140.7, and 141.0.

TABLE 150.0-A. CLASSIFICATION OF HIGH EFFICACY ~~AND LOW EFFICACY~~ LIGHT SOURCES

High Efficacy Light Sources Luminaires ~~manufactured, designed and rated for use~~ installed with only the lighting technologies in this ~~column~~ table shall be classified as high efficacy:	
Light sources in this column are classified as high efficacy but are **not** required to comply with Reference Joint Appendix JA8.	Light Sources in this column shall be certified to the Commission as High Quality, High Efficacy Light Sources in accordance with Reference Joint Appendix JA8 and be labeled as meeting JA8.
1. Pin-based ~~linear or compact~~ fluorescent lamps with electronic ballasts. ~~Compact fluorescent lamps ≥ 13 watts shall have 4 pins for compliance with the electronic ballast requirements in Section 150.0(k)1D.~~	~~4.~~1. GU-24 sockets ~~rated for~~ containing LED ~~lamps~~ light sources. 2.-Light sources in recessed luminaires. Note that recessed luminaires shall not have screw bases regardless of lamp type as described in Section 150.0(k)1C.

2. Pulse-start metal halide lamps. 3. High pressure sodium lamps. 4. Luminaires with hardwired high frequency generator and induction lamp. 5. GU-24 sockets ~~rated for compact fluorescent lamps~~ containing light sources other than LEDs; including but not limited to compact fluorescent lamps and induction lamps. Note CA Title 20 Section 1605(k)3 does not allow incandescent sources to have a GU-24 base.	3. All other light sources including those with screw bases. ~~6. Luminaires using LED light sources which have been certified to the Commission as high efficacy in accordance with Reference Joint Appendix JA8.~~ ~~7. Luminaire housings rated by the manufacturer for use with only LED light engines.~~ 8. ~~Induction lamps~~. ~~**Note:** Adaptors which convert an incandescent lamp holder to a high-efficacy luminaire shall not be used to classify a luminaire as high efficacy.~~

~~**High Efficacy Light Sources**~~ ~~Luminaires manufactured, designed and rated for use with only lighting technologies in this column shall be classified as high efficacy:~~	~~**Low Efficacy Light Sources**~~ ~~Luminaires manufactured, designed or rated for use with any of the lighting technologies in this column shall be classified as low efficacy.~~
~~1. Pin-based linear or compact fluorescent lamps with electronic ballasts. Compact fluorescent lamps ≥ 13 watts shall have 4 pins for compliance with the electronic ballast requirements in Section 150.0(k)1D.~~ ~~2. Pulse-start metal halide lamps.~~ ~~3. High pressure sodium lamps.~~ ~~4. GU-24 sockets rated for LED lamps.~~ ~~5. GU-24 sockets rated for compact fluorescent lamps.~~ ~~6. Luminaires using LED light sources which have been certified to the Commission as high efficacy in accordance with Reference Joint Appendix JA8.~~ ~~7. Luminaire housings rated by the manufacturer for use with only LED light engines.~~ ~~8. Induction lamps.~~	~~1. Line-voltage lamp holders (sockets) capable of operating incandescent lamps of any type.~~ ~~2. Low-voltage lamp holders capable of operating incandescent lamps of any type.~~ ~~3. High efficacy lamps installed in low-efficacy luminaires, including screw base compact fluorescent and screw base LED lamps.~~ ~~3. Mercury vapor lamps.~~ ~~4. Track lighting or other flexible lighting system which allows the addition or relocation of luminaires without altering the wiring of the system.~~ ~~6. Luminaires using LED light sources which have not been certified to the Commission as high efficacy.~~ ~~7. Lighting systems which have modular components that allow conversion between high-efficacy and low-efficacy lighting without changing the luminaires' housing or wiring.~~ ~~8. Electrical boxes finished with a blank cover or where no electrical equipment has been installed, and where the electrical box can be used for a luminaire or a surface mounted ceiling fan.~~

~~**Note:** Adaptors which convert an incandescent lamp holder to a high-efficacy luminaire shall not be used to classify a luminaire as high efficacy.~~	

~~*TABLE 150.0-B MINIMUM REQUIREMENTS FOR OTHER LIGHT SOURCES TO QUALIFY AS HIGH EFFICACY*~~

~~**Use this table to determine luminaire efficacy only for lighting systems not listed in** TABLE **150.0**-A~~	
~~**Luminaire Power Rating**~~	~~**Minimum Luminaire Efficacy to Qualify as High Efficacy**~~
~~5 watts or less~~	~~30 lumens per watt~~
~~over 5 watts to 15 watts~~	~~45 lumens per watt~~
~~over 15 watts to 40 watts~~	~~60 lumens per watt~~
~~over 40 watts~~	~~90 lumens per watt~~
~~**Note:** Determine minimum luminaire efficacy using the system initial rated lumens divided by the luminaire total rated system input power.~~	

APPENDIX 1-A STANDARDS AND DOCUMENTS REFERENCED IN THE ENERGY EFFICIENCY REGULATIONS

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

NEMA SSL 7A-2013	"Phase Cut Dimming for Solid State Lighting: Basic Compatibility"
Available from:	1300 North 17th Street, Suite 1752 Rosslyn, VA 22209 703-841-3200 www.nema.org

6.2 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)

ANSI C82.77 is the American National Standard for Harmonic emission limits - related power quality requirements for lighting equipment (ANSI C82.77-2002)

CIE 13.3 is the International Commission on Illumination (Commission Internationale de l'Eclairage) document titled "Method of Measuring and Specifying Colour Rendering Properties of Light Sources," 1995 (CIE 13.3-1995)

CIE 15 is the International Commission on Illumination (Commission Internationale de l'Eclairage) document titled "Technical Report: Colorimetry," 2004 (CIE 15:2004)

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.

COLOR RENDERING INDEX (CRI). The ability of a light source to reflect the color of illuminated objects with fidelity relative to ideal or natural light sources of the same color temperature. CRI is calculated according to CIE 13.3

CORRELATED COLOR TEMPERATURE (CCT). Description of color of light relative to the chromaticity of the radiative emission of heated black body and reported in temperature units of Kelvin according to CIE 15

Code of Federal Regulations 10 CFR 430.23(q) is a section from the Code of Federal Regulations entitled § 430.23 "Test procedures for the measurement of energy and water consumption" with subsection (q) entitled "Fluorescent Lamp Ballasts."

Code of Federal Regulations 10 CFR 430 Subpart B, Appendix R is a section from the Code of Federal Regulations entitled § 430.23 "Test procedures for the measurement of energy and water consumption" with subsection (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 430.23 (r))

Code of Federal Regulations 10 CFR 430 Subpart B, Appendix W is a section from the Code of Federal Regulations entitled § 430.23 "Test procedures for the measurement of energy and water consumption" with subsection (w) entitled "Uniform Test Method for Measuring the Energy Consumption of Medium Base Compact Fluorescent Lamps." (10 CFR 430.23 (w))

Code of Federal Regulations 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 § 430.23 "Test procedures for the measurement of energy and water consumption" with subsection (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." (10 CFR 430.23 (bb))

Duv is defined as the closest distance from the Planckian locus on the (u', 2/3v') chromaticity diagram (Equivalent to the CIE 1960 (u, v) diagram, now obsolete)

ENERGY STAR Start Time Test Method is the ENERGY STAR program document entitled "ENERGY STAR Program Requirements for Lamps Version 1.0 – Start Time Test Method – Final" (August-2013)

ENERGY STAR Ambient Temperature Life Test Method is the ENERGY STAR program document entitled "ENERGY STAR Program Requirements for Lamps Version 1.0 - Ambient Temperature Life Test Method – Fina"l (August-2013)

ENERGY STAR Elevated Temperature Light Output Ratio Test Method is the ENERGY STAR program document entitled "ENERGY STAR Program Requirements for Lamps Version 1.0 – Elevated Temperature Light Output Ratio Test Method – Final" (August-2013)

ENERGY STAR Elevated Temperature Life Test Method is the ENERGY STAR program document entitled "ENERGY STAR Program Requirements for Lamps Version 1.0 – Elevated Temperature Life Test Method – Final" (August-2013)

ENERGY STAR Product Specification for Lamps Noise Recommended Practice is the ENERGY STAR program document entitled, "ENERGY STAR Program Requirements for Lamps Version 1.0 – Noise Recommended Practice – Final" (August-2013).[9]

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)

IES LM-51, is the Illuminating Engineering Society document titled, "Electrical and Photometric Measurements of High Intensity Discharge Lamps." (IES LM-51-13)

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)

NEMA SSL 7A is the National Electrical Manufacturers Association document titled "Phase Cut Dimming for Solid State Lighting: Basic Compatibility," 2013. (NEMA SSL 7A-2013)

UL 1598 is an Underwriters Laboratory document titled, "Luminaires." (UL 1598 3d Edition 2008)

[9] As of Fall 2014 ENERGY STAR is considering revisions to its recommended test method for audible noise due to comments they received indicating that this test method could be simplified. If ENERGY STAR makes updates before Title 24 adoption, Title 24 should adopt the most recent version. Comments received indicate that this recommended test method could be simplified.

ISO/IEC 17011 is an International Standards Organization/ International Electrotechnical Commission document titled, "Conformity assessment -- General requirements for accreditation bodies accrediting conformity assessment bodies." Reconfirmed in 2008. (ISO/IEC 17011:2004)

ISO/IEC 17020 is an International Standards Organization/ International Electrotechnical Commission document titled, "Conformity assessment -- Requirements for the operation of various types of bodies performing inspection." (ISO/IEC 17020:2012)

ISO/IEC 17025 is an International Standards Organization/ International Electrotechnical Commission document titled, "General requirements for the competence of testing and calibration laboratories." (ISO/IEC 17025:2005)

Appendix JA8 – Qualification Requirements for Residential Luminaires Using ~~LED~~ High Quality, High Efficacy Light Sources

To qualify as a residential high efficacy luminaire using a High Quality, High Efficacy ~~Light Emitting Diode (LED) as the~~ light source ~~(as defined in IES LM-80-2008)~~, the ~~LED light engine (as defined in ANSI/IES RP-16-2010)~~ (including ballast and driver if applicable), the light source used in the luminaire shall be certified to the Energy Commission according to all of the following requirements, or by a method approved by the Executive Director. If the ~~LED light engine~~ light source is integral with the luminaire then the entire luminaire shall meet the same requirements. ~~LED light engine (s) and integral LED luminaires(s) are referred to as LED luminaire(s) below.~~

~~(a) Shall be manufactured for use in residential applications. LED luminaires not intended for use in residential applications, LED landscape luminaires, and luminaire housings not containing a light engine shall not be certified to the Energy Commission for the purpose of complying with Joint Appendix JA-8.~~

JA8.1 Certification of Test Apparatus and Test Labs

~~(g)~~ ~~The integral LED luminaire or LED light engine~~ The light source under test shall be tested in a Underwriters Laboratory (UL) 1598 testing apparatus in a testing laboratory participating in the ISO/IEC 17025, by the National Voluntary Laboratory Accreditation Program (NVLAP) or other laboratory accreditation body operating in accordance with ISO/IEC 17011 and produced under an ongoing inspection program carried out by a Type A inspection body in accordance with ISO/IEC 17020, accredited to ISO/IEC 17020 by an accreditation body operating in accordance with ISO/IEC 17011. Maintain status as an International Laboratory Accreditation Cooperation Mutual Recognition Agreement (ILAC MRA) signatory.

JA8.2 Efficacy

~~(b)~~ The efficacy of the light source ~~integral LED luminaire or LED light engine~~ when tested in accordance with the following test methods ~~IES LM-79- 2008~~, shall be equal to or greater than 45 lumens/Watt, where efficacy is the luminous flux of the light source divided by the input watts. ~~the efficacies contained in TABLE JA-8~~ .

- Incandescent and halogen reflector lamps: 10CFR 430.23(r).
- Incandescent non-reflector lamps: 10CFR 430.23(r).

- Medium base compact fluorescent lamps: 10 CFR 430.23(w).
- General service fluorescent lamps: 10CFR 430.23(r).
- 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.
- Other applicable test procedure approved by the Executive Director.

JA8.3 Power factor

Light sources shall have a power factor of 0.90 or greater when operated at their full rated power (as defined by the appropriate test methods listed in JA8.2), when tested in accordance with Section 6 and 7 of ANSI C82.77, notwithstanding scope.

JA8.4 Correlated Color Temperature (CCT)

~~(c)~~ ~~When designed or rated for indoor use~~ All light sources, except lamps with a GU-24 base, shall be capable of providing a Correlated Color Temperature (CCT) ~~that includes at least one point~~ ~~within the range of~~ ~~2700K to 4000~~that is 3000 Kelvin or less and within-0.0033 Duv of the black body locus in the 1976 CIE color space when tested in accordance with one of the following test methods: ~~; when designed or rated for outdoor use shall be capable of providing a nominal CCT that includes at least one point within the range of 2700K to 5000K; with tolerance defined as in ANSI C78-377-2008.~~

> ~~**Exception to Section (c):** Monochromatic LEDs that are only for decorative purposes~~

- Incandescent and halogen reflector lamps*:* IES LM-20.
- Incandescent non-reflector lamps: IES LM-45.
- General service fluorescent lamps: 10CFR 430.23(r).
- Single ended compact fluorescent lamps: IES LM-66.
- Fluorescent lamps that are not single ended 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.
- Other applicable test procedure approved by the Executive Director.

JA8.5 Color Rendering: Minimum CRI and R9

~~(d)~~ ~~Shall be capable of providing~~ Light source shall provide a minimum Color Rendering Index (CRI) of 90 and a minimum color rendering R9 value (red) of 50, when tested in accordance with the appropriate test methods in section JA8.4 above.

> ~~**Exception 1 to Section (d):** Monochromatic LEDs that are only for decorative purposes~~

~~(e) An LED light engine shall be capable of being installed in luminaire housing without using any type of base or socket used for incandescent lamps; it may include a GU-24 or~~

~~modular quick connect, but shall not include screw base sockets or adaptors of type and size E12 through E39.~~

~~(f) An LED lamp, integrated or non-integrated type in accordance with the definition in ANSI/IES RP-16-2010, shall not be certified to the Energy Commission as a high efficacy luminaire or high efficacy light engine, and shall not be classified as a high efficacy luminaire for compliance with Title 24, Part 6 of the CCR.~~

JA8.6 Dimmability, Dimmer Compatibility, Reduced Flicker Operation and Low Noise

Light source shall be dimmable down to 10% light output.

LED-based light sources that are designed to be controlled by phase-cut dimmers shall meet the requirements of NEMA Standard SSL7A as Type 1 or Type 2 products. When tested on a NEMA SSL7A compliant dimmer, source must be able to dim to 10% or lower. LED systems designed to be dimmed by controls other than phase cut dimmers including powerline carrier, digital signal, and 0-10VDC control signal, must be able to dim to 10% or lower when tested on at least one of these dimmer types.

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

Light source shall not emit noise above 24dBA measured at 1 meter or less from the light source, when tested at 100% and 20% of full light output in accordance with ENERGY STAR Product Specification for Lamp Noise, Recommended Practice.

JA8.7 Light Output: Start Time

Light source shall have start time no greater than 0.3 seconds as measured in accordance with ENERGY STAR Program Requirements for Lamps Start Time Test Method notwithstanding scope.

JA8.8 Rated Life, and Warranty

Rated Life: Light source shall have a minimum rated lifetime of 15,000 hrs as listed on the lamp, its base or packaging, product literature or point-of-purchase materials, either printed or electronic.

Warranty: Light source shall have five year manufacturer warranty (based on 1,200 h/yr)

JA8.9 Lumen Maintenance and 6,000 hour survival rate.

All lighting products shall comply with the lumen maintenance and 6,000 hour survival rate requirements in Section JA8.9.1 at ambient temperatures or in Section JA8.9.2 at elevated temperatures. Ten lighting products per model shall be tested with 5 units tested base-up and 5 units tested base-down unless the manufacturer restricts specific use or position. If position is restricted, all units shall be tested in restricted position.

JA8.9.1 Ambient Temperature Life Test

The following light sources shall be tested in accordance with the ENERGY STAR Ambient Temperature Life Test, in an ambient temperature condition between 20°C and 35°C and satisfy the lumen maintenance and 6,000 hour survival rate criteria.

- Omnidirectional lamps < 10 watts
- Omnidirectional lamps labeled “not for use in enclosed fixtures” on the lamp and lamp packaging
- Lamps labeled “not for use in recessed fixtures” on the lamp and lamp packaging
- Light sources integral to the fixture.
    - If luminaire with integral light source is designed to be recessed, the luminaire shall be ICAT (insulation contact air tight) rated in accordance with Title 24, part 6 Section 150.0(k)1C(i and ii) and tested with sides and top of luminaire in direct contact of least 12" of R-38 fiberglass insulation.

Lumen Maintenance Criteria: Minimum percentage of 0-hour light output after a 6,000 hour test shall be 86.7% measured in accordance with the ENERGY STAR Ambient Temperature Life Test Method, notwithstanding scope.

6,000 Hour Survival Rate: 90% of tested units shall be operational at 6,000 hours measured in accordance with the ENERGY STAR Ambient Temperature Life Test Method, notwithstanding scope.

JA8.9.2 Elevated Temperature Life Test

The following light sources shall meet the lumen maintenance and 6,000 hour survival rate criteria when measured in accordance with the ENERGY STAR Elevated Temperature Life Test.

- Omnidirectional light sources 10 Watts and greater that that are not labeled "not for use in enclosed luminaires" or "not for use in recessed luminaires"
- All other lamp types (including retrofit kits) that are not labeled "not for use in enclosed luminaires" or "not for use in recessed luminaires."

The Option A test method ENERGY STAR Elevated Temperature Life Test shall be modified as follows: Light source shall be tested in an ICAT (insulation contact, air-tight) recessed luminaire of the appropriate size for the source under test. The ICAT luminaire shall be listed for zero clearance insulation contact (IC) by Underwriters Laboratories or other nationally recognized testing/rating laboratory and have a label that certifies that the luminaire is airtight with air leakage less than 2.0 CFM at 75 Pascals when tested in accordance with ASTM E283. The sides and top of ICAT recessed luminaire shall be in direct contact of least 12" of R-38 fiberglass insulation.

Light sources tested in accordance with the ENERGY STAR Elevated Temperature Life Test, notwithstanding scope, shall use the modified Option A test method as described above or Option B or C with an operating temperature of:

- 45°C +/-5°C for omnidirectional sources between 10 and 20 Watts
- 45°C +/-5°C for all sources other than omnidirectional no greater than 20 Watts.
- 55°C +/-5°C for all sources greater than 20 Watts.

Lumen Maintenance Criteria: Minimum percentage of 0-hour light output after a 6,000 hour test shall be 86.7% measured in accordance with the ENERGY STAR Elevated Temperature Life Test, notwithstanding scope.

6,000 Hour Survival Rate: 90% of tested units shall be operational at 6,000 hours measured in accordance with the ENERGY STAR Elevated Temperature Life Test, notwithstanding scope.

Any omnidirectional lamps 10 watts or greater that have been labeled JA8 compliant but are not compliant with the elevated temperature life test in this section (JA8.9.2) shall be labeled "not for use in enclosed fixtures" on the lamp and lamp packaging.

Any sources that are not integral to a luminaire, are not omnidirectional, and have been labeled JA8 compliant but are not compliant with the elevated temperature life test in this section (JA8.9.2) shall be labeled "not for use in recessed fixtures" on the lamp and lamp packaging.

(g) The integral LED luminaire or LED light engine under test shall be tested in a Underwriters Laboratory (UL) 1598 testing apparatus in a testing laboratory participating in the ISO/IEC 17025, by the National Voluntary Laboratory Accreditation Program (NVLAP) or other laboratory accreditation body operating in accordance with ISO/IEC 17011 and produced under an ongoing inspection program carried out by a Type A inspection body in accordance with ISO/IEC 17020, accredited to ISO/IEC 17020 by an accreditation body operating in accordance with ISO/IEC 17011.

(h) Each integral lamp, LED luminaire or LED light engine tested shall produce the same quantity and quality of light. An integral LED luminaire or LED light engine under test producing different Correlated Color Temperature (CCT), Color Rendering Index (CRI), total flux (per linear foot for linear systems) or other quantitative and qualitative differences in light shall be separately tested and separately certified to the Energy Commission.

(i) A worst case test may be used to certify a group of integral LED luminaires or LED light engines having the same quantity and quality of light in accordance with section (h).

(j) For determining efficacy, the input wattage of the integral LED luminaire or LED light engine under test shall be determined as follows:

1. For single LED luminaires, use the maximum rated input wattage of the luminaire.

2. When multiple LED light engines are connected to a single power supply, all possible combinations shall be tested to determine the various input wattages and efficacies for the power supply under test. The combination providing the worst case efficacy shall be the system efficacy.

3. LED luminaires, installed on lighting track that is capable of being used with multiple lighting technologies, shall be treated as single LED luminaires in accordance with section (j)1. Lighting track capable of accommodating any non-LED lighting technologies shall not be certified as LED lighting.

JA8.10 Product labeling

(k) For single LED luminaires, m Maximum rated input wattage, total luminous flux, CCT, and CRI of the integral lamp, LED luminaire or LED light engine light source under test shall be listed on a permanent, pre-printed, factory-installed label on the light source circuit board, light engine, or luminaire light source housing. Product shall contain marking indicating "CA T-24

JA8 Compliant." Product shall contain a marking that indicates the date of manufacture in the following format: "Date of Manuf: MM/YYYY"

~~(l) For LED systems in accordance with section (j)2, all possible wattage combinations, luminous flux, CCT, CRI, and efficacies of each of possible combination of the integral LED luminaire or LED light engine under test shall be listed on a permanent, pre-printed, factory-installed label on the power supply, or published in manufacturer's catalogs.~~

JA 8.11 Test Report and Data Format

For all system where the reporting of flicker is required, the test data shall be submitted to the California Energy Commission in the format specified in Table JA-8.

TABLE JA-8. DATA SUBMITTED TO THE CALIFORNIA ENERGY COMMISSION FOR CERTIFICATION AS A HIGH QUALITY, HIGH EFFICACY LIGHT SOURCE

Required Information	**Permissible Answers**	**Compliance Threshold**
Manufacturer, Model number, Description		
Light Source Type	LED, OLED, Fluorescent, HID, Incandescent, Other	
GU-24 Base?	Yes/No	
Lamp type	Omnidirectional, Directional, Decorative, N/A	
Accredited NVLAP test lab?	Yes/No	Yes
Light Source Initial Efficacy	Number lm/W	≥ 45 lm/W
Power factor at Full Rated Power	0 – 1 Fraction	≥ 0.90
Correlated Color Temperature (CCT)	Number Kelvin	If not GU-24, ≤ 3000 Kelvin GU-24 base, any value
Duv	Number Duv	≥ -0.0033 and ≤ +0.0033
Color Rendering Index (CRI)	0-100	≥ 90
Color Rendering R9 (red)	0-100	≥ 50
Minimum dimming level	0-100%	≤ 10%
Dimming control	Phase cut control, powerline carrier, digital, 0-10 VDC, other	
NEMA SSL 7 compatible	Yes/No	If powerline carrier, digital, 0-10 VDC, other, "Yes" or "No" If phase cut control, "Yes"
Flicker: Amplitude Modulation ≤200 Hz @ 100% Amplitude Modulation ≤200 Hz @ 20% light output	0-100% 0-100%	≤ 30% ≤ 30%
Noise in dBA 100% light output Noise in dBA 20% light output	Value dBA Value dBA	≤ 24 dBA ≤ 24 dBA
Start time	Value Seconds	≤ 0.3 sec

Required Information	Permissible Answers	Compliance Threshold
6,000 hour lumen maintenance	0-100%, N/A	≥ 86.7% or NA for sources complying w/ elevated temperature lumen maint
Rated life	Value Hours	≥ 15,000 hours
3,000 hour survival rate	0-100%	≥ 90%
Manufacturer Warranty	Value Years	≥ 5 years
Elevated temperature lumen maintenance	0-100%	If recessed/ enclosed fixture:≥ 86.7% Otherwise no requirement
Product labeling		
Maximum rated input wattage	Yes/No	Yes
Full output luminous flux (lumens)	Yes/No	Yes
CCT	Yes/No	Yes
CRI	Yes/No	Yes
"CA T-24 JA-8 Compliant"	Yes/No	Yes
"Date of manuf" with date	Yes/No	Yes
"not for use in enclosed fixtures" "not for use in recessed fixtures"	Omnidirectional not passing elevated temp test All other not passing elevated temp test	

TABLE JA-8 HIGH EFFICACY QUALIFICATION REQUIREMENTS FOR LUMINAIRES OR LIGHT ENGINES USING LED LIGHT SOURCES

Power Rating per Light Source Integral Lamp, LED Luminaire, or LED Light Engine and Driver Under Test	Minimum Efficacy (Lumens Per Watt)
5 watts or less	30
over 5 watts to 15 watts:	45
over 15 watts to 40 watts:	60
over 40 watts:	90

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) above a given cut-off frequency (frequency above which the signal is filtered to remove high frequency components). 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 systems that utilize the same control protocol. If a proprietary protocol is used control dimming, the results 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 UUT (unit under test). Provision shall be made so that conditions in the test enclosure are able to be maintained at a constant temperature of 25°C ±5°C.

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 record rate 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 430.23(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 lamps types is not required.

Input power: Input power to the UUT (unit under test) shall be provided at the rated primary voltage and frequency within 0.5% for both voltage and frequency. When ballasts are labeled for a range of primary voltages, the ballasts should be operated at the primary application voltage. 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 percent of the fundamental.

Temperature: Temperature shall be maintained at a constant temperature of 25°C ±5°C.

Dimming levels: 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 operating the light source at the maximum setting provided by the control. 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

Lamp stabilization. Lamp stabilization for the initial flicker measurement out of the series of flicker measurements at different dimming levels and/or with different dimmers shall be determined in accordance with:

- Incandescent and halogen reflector lamps*:* 10CFR 430.23(r).
- Incandescent non-reflector lamps: 10CFR 430.23(r).
- Medium Base Compact Fluorescent Lamps: 10 CFR 430.23(w).
- General service fluorescent lamps: 10CFR 430.23(r).
- 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.Other applicable test procedure approved by the Executive Director.

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

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 (in footcandles or volts) from test equipment with readings taken at intervals of no greater than 50 microseconds. These readings are compiled for an equipment period of no less than two seconds into a comma separated data file (*.csv).

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. Windowing procedures shall use at least one half of the data with no gaps or manipulation of the data within the window of data selected.
3. Filter frequency data to evaluate the data under four additional different conditions: frequencies under 40 Hz and frequencies under 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.[10]
4. Transform the filtered frequency-domain data back into the time-domain using an inverse Fourier transform technique.[11].
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 is required, the test data shall be submitted to the California Energy Commission in 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 from calculations performed on the raw data.

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

Data	Units/Format
Test Date	2 comma separated text strings: “Test Date”, and: 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, and: Company, Contact Name, Phone Number, e-mail address
Entity submitting results	5 comma separated text strings: Entity submitting results, and: Company, Contact Name, Phone Number, e-mail address
Product submitted for certification	5 comma separated text strings: Product for certification, and: Product type (dimmer, ballast or driver, lamp etc.) manufacturer, model number, other description
Tested lighting system component: Dimmer	5 comma separated text strings: Dimmer, and: Manufacturer, model number, other description (enter NA if not applicable)
Tested lighting system component: light source (lamp or light engine)	5 comma separated text strings: Light source, and: Manufacturer, model number, other description
Tested lighting system component: Ballast or Driver	5 comma separated text strings: Ballast or Driver, and: Manufacturer, model number, other description (enter NA if not applicable also applies to integral lamps)
Recording interval	1 text string and 1 number: “Recording interval” and value in sec (no greater than 0.00005 sec)
Count of data points	1 text string and 1 number: “Count of data points” and value (number of points, no less than 40,000 points)

[10] 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.

[11] 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	
Data	Units/Format
Equipment Measurement Period	1 text string and 1 number: "Equipment measurement period" and 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 Percent,80 Percent,50 Percent,20% or minimum"
Fraction of rated light output integrated over measurement period at 100%, 80%, 50% and the greater of 20% or minimum fraction of light output.	1 text string and 4 numbers: "Measured fraction of max output," and fractional measured values for 100%, 80%, 50% and the greater of 20% or minimum light output.
Amplitude modulation separator	1 text string and 4 numbers: "Cut-off Frequency Hz for dimming fractions" and same 4 values from line above
Amplitude modulation 40 Hz cut-off	5 comma separated numbers: Cut-off Hz (40) and calculated percent amplitude modulation for cut-off frequency for each nominal dimming level: (100%, 80%, 50% and the greater of 20% or minimum fraction of light output)
Amplitude modulation 90 Hz cut-off	5 comma separated numbers:: Cut-off Hz (90) and calculated percent amplitude modulation for cut-off frequency for each nominal dimming level: (100%, 80%, 50% and the greater of 20% or minimum fraction of light output)
Amplitude modulation with 200 Hz cut-off	5 comma separated numbers: Cut-off Hz (200) and calculated percent amplitude modulation for cut-off frequency for each nominal dimming level: (100%, 80%, 50% and the greater of 20% or minimum fraction of light output)
Amplitude modulation with 400 Hz cut-off	5 comma separated numbers: Cut-off Hz (400) and calculated percent amplitude modulation for cut-off frequency for each nominal dimming level: (100%, 80%, 50% and the greater of 20% or minimum fraction of light output)
Amplitude modulation with 1,000 Hz cut-off	5 comma separated numbers: Cut-off Hz (1,000) and calculated percent amplitude modulation for cut-off frequency for each nominal dimming level: (100%, 80%, 50% and the greater of 20% or minimum fraction of light output)
Amplitude modulation of unfiltered data	1 text string and 4 numbers: "Unfiltered Percent Amp Mod" and calculated percent amplitude modulation, for each dimming level: (100%, 80%, 50% and the greater of 20% or minimum fraction of light output)
Raw data separator	5 comma separated text strings: "Unfiltered raw photometric data for the following fractions of full light output: 100%, 80%, 50% and the greater of 20% or minimum fraction of light output"
Raw data column headers	5 comma separated text strings: "Time stamp (sec), 100% data, 80% data, 50% data, 20% or min data"
Raw Photometric Flicker Waveform (unfiltered) at 100%, 80%, 50% and the greater of 20% or minimum fraction of light output.	4 comma separated data values per row, with the number of rows being the number of data points taken during the test duration. Each row contains the measurement for the unit under test at the following dimmed conditions: 100%, 80%, 50% and the greater of 20% or minimum fraction of light output

6.3 Compliance Manuals

Chapter 6 of the Residential Compliance Manual will need to be revised to reflect the changes in the Standards. The proposed revisions should allow for simplification of the Residential Lighting chapter of the Compliance Manual.

6.4 Compliance Forms

The proposed code change will require some modifications to the residential lighting compliance forms to accommodate the changes in high efficacy requirements and definitions. Compliance forms will need to be able to confirm whether fixtures are high efficacy, and whether lamps comply with JA8 requirements in fixtures that are not automatically qualified as high efficacy. Compliance forms will also need to verify the installation of required controls, in keeping with current forms.

If this proposal is adopted Residential Lighting Compliance Form CF2R-LTG-01-E will need to be revised as follows.

- Section F "Kitchen Lighting" and the calculation sheet are deleted as the wattage calculation is no longer needed to show compliance.
- Section G is "Lighting Integral to Cabinets" is deleted as the cabinet lighting wattage would no longer be calculated.
- Sections H through I would be deleted as the requirements are simplified.
- Section J would be a checklist of rooms where vacancy sensors are required.
- A luminaire schedule would be added that would include Quantity, Description, Model, Recessed (Y/N), Lighting Source, JA-8 lamp (Y/N), Meets High Eff Requirements (Y/N)
- It is likely this form can be simplified further.

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Appendix A: Environmental Impacts Methodology

Greenhouse Gas Emissions Impacts Methodology

The avoided GHG emissions were calculated assuming an emission factor of 353 metric tons of carbon dioxide equivalents ($MTCO_2e$) per GWh of electricity savings. The Statewide CASE Team calculated air quality impacts associated with the electricity savings from the proposed measure using emission factors that indicate emissions per GWh of electricity generated.[12] When evaluating the impact of increasing the Renewable Portfolio Standard (RPS) from 20 percent renewables by 2020 to 33 percent renewables by 2020, California Air Resources Board (CARB) published data on expected air pollution emissions for various future electricity generation scenarios (CARB 2010). The Statewide CASE Team used data from CARB's analysis to inform the air quality analysis presented in this report.

The GHG emissions factor is a projection for 2020 assuming the state will meet the 33 percent RPS goal. CARB calculated the emissions for two scenarios: (1) a high load scenario in which load continues at the same rate; and (2) a low load rate that assumes the state will successfully implement energy efficiency strategies outlined in the AB32 scoping plan thereby reducing overall electricity load in the state.

To be conservative, the Statewide CASE Team calculated the emissions factors of the incremental electricity between the low and high load scenarios. These emission factors are intended to provide a benchmark of emission reductions attributable to energy efficiency measures that could help achieve the low load scenario. The incremental emissions were calculated by dividing the difference between California emissions in the high and low generation forecasts by the difference between total electricity generated in those two scenarios. While emission rates may change over time, 2020 was considered a representative year for this measure.

Avoided GHG emissions from natural gas savings were calculated using an emission factor of 5,303 $MTCO_2e$/million therms (U.S. EPA 2011).

[12] California power plants are subject to a GHG cap and trade program and linked offset programs until 2020 and potentially beyond.

APPENDIX B: JOB CREATION BY INDUSTRY

Table 29 shows total job creation by industry that is expected from all investments in California energy efficiency and renewable energy (UC Berkeley 2010b, Appendix D). While it is not specific to codes and standards, this data indicates the industries that generally will receive the greatest job growth from energy efficiency programs.

Table 29: Job Creation by Industry

NAICS	Industry Description	Direct Jobs	
		2015	2020
23822	Plumbing, Heating, and Air-Conditioning Contractors	8,695	13,243
2361	Residential Building Construction	5,072	7,104
2362	Nonresidential Building Construction	5,345	6,922
5611	Office Administrative Services	2,848	4,785
23821	Electrical Contractors	3,375	4,705
551114	Corporate, Subsidiary, and Regional Managing Offices	1,794	3,014
54133	Engineering Services	1,644	2,825
5418	Advertising and Related Services	1,232	2,070
334413	Semiconductor and Related Device Manufacturing	1,598	1,598
541690	Other Scientific and Technical Consulting Services	796	1,382
23831	Drywall and Insulation Contractors	943	1,331
3334	Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equipment Manufacturing	453	792
3351	Electric Lighting Equipment Manufacturing	351	613
926130	Regulation and Administration of Communications, Electric, Gas, Other Utilities	322	319
23816	Roofing Contractors	275	277
54162	Environmental Consulting Services	151	261
484210	Used Household and Office Goods Moving	137	239
23835	Finish Carpentry Contractors	120	120
23829	Other Building Equipment Contractors	119	113
3352	Household Appliance Manufacturing	63	110
other	other	454	547
	Total	**35,788**	**52,369**

APPENDIX C 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);
```