ADAMS BROADWELL JOSEPH & CARDOZO
A PROFESSIONAL CORPORATION
ATTORNEYS AT LAW
520 CAPITOL MALL, SUITE 350
SACRAMENTO, CA 95814-4721
TEL: (916) 444-6201
FAX: (916) 444-6209
tenslow@adamsbroadwell.com

DANIEL L. CARDOZO
CHRISTINA M. CARO
THOMAS A. ENSLOW
TANYA A. GULESSERIAN
LAURA E. HORTON
MARC D. JOSEPH
RACHAEL E. KOSS
JAMIE L. MAULDIN
ADAM J. REGELE
ELLEN L. WEHR

SO. SAN FRANCISCO OFFICE
601 GATEWAY BLVD., SUITE 1000
SO. SAN FRANCISCO, CA 94080
TEL: (650) 589-1660
FAX: (650) 589-5062

California Energy Commission
DOCKETED
15-BSTD-01
TN # 76120
AUG 10 2015

August 10, 2015

VIA EMAIL ONLY

California Energy Commission
Attn: Docket 15-BSTD-01
Dockets Office, MS-4
1516 Ninth Street
Sacramento, CA 95814
Docket@energy.ca.gov

Re: Docket No. 15-BSTD-01 - Adoption of 15 Day Language for the 2016 Building Energy Efficiency Standards - Opposition to Proposed Lighting Retrofit Control and Acceptance Test Exemptions - Section 141.0(b)(2) and Table 141.0-F

Dear Commissioners and Commission staff:

On behalf of the California chapters of the National Electrical Contractors Association ("NECA"), the California International Brotherhood of Electrical Workers locals ("IBEW"), and the California State Labor Management Cooperation Committee for the International Brotherhood of Electrical Workers and the National Electrical Contractors Association ("LMCC"), I am writing to oppose the proposed amendments to Section 141.1, subdivision (b)(2) of the 2016 Building Energy Efficiency Standards that would weaken, rollback and water down current lighting control, lighting power and acceptance test requirements for lighting retrofits in existing nonresidential buildings. NECA, IBEW and the LMCC represent over a 1,000 contractors and over 30,000 electricians who install lighting systems and lighting controls in California.

NECA, IBEW and the LMCC strongly support the Governor's goal of doubling the efficiency of existing buildings over the next 15 years. This mandate is not achievable, however, unless energy efficiency standards for existing building alterations and modifications are substantially advanced every triennial cycle.

We previously submitted comments on an earlier 15 day version of these proposals. These comments address the revised version and the supporting documents relied upon to justify this proposal. As discussed below, even with the changes to these proposals, retrofits subject to 2016 requirements will be significantly less efficient than retrofits subject to current 2013 requirements.

The 2013 Code currently requires most lighting system alterations, luminaire modifications and lighting wiring alterations in nonresidential buildings to install the following advanced lighting systems: (1) Section 130.1(a) area controls; (2) Section 130.1(b) multi-level controls (or in some limited cases one-step controls); (3) Section 130.1(c) shut-off controls; and (4) Section 130.1(d) Automatic Daylight Controls. These lighting controls are an essential component to meeting California's energy efficiency goals. Lighting controls can almost double a retrofit's energy savings over just putting in more efficient LEDs.

In addition, the 2013 Code requires acceptance testing for all retrofits that require installation of controls. Lighting control acceptance tests are necessary to ensure that controls operate correctly so they can achieve their desired energy saving potential instead of just providing illusory paper savings. Studies have found that, without acceptance testing, the actual energy savings achieved by lighting controls may be less than half of what would be achieved with acceptance testing.

The LMCC engaged an independent engineering firm, M. Neils Engineering, to perform an independent evaluation of the potential energy impact from the proposed exemptions. A copy of the report is attached to this letter. M. Neils Engineering found that the Lighting Alteration Savings Analysis relied upon to support the proposed 2016 amendments contains several critical errors and omissions.

When these errors and omissions are corrected, the calculations show that the proposed 2016 lighting retrofit changes will result in a net loss in energy savings of between 168 GWh and 209 GWh per year. This will create a 2016 standard for lighting retrofits that increases energy use in California buildings and costs California rate payers millions over the life of their lighting systems.

Since nonresidential lighting systems typically have a useful lifespan of approximately 15 years, these lost savings will compound every year. Assuming that the 2016 code is effective for three years, **retrofits installed under the 2016 code could consume over 9,400 more gigawatt hours of energy over their lifespan than retrofits installed under the 2013 code.**

By creating significant new loopholes to lighting efficiency requirements for nonresidential retrofits, this proposal will significantly decrease the energy efficiency of lighting retrofits compared to existing code requirements. This roll back of current energy efficiency requirements is contrary to the Governor's goal to double the efficiency of existing buildings in the next 15 years and is inconsistent with the Commission's statutory mandate to adopt building standards that "increase" energy efficiency in buildings. Moreover, these proposals have been proposed in violation of the California Procedure Act and the California Environmental Quality Act. We urge the Commission to reject these proposed amendments.

I. SUMMARY OF PROPOSED TITLE 24 LIGHTING RETROFIT AMENDMENTS

The below amendments proposed for adoption into the 2016 Code create significant new exemptions to current lighting control and acceptance testing requirements for retrofits in existing non-residential buildings. Accordingly, IBEW, NECA, and the NECA-IBEW LMCC respectfully request that these proposed code changes be rejected by the Commission:

A. Proposed Changes to Lighting System Alteration Requirements (Section 141.0, subdivision (b)2.I)

1. New Alternative 35% Power Reduction Compliance Pathway for Alterations.

The 2016 Code Proposal creates a new alternative compliance pathway that exempts lighting alterations from otherwise applicable control and power allowance requirements if the replacement luminaires collectively have at least 35% lower rated power than the existing luminaires being replaced. Under the current 2013 Code, lighting alterations must meet maximum lighting power density ("LPD) requirements (i.e., watts per square feet), and must install applicable automatic

shutoff, area, multi-level, daylighting and demand response controls. Lighting alterations that do not involve changing the area or use of the space are provided an exemption from multi-level, daylighting and demand response control requirements, however, if they maintain an LPD of 85% or less of the maximum allowed for the function area. For modifications with lighting power 85% or less than the lighting power allowance, the 2013 Code still requires installation of area controls and automatic shutoff controls, and also requires installation of two-step (bi-level) lighting controls (instead of multi-level controls).

Alterations taking the new 35% power reduction pathway are required to install area and automatic shutoff controls, but are exempt from multi-level, daylighting and demand response control requirements. In addition to a different threshold, the 35% power reduction pathway differs from the 85% LPD pathway in two significant ways which can result in significantly increased energy use under the 35% pathway. First, the 35% power reduction pathway does not require the installation of the two-step lighting controls that is required under the 85% LPD pathway if multi-level controls are not installed. Second, alterations taking the 35% power reduction pathway are not required to meet any lighting power allowance requirements. Under this pathway, power reduction requirements are capped at 35% even if the reduction would still exceed the maximum lighting power allowance otherwise applicable to the function area. As discussed below, this is a significant difference because the maximum LPD requirement for many key function areas, such as office, retail and hotel occupancies, have been reduced by greater than 35% over the last decade. This means that a 35% power reduction in those occupancies is unlikely to meet either the 85% LPD or the 100% LPD requirements.

2. New Exemption for Alterations that Change the Area of the Enclosed Space or Change the Occupancy Type or Increase the Lighting Power in the Enclosed Space.

Under the 2013 Code, alterations that change the area of the enclosed space (and thus open up walls or ceilings), change the occupancy type, or increase lighting are required to comply with all applicable automatic shutoff, area, multi-level, daylighting and demand response controls and are may not exceed maximum LPD requirements. The 2013 Code provides no exemptions to these requirements for these types of alterations.

In contrast, the 2013 Code provides two exemptions for lighting system alterations that do not change the area of the enclosed space, change the occupancy type or increase the lighting power. First these type of alterations may avoid installation of multi-level, daylighting and demand response control requirements if the lighting uses less than 85% of the maximum allowed power allowance for the given function area. Second, the 2013 Code provides that Lighting System Alterations that do not change the area of the enclosed space, change the occupancy type or increase the lighting power are exempt from all lighting control and maximum LPD requirements if the alterations involve 10% or fewer of the existing luminaires.

The 2016 Code Proposal expands both of these limited exemptions to now cover *all* alterations, including those that change the area of the enclosed space, change the occupancy type or increase the lighting power.

B. Proposed Changes to Luminaire Modification Requirements (Section 141.0, subdivision (b)2.J and Table 141.0-F)

1. Title 24 Compliance Threshold Increased from 40 to 70 Luminaires.

Under the 2016 Code Proposal, the threshold for applying any Title 24 control or LPD requirements to nonresidential lighting modifications is raised from 40 luminaire modifications to 70 luminaire modifications. In addition, the 2016 code *eliminates the per year restriction on this threshold*. 70 Luminaires is generally equivalent to a 7,000 square foot office space. The elimination of the per-year requirement means that that a building owner would be able to modify 7,000 square feet of space *every month* without triggering *any* energy efficiency requirements. Accordingly, an 80,000 square foot building could modify all of its luminaires over a year period without having to comply with any Title 24 control or LPD requirements – *even if the modifications substantially increase power consumption over existing levels*.

2. Elimination of Daylight and Multi-level Control Requirements for All Modifications.

The 2016 Code Proposal only requires luminaire modifications to install area controls and shut-off controls, jettisoning the existing requirement to also install

multi-level and daylighting controls. (Multi-level and daylighting controls are required for modification under the current 2013 Code if lighting power is greater than 85% of the lighting power allowance. For modifications with lighting power 85% or less than the lighting power allowance, the 2013 Code requires installation of two-step (bi-level) lighting controls.)

3. Modifications Allowed to Exceed Lighting Power Allowance.

Under the 2016 Code Proposal, modifications may exceed the maximum LPD allowance in Section 140.6 as long as the modified luminaires collectively have at least 35% lower power consumption ratings compared to the original luminaires. In contrast, the 2013 Code requires modification to comply with the maximum LPD requirements even if compliance with the LPD allowance requires more than a 35% reduction in rated power from the existing lighting. The 2016 Code thus caps the required reduction at 35% *even if the lighting power allowances are not met*. This is not an academic distinction. As discussed below, office, the LPD for retail and hotel function areas has been reduced by more than 35% over the last decade. Accordingly, a 35% reduction of power consumption in these occupancies can still result in an exceedance of the LPD allowance – allowing increased energy consumption over existing requirements.

C. Proposed Changes to Lighting Wiring Alteration Requirements (Section 141.0, subdivision (b)2.K)

1. Eliminates Demand Response Control Requirements.

The 2016 Code Proposal exempts lighting wiring alterations from existing demand response control requirements.

2. Replaces Multi-Level Controls Requirement with a Pre-Wiring Requirement.

The 2016 Code Proposal deletes the existing requirement for lighting wiring alterations to install multi-level controls and replaces it with a requirement to pre-wire for two-level controls.

3. Creates New Exemption From Daylight Control Requirements.

The 2016 Code Proposal exempts lighting wiring alterations from existing daylight control requirements where less than 20 luminaires are located within the primary sidelit daylit zone and the skylit daylit zone.

D. Elimination of Specific Area Control and Automatic Shut-Off Control Requirements for Luminaire Alterations, Modifications and Lighting Wiring Alteration

1. Deletion of Section 130.1(a)(4) Area Control Requirements.

The 2013 Code requires lighting system alterations, luminaire modifications and lighting wiring alterations to comply with *all* the area control requirements set forth in Section 130.1(a).

The 2016 Code Proposal limits this existing requirement by exempting all lighting system alterations, luminaire modifications and lighting wiring alterations from compliance with Section 130.1(a)(4), which requires that: (A) General lighting shall be separately controlled from all other lighting systems in an area; (B) Floor and wall display, window display, case display, ornamental, and special effects lighting shall each be separately controlled on circuits that are 20 amps or less; and (C) When track lighting is used, general, display, ornamental, and special effects lighting shall each be separately controlled.

2. Deletion of Automatic Shut-Off Control Requirements for Display Cases, Corridors, Stairwells and Hotel Guest Rooms.

The 2013 Code requires that luminaire modifications and lighting wiring alterations subject to automatic shut-off control requirements shall comply with all the requirements set forth in Section 130.1(c). The 2016 Code Proposal limits this existing requirement by exempting all modifications and lighting wiring alterations from compliance with numerous provisions of Section 130.1(c), including 130.1, subdivisions (c)(1)(d) [separate controls form general, display, ornamental, and display case lighting], (c)(6)(B) [Library book stack aisle occupancy sensors],

(c)(6)(C) [corridor and stairwell occupancy sensors], (c)(7)(A) [hotel/motel corridor and stairwell occupancy sensors], and (c)(8) [hotel/motel guest room occupancy sensors]. The 2016 Code Proposal also exempts lighting wiring alterations from compliance with a number of additional subdivision of Section 130.1, including subdivisions (c)(2) [prohibition on countdown timer switches], (c)(5) [areas where occupant sensors must shut off all lighting], (c)(6) [additional occupancy sensor requirements for warehouses, corridors and stairwells]; and (c)(7) [parking garages and hotel/motel stairwells and corridors].

E. Acceptance Test Exemption

Under the 2013 Code, all new installations of lighting controls must comply with acceptance test requirements to verify they provide the assumed functionality and energy savings. The 2016 Code Proposal rolls back this requirement by now exempting lighting system alterations, luminaire modifications, lighting wiring alterations and outdoor lighting system alterations from acceptance test requirements where lighting controls are added to control 20 or fewer luminaires.

II. INDEPENDENT ANALYSIS CONFIRMS THAT THE 2016 CODE PROPOSAL WILL RESULT IN SIGNIFICANT LOST ENERGY SAVINGS COMPARED TO MAINTAINING CURRENT CONTROL AND ACCEPTANCE TEST REQUIREMENTS

In its supporting documentation, the California Energy Commission relies on a Lighting Alteration Savings Analysis that compares the energy savings from lighting system alterations, luminaire modifications and lighting wiring alterations under the 2013 California Energy Code requirements with the energy savings from lighting system alterations, luminaire modifications and lighting wiring alterations under the 2016 Code Proposal. The Lighting Alteration Savings Analysis concludes that these amendments would result in an additional 74 Gigawatt-hours (GWh) of energy savings per year as compared to the current 2013 standards.

M. Neils Engineering reviewed the Lighting Alteration Savings Analysis and the other supporting documentation relied upon by the Commission, and identified several critical errors and omissions in the data. When these errors and omissions are corrected, the calculations show that the proposed 2016 lighting retrofit changes will result in a **net loss in energy savings of 168 GWh to 209 GWh *per year***.

This will create a 2016 standard for lighting alterations that **increases energy use** in California buildings. As discussed below, these per year energy losses will compound over the lifespan of the retrofits and may result in more than **9,400 gigawatt hours in total lost energy savings** before these systems are updated again.

Among the errors and omissions found by M. Neils Engineering are the following:

A. Failure to Take Into Account Lost Savings from Elimination of Multi-Level Control Requirements

The Lighting Alteration Savings Analysis incorrectly assumes that the elimination of multi-level control requirements will not result in any energy saving losses beyond what is already lost from the elimination of daylighting control requirements. Multi-level controls, however, also save energy by enabling task tuning, manual dimming/switching, and multiple levels of scheduled dimming. The CASE study on multilevel controls conducted to support the 2013 standards identifies specific energy savings from multi-level control task tuning *that are not associated with other control strategies*. Moreover, the supporting documentation for the Lighting Alterations Savings Analysis sets forth the additional energy savings resulting from the installation of multi-level controls separately from the savings resulting from other controls. Based on these calculations, the proposed elimination of multi-level control requirements will result in 148 GWh per year of lost energy savings that were not accounted for in the Analysis.

B. Failure to Use CEC's Weighted Average Lighting Power Density Calculations

The Lighting Alteration Savings Analysis incorrectly assumes that LPD requirements under the 2016 standards are an average of 20% lower than allowed under the 1998/2001 standards. A building space's maximum LPD depends upon the function of the space. The maximum LPD varies substantially from space to space. Moreover, the percentage reduction of the maximum LPD from the 1998/2001 standards to the 2016 standards also varies greatly. The LPD for some function areas, such as commercial storage, gym or theatre areas have not been reduced at all. On the other hand, the LPD for function areas such as retail, office

and hotel occupancies have each been reduced by more than 35% since the 1998/2001 standards.

The Lighting Alteration Savings Analysis calculates the raw average reduction of each type of function area, but fails to take into account that certain function areas (such as retail, office and hotel areas) represent a much larger percentage of the existing building stock than other function areas. Subsequent to this calculation the CEC prepared a more accurate weighted average LPD reduction calculation based upon the percentage of total square footage of existing buildings represented by each occupancy type. Under this revised percentage, the CEC calculated that the average 2016 LPD savings over pre-2005 Code would be 27%, not 20%.

The CEC, however, failed to update the Lighting Alteration Savings Analysis with this corrected average. Changing the average 2016 LPD savings over vintage LPD savings from 20% to 27% would reduce energy savings by approximately 63 gigawatt hours per year. Even adjusting this calculation to assume that some percentage of lighting retrofits would meet 2005 Code LPD requirements (which the Lighting Alteration Savings Analysis did not do), the additional lost energy savings would still amount to between 22 and 45 gigawatt hours per year.

C. Overestimate of Percentage of Existing Systems with Automatic Shutoff and Multi-Level Controls

The Lighting Alteration Savings Analysis overestimates the fraction of existing lighting systems that already utilize automatic shutoff and multi-level lighting controls. The Analysis assumes there is no way to know how many existing systems use these controls and arbitrarily assumes a usage rate of 50%. This is incorrect, the California Appliance Saturation Survey issued by Itron on behalf of the CPUC in 2014, surveyed approximately 1400 commercial businesses on what types of lighting controls they had installed. Only about 10-30% of large businesses and between 0% and 20% of all other businesses had some form of auto shutoff control. Adjusting the number to 20%, results in an additional 50 GWh per year of lost savings.

D. Rounding Error

The Lighting Alteration Savings Analysis improperly rounded down a reconciliation factor for determining the fraction of total commercial floor space applicable to the 2013 standards from 0.916 to 0.91. This rounding error results in about 0.5 GWh per year of lost savings.

E. Arbitrary and Unsupported Market Share Adjustments

The Lighting Alteration Savings Analysis arbitrarily and without justification assumed the 2016 proposed standards would affect a 3% bigger market share than the 2013 standards despite substantially decreasing the number of lighting retrofits that would be subject to compliance with the standards.[1] Removing this arbitrary market share assumption results in an additional 20.5 GWh per year of lost savings.

F. Additional Factors that Further Reduce Energy Savings

In addition to the errors described above, a number of additional factors have not been taken into account that will result in even greater energy savings losses beyond the 168 GWh to 209 GWh per year of losses identified in our revised calculations. The potential lost energy savings from these factors must also be estimated and disclosed before the Commission considers approving this code change.

1. Failure to Take into Account Disparate Effect on Different Function Areas.

The Lighting Alteration Savings Analysis fails to take into account that function area types whose LPD maximums have been reduced by more than 35% since the 1998/2001 code are much more likely to utilize the newly proposed 35% lighting power reduction compliance path than function areas whose LPD maximums have been reduced by less than 10% since the 1998/2001 code. Under the 2016 Code proposal, retrofits will have two options for avoiding multi-level,

[1] The 2016 Code proposal decreases the number of retrofits subject to the standards by expanding the applicability of the 10% threshold for alterations and increasing the threshold for modifications from 40 to 70, without any per year restrictions.

daylighting and demand response lighting control requirements: (1) installing alterations that use less than 85% of the LPD maximum or (2) reducing overall power consumption by 35%. Under the 2013 Code, only the 85% LPD option was available to avoid full lighting control requirements. Because building owners will most often select the option that is the easiest and cheapest to meet, not all function areas will select the 35% lighting power reduction compliance path at an equal rate. The rate that different function areas select the 35% lighting power reduction compliance path will have a significant effect on how much energy savings or losses will result from the adoption of this path.

For example, the LPD requirement for office, retail and hotel function areas has decreased by more than 35% since the 1998/2001 code. Accordingly, these function areas could reduce their power consumption by 35% from 1998/2001 code requirements and still exceed the 2013 or 2016 LPD requirements. Lighting alterations of office, retail and hotel function areas (which collectively make up over 43% of existing nonresidential building space) are thus allowed to use substantially more energy under the proposed 35% power reduction path than they would be allowed under the 100% LPD (with full controls) or the 85% LPD (with partial controls) paths. Moreover, the 35% power reduction path will be much cheaper and easier to meet for these function areas than either of the existing lighting alteration compliance options since the 35% power reduction option does not require as deep power density reductions or control installation requirements.

Function areas such as commercial storage, theatre or gym occupancies, on the other hand, would be significantly more energy efficient under the 35% lighting reduction pathway because their maximum allowed LPDs have not changed. The 1998 LPDs for these function areas are exactly the same as the 2016 LPDs. Accordingly, a 35% power reduction would effectively reduce the power density to 35% below the maximum allowed LPD – significantly more power reduction than if the 85% LPD path (requiring a 15% LPD reduction) were taken. However, this energy savings is illusory because these function areas are highly unlikely to use the 35% reduction path since they can obtain the same reduction in lighting control requirements by just using the much easier to meet 85% LPD path (requiring a 15% LPD reduction instead of a 35% LPD reduction).

Because of the significant variations in cost and energy efficiency requirements among function areas, the assumption in the Analysis that each function area will use the 35% power reduction path at an equal rate is not credible.

Function areas that would be less energy efficient under the 35% power reduction path are inherently much more likely to use that path than function areas that would be more energy efficient under the 35% power reduction path. This likely disparity in the rate that function areas use the 35% power reduction path will result in lost energy savings even greater than has been calculated in the M. Neils Engineering analysis. The potential lost energy savings from this disparity needs to be estimated and disclosed in order to meaningfully assess the potential impact of this proposed new loophole from existing control requirements.

2. Verification and Enforcement Issues.

The 35% power reduction path will also result in additional energy saving losses due to enforcement issues that are structurally inherent with this approach. In order to verify compliance, the Authority Having Jurisdiction would need to be able to verify the power rating of the original lighting system.

Inspections of permitted alteration work, however, do not occur until after the original system has been removed and rough installation has been finished. At this stage of a construction project, the original lighting fixtures or components would already be gone so the *baseline value of the existing luminaires could not be verified*. Furthermore, the 2016 Code proposal does not include any other requirement for documenting or verifying the baseline level of the altered luminaires. Accordingly, there is no practical way for a building official to enforce the proposed 30% more efficient lamp option.

Moreover, this exemption provides an economic incentive to overstate the actual power reduction savings from a lamp change out or modification in order to avoid the additional upfront expense of advanced control requirements. Without a verifiable compliance mechanism, the 35% more efficient lamp option will just result in paper savings. Further study of this control-avoidance option is needed to address its intrinsic compliance and enforcement issues. These are the sort of considerations that should be sorted out during pre-rulemaking stakeholder proceedings, rather than during truncated 15 day language comment periods.

3. Expansion of Scope of Existing Exemptions.

The 2013 Code provides a limited exemption from multi-level, daylighting and demand response control requirements for lighting alterations that result in an

average lighting power density that is at least 85% less than the maximum watts per square feet allowed for the function area, and a complete exemption from any energy efficiency requirements where less than 10% of luminaires are altered – but these exemptions only apply if no walls or ceilings are moved and the occupancy type stays the same. As a result, most tenant improvement work is not eligible for this advanced control exemption. The 2016 proposal expands these exemptions to include all lighting alterations, including where the alteration moves walls or ceilings, or changes the occupancy type.

4. New Partial Exemption from Acceptance Test Requirements.

The 2016 Code Proposal exempts indoor and outdoor lighting retrofits from current acceptance test requirements where controls are added to 20 or fewer luminaires. This exemption will further reduce energy savings from what would be achieved through compliance with 2013 Code requirements.

Acceptance testing, which has been required by Title 24 since 2005, is necessary to ensure that assumed paper energy savings translate to actual energy savings. Studies have found that the gap between the expected energy efficiency savings of HVAC and lighting control installations and the energy savings actually realized when evaluated has been as much as 51% and 63%.[2]

This gap is particularly prevalent with the installation of advanced lighting controls. An evaluation of Title 24 acceptance testing effectiveness found that automatic daylighting controls failed in 7 out of 7 tests, and occupancy sensors failed in 2 out of 3 tests. All of the failures were due to design, installation, and/or calibration issues that would not have been identified without acceptance testing.[3]

---

[2] See Energy Division, California Public Utilities Commission, *Energy Efficiency Evaluation Report for the 2009 Bridge Funding Period* (January 2011). http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/2009_Energy_Efficiency_Evaluation_Report.htm; Lutz, Al and Vishy Tirumalashett, ACEEE Summer Study Proceedings, *Measure by Measure: the Real Reasons for Gaps in Claimed and Evaluated Savings* (2012), http://aceee.org/files/proceedings/2012/data/papers/0193-000134.pdf#page=1.

[3] Tyler, Matthew, John Farley and Eliot Crowe. Evaluation of Title 24 Acceptance Testing Enforcement and Effectiveness. PECI, September 2011. http://www.cacx.org/PIER/documents/T24_Acceptance_Testing_Final_Report.pdf.

As these studies show, without acceptance testing, the actual energy savings achieved by the installation of lighting controls may be less than half of what would be achieved with acceptance testing. The lost energy savings from this proposed exemption should be calculated and disclosed before the Commission considers approving this code change.

As a general policy matter, the LMCC urges the Commission to maintain acceptance test requirements for all lighting control installations to ensure that lighting controls are installed and calibrated correctly so they can achieve their assumed energy saving potential. Without such verification, customers won't earn back their investment in these controls and inefficient lighting systems will be locked in for years to come.

G. Lost Energy Savings Will Compound Every Year

The revised Lighting Analysis prepared by M. Neils Engineering calculates that the proposed 2016 amendments to the lighting retrofit requirements will result in lost energy savings of 168 to 209 gigawatt hours each year. The total lost energy savings, however, will compound each year. Nonresidential lighting systems typically have a useful lifespan of approximately 10 to 15 years. This means that retrofits installed each year under the 2016 code may use 2,090 (209 GWh/year x 10 years) to 3,135 (209 GWh/year x 15 years) more gigawatt hours of energy over their lifespan than if installed under the 2013 code. Moreover, each year the 2016 Code is in effect will result in new retrofit installations with additional lost energy saving opportunities. Assuming that the 2016 code is effective for three years, this means that retrofits installed under the 2016 code may use between 6,270 to 9,405 more gigawatt hours of energy over their lifespan than retrofits installed under the 2013 code.

These calculations don't take into account the additional energy losses that would occur due to the likely disparity in the rate that different function areas will use the proposed new 35% power reduction path, due to the structurally inherent verification and enforcement issues related to the proposed new 35% power reduction path, due to the expansion of the scope of existing exemptions and due to the limited exemptions from acceptance test requirements. Accordingly, actual lost energy savings from this proposed code change could be even greater.

III. ADOPTION OF THE PROPOSED AMENDMENTS VIOLATES THE FEDERAL REQUIREMENT TO ADOPT ENERGY EFFICIENCY STANDARDS AT LEAST AS STRINGENT AS ASHRAE 90.1

The proposed amendment to Section 141.0, subdivision (b)2I.ii provides that lighting system alterations shall be exempt from lighting power allowance requirements if the luminaires are at least 30% more efficient than the original luminaires. This exemption violates the federal requirement to adopt energy efficiency standards for commercial buildings that are at least as stringent as the ASHRAE 90.1 standards. The Energy Policy Act (EPACT) of 1992 requires that all states adopt an energy code that is at least as stringent as ASHRAE 90.1. ASHRAE standard 90.1-2010 requires compliance with lighting power density requirements if more than 10% of the lighting is retrofitted. By allowing retrofits to exceed lighting power density requirements, this exemption fails to maintain energy efficiency standards for commercial buildings that are at least as stringent as the ASHRAE 90.1 standards.

IV. PROPOSED ROLLBACK OF STANDARDS IS CONTRARY TO THE ADMINISTRATION'S ENERGY EFFICIENCY GOALS AND POLICIES FOR EXISTING BUILDINGS

The proposed rollback of control and LPD requirements for lighting alterations and modifications is contrary to the Governor's mandate set forth in his inaugural address earlier this year to double the efficiency of existing buildings over the next 15 years. Lighting controls are also critical to meeting California's greenhouse gas reduction goals. The CPUC's 2008 *Long Term Energy Efficiency Strategic Plan* noted that long-term strategic planning is needed to achieve California's energy efficiency and greenhouse gas reduction goals. The plan called for reducing energy consumption in existing residential buildings by 40% by 2020 and for 50% of California's existing commercial buildings to be zero net energy by 2030. These mandates are not achievable if buildings are allowed to evade current lighting system efficiency requirements through the creation of new loopholes.

The requirement to install advanced lighting controls when alterations or modifications are made to lighting systems or luminaires is an essential component to meeting these greenhouse gas reduction and energy efficiency goals. Lighting accounts for almost 40% of a commercial building's electrical use. This is double the

energy used for cooling. While changing to more efficient bulbs and fixtures is a key first step toward increasing energy efficiency in existing buildings, the deeper energy savings needed to achieve California's aggressive energy efficiency goals require also installing advanced lighting controls.

Lighting controls significantly increase a retrofit's energy savings over just putting in more efficient LED luminaires. A study of the commercial lighting sector found that lighting controls reduce commercial buildings' energy use for lighting by up to an additional 38%.[4] By creating new exemptions to control installation requirements in existing buildings, the Commission will lose substantial energy savings that would be achieved under the current code.

Furthermore, California's energy efficiency and greenhouse gas (GHG) reduction goals cannot be met solely by requiring advanced lighting controls in new buildings. New buildings are a small percentage of the total building stock. There is approximately 8 billion square feet of existing, nonresidential space in California. Approximately half of this stock was built prior to the establishment of the Building Energy Efficiency Standards. Shallow retrofits to this existing stock will lock in shallow savings, and are thus an obstacle, not a solution, to meeting these energy efficiency goals.

Nonresidential property owners rarely update their lighting systems more than once every 10-15 years. Accordingly, once these shallow retrofits are installed, deeper energy saving opportunities will be lost for years to come. Conversely, the greater savings achieved under the current advanced control requirements will continue to pay energy savings dividends for the life of the equipment. These savings will be lost under the current proposed amendments and these losses will continue to compound for the next four to five code cycles or more.

The proposed rollback of demand response control requirements is also antithetical to the Governor's mandate to increase the Renewable Portfolio Standard to 50% within the next 15 years. Advanced lighting controls coupled with automated demand response controls provide important grid management capability to allow increased reliance on less predictable wind and solar energy

---

[4] Jackson, et al, ACEEE Summer Study Proceedings, *California's Advanced Lighting Controls Training Program: Building a Skilled Workforce in the Energy Efficiency Market* (2012), http://www.aceee.org/files/proceedings/2012/start.htm.

sources. Providing new loopholes for avoiding the installation of demand response controls in existing buildings creates an unnecessary barrier to achieving the increased renewable energy goal.

Finally, the proposed rollback of these requirements is contrary to the Commission's statutory mandate to adopt building standards that "increase" energy efficiency in buildings. As discussed above, the 2016 Code Proposals before the Commission will result in a significant decrease in the energy efficiency of lighting retrofits compared to existing code requirements.

V. COMPLAINTS OF 2013 CODE'S EFFECT ON RETROFIT DEMAND ARE ANECDOTAL AND HAVE BEEN REFUTED BY PG&E STUDIES

Staff has indicated that they proposed these exemptions based upon complaints that the cost and complexity of compliance with the 2013 lighting control requirements for alterations and modifications have reduced the rate of retrofits. These complaints are anecdotal and inaccurate. No studies or reliable evidence has been presented in support of their claim that the 2013 lighting control requirements have resulted in reduced energy savings due to its impact on retrofit demand.

To the contrary, in comments submitted on April 24, 2015, PG&E expressly refuted the claim that the 2013 Title 24 lighting retrofit requirements have had a negative impact on retrofit energy savings.[5] PG&E evaluated projects that utilized utility incentives and those that did not, and found that in both cases the 2013 Title 24 lighting retrofit requirements "have been successfully implemented in the state to general real energy savings."[6] The PG&E letter noted that the claimed downturn in lighting retrofit business actually predated the effective date of the 2013 standards and was due to increasing federal appliance regulation baselines.[7] PG&E found that, rather than further decreasing retrofit business demand, the 2013

[5] PG&E Statewide Codes and Standards Program, PG&E Comments on 15 Day Proposed Changes to Nonresidential Lighting Retrofit Requirements in 2016 Title 24 Standards, Docket # 15-BSTD-01 (April 24, 2015) at pp. 4-5, 10.
[6] *Id*. at p. 10.
[7] *Id*. at p. 4.

lighting retrofit requirements have increased the demand for deeper retrofits, resulting in substantially increased energy savings.[8]

PG&E's findings are consistent with the feedback that NECA and IBEW have gotten from their contractors and installers regarding the impact of the 2013 code requirements on demand for lighting retrofits. Their members also found that this increased demand has resulted in a significant decrease of lighting control costs since the 2013 Code went into effect. There are also many more suppliers and many more systems available than there were in 2013, further contributing to downward price trends. As a result, the time it takes customers to recoup the cost of lighting controls with savings in electricity cost has gone down substantially since the adoption of the 2013 requirements.

VI. ADOPTION OF THE PROPOSED EXEMPTIONS WOULD VIOLATE THE CALIFORNIA ADMINISTRATIVE PROCEDURE ACT

The proposal of these exemptions as 15 day language violates the requirements of the California Administrative Procedure Act. Most of the proposed exemptions were not included or even alluded to during the 45 day public comment period held for the 2016 Code (or in any of the stakeholder pre-rulemaking proceedings held prior to the 45 day public comment period). Instead, they were proposed for the first time in 15 day language.

The Administrative Procedure Act requires agencies to provide a 45 day public comment period on proposed regulations. If changes to these proposed regulations are made, an additional 45 day public comment period is generally required. A 15 day public comment period is permitted only if the proposed changes are not substantial and are sufficiently related to the text contained in the 45 day language that the public was adequately placed on notice that the proposed change could result from the originally proposed regulatory action.[9]

Here, the 45 day language did not propose any exemptions to control requirements for alterations, did not propose any exemptions based upon altered or modified luminaires reducing power consumption by some certain amount over the

---

[8] *Id*. at pp. 4-5.
[9] Gov. Code section 11346.8, subd. (c).

original luminaires, did not propose exempting alterations or modifications from power allowance requirements, and did not propose any exemptions from existing acceptance test requirements. Accordingly, nothing in the 45 day language put the public on notice that the originally proposed amendments could be modified as now being proposed in the 15 day language.

Rather than correcting this error by identifying these changes as significant new amendments and providing for a full 45 day public comment period, these amendments are again noticed as 15 day language and the public has again been provided less than 45 days to review and comment on the proposals.

Before setting the precedent of adopting amendments that *reduce* existing energy efficiency requirements, the Commission should ensure that the amendments have been properly noticed and that sufficient time for public review and comment has been provided. Because notice and comment period requirements have not been properly provided, approval of this 15 day language would violate the California Administrative Procedure Act.

VII. ADOPTION OF THE PROPOSED EXEMPTIONS WOULD VIOLATE CEQA

The proposed Initial Study/Negative Declaration prepared for the 15 day language concludes that there is no evidence that the 2016 Code Proposal would result in any significant environmental impacts because the Proposal would result in increased energy savings. As discussed above, this assumption is incorrect. As a result, these proposed code changes require revised review under the California Environmental Quality Act ("CEQA") and may require preparation of an Environmental Impact Report ("EIR").

CEQA requires that an agency analyze the potential environmental impacts of its proposed actions in an EIR if "there is substantial evidence, in light of the whole record before the lead agency, that the project may have a significant effect on the environment."[10] A negative declaration is only allowed in lieu of an EIR

[10] Pub. Resources Code, § 21080, subd. (d) (emphasis added); CEQA Guidelines, § 15064.

where there is not even a "fair argument" that the project will have a significant environmental effect.[11]

The "fair argument" standard is an exceptionally "low threshold" favoring environmental review in an EIR rather than a negative declaration.[12] The "fair argument" standard requires preparation of an EIR, if any substantial evidence in the record indicates that a project may have an adverse environmental effect.[13] As a matter of law, substantial evidence includes both expert and lay opinion.[14] Even if other substantial evidence supports the opposite conclusion, the agency nevertheless must prepare an EIR.[15] Under the "fair argument," CEQA always resolves the benefit of the doubt in favor of the public and the environment.

Here, a fair argument exists that the proposed exemptions will reduce energy savings and may result in increased GHG emissions. The expert report of M. Neils Engineering is substantial evidence that adoption of the 2016 Code Proposal will result in significant increased energy consumption. This increased energy consumption over what would be required if the 2016 Code proposal were not adopted will have the indirect impact of requiring increased energy generation that will likely result in increased GHG emissions. An EIR must be prepared to evaluate this impact.

X. CONCLUSION

NECA, IBEW and the LMCC strongly support the energy efficiency goals of the Commission and the administrations. However, the shallow and unverified retrofits proposals now being considered are contrary to these goals and will result in substantial lost energy savings. Moreover, the 2013 code requirements have already been shown to work. PG&E's study of the 2013 requirements show that that they have substantially increased energy savings. In addition, the increased demand for deeper retrofits spurred by the 2013 requirements have resulted in

---

[11] *Citizens of Lake Murray v. San Diego* (1989) 129 Cal.App.3d 436, 440; Pub. Resources Code, §§ 21100, 21064.
[12] *Pocket Protectors v. City of Sacramento* (2004) 124 Cal.App.4th 903, 928.
[13] CEQA Guidelines, § 15064, subd. (f)(1); *Pocket Protectors v. City of Sacramento, supra*, 124 Cal.App.4th at 931.
[14] Pub. Resources Code, § 21080, subd. (e)(1); CEQA Guidelines, § 15064, subd. (f)(5).
[15] *Arviv Enterprises v. South Valley Area Planning Comm*. (2002) 101 Cal.App.4th 1333, 1346.

substantial cost reductions for lighting controls and faster payback of savings to building owners. We urge the Commission to reject the efforts to weaken current standards. California's energy efficiency requirements for existing buildings need to move forward, not backwards.

Sincerely,

Thomas A. Enslow

TAE:ljl

cc: andrew.mcallister@energy.ca.gov, mshirakh@energy.ca.gov
Eurlyne.Geiszler@energy.ca.gov

Attachment: M. *Neils Engineering, Inc., Evaluation of July 10, 2015 15-Day Language re Proposed Revisions to Section 141.0 of the California Energy Code (Aug. 7, 2015) and Neils Exhibits A-G.*

August 7, 2015
Evaluation of July 10, 2015 15-Day Language regarding Proposed Revisions to Section 141.0 of the California Energy Code.

Prepared for IBEW-NECA-LMCC by
Michael F. Neils, P.E., LC

I. BACKGROUND

In response to a request from IBEW-NECA LMCC, this report evaluates the proposed revisions to Section 141.0 of the California Building Energy Efficiency Standards California Code of Regulations, Title 24, Part 6 (California Energy Code) set forth in the 15-day language published on July 10, 2015. These proposed revisions would alter lighting control, demand response control and acceptance test requirements for lighting system alterations, luminaire modifications, and lighting wiring alterations.

The author has participated in the California Energy Code revisions process since 1981, most recently as a principal investigator for the CASE Report on Requirements for Controllable Lighting that were included in the 2013 California Energy Code. Additionally, he chaired the California Energy Commission Title 24 Professional Advisory Group lighting subcommittee from 1982 to 1991. He chaired the Commission's Advanced Lighting Professional Advisory Committee (ALPAC), from 1987 through 1993. He was a co-author of the "Advanced Lighting Guidelines, 2001 Edition," published by the New Buildings Institute. In 2001/2002, he provided technical assistance to RLW Analytics and New Buildings Institute in support of the "Outdoor Lighting Baseline Assessment," which evaluated energy use for outdoor lighting in California, on behalf of the California Energy Commission Public Interest Energy Research (PIER) Program. He also was principal investigator for the "Electric Sign Efficiency CASE Report," as part of the 2008 California Energy Commission Title 24 Building Energy Efficiency Standards Rulemaking Proceeding.

II. SUMMARY OF CONCLUSIONS

The Lighting Alteration Savings Analysis relied upon to support the proposed 2016 amendments to current lighting system alteration, luminaire modification and lighting wiring alteration requirements contains several critical errors or omissions. When these errors and omissions are corrected, the calculations show that the proposed 2016 lighting retrofit changes will result in a net loss in energy savings of between 168 GWh and 209 GWh per year.

The 15-day language will create a 2016 Standard for lighting alterations that increases energy use in California buildings and cost California rate payers millions over the life of their lighting systems. Since nonresidential lighting systems typically have a useful lifespan of approximately 10 to 15 years, retrofits installed each year under the 2016 code would use 2,090 to 3,135 more

gigawatt hours of energy over their lifespan than if installed under the 2013 code, assuming a 15-year system life. Assuming that the 2016 code is effective for three years, retrofits installed under the 2016 code will use between 6,270 and 9,405 more gigawatt hours of energy over their lifespan than retrofits installed under the 2013 code.

Among the errors and omissions in the Lighting Alteration Savings Analysis are the following:

A. Failure to Take Into Account Lost Savings from Elimination of Multi-Level Control Requirements.

The Lighting Alteration Savings Analysis incorrectly assumes that the elimination of multi-level control requirements will not result in any energy saving losses beyond what is lost from the elimination of daylighting control requirements. Multilevel controls, however, also save energy by enabling task tuning, manual dimming/switching, and multiple levels of scheduled dimming. The CASE study on multilevel controls conducted to support the 2013 Standards identifies specific energy savings from multilevel control task tuning *that are not associated with other control strategies*. Based on the Lighting Alteration Savings Analysis that supported the savings from 2013 Code lighting measures, the proposed elimination of multi-level control requirements will result in 148 GWh per year of lost energy savings that were not accounted for in the analysis.

B. Failure to Use CEC's Weighted Average Lighting Power Density Calculations.

The Lighting Alteration Savings Analysis incorrectly assumes that lighting power requirements under the 2016 standards are an average of 20% lower than allowed under the 1998/2001 standards. Subsequent to this calculation the CEC prepared a more accurate weighted lighting power density (LPD) calculation based upon the percentage of total square footage of existing buildings represented by each occupancy type. (See Exhibit D.) Under this revised percentage, the CEC calculated that the average 2016 LPD savings over pre-2005 Code would be 27%, not 20%. However, the CEC failed to update this corrected average in the Lighting Alteration Savings Analysis. Changing the average 2016 LPD savings over vintage LPD savings from 20% to 27% would reduce energy savings by approximately 63 gigawatt hours per year. Even assuming that some percentage of lighting retrofits would meet 2005 Code LPD requirements, the additional lost energy savings would still amount to between 22 and 45 gigawatt hours per year.

C. Overestimate of Percentage of Existing Systems with Automatic Shutoff and Multi-Level Controls.

The Lighting Alteration Savings Analysis overestimates the fraction of existing lighting systems that already utilize automatic shutoff and multi-level lighting controls. The Analysis assumes there is no way to know how many existing systems use these controls and arbitrarily assumes a usage rate of 50%. This is incorrect, the California Appliance Saturation Survey issued by Itron on behalf of the CPUC in 2014, surveyed approximately 1400 commercial businesses on what types of lighting controls they had installed. Only about 10-30% of large businesses had some

form of auto shutoff control and between 0% and 20% of all other businesses had these controls. Adjusting the number to 20% results in and additional 50 GWh per year of lost savings.

D. Rounding Errors.

The Lighting Alteration Savings Analysis improperly rounded down a reconciliation factor for determining the fraction of total commercial floor space applicable to the 2013 standards from 0.916 to 0.91. This rounding error results in about 0.5 GWh per year of lost savings.

E. Arbitrary and Unsupported Market Share Adjustments.

The Lighting Alteration Savings Analysis arbitrarily and without justification assumed the 2016 proposed standards would affect a 3% bigger market share than the 2013 Standards despite actually increasing the number of lighting retrofits that would be exempt from compliance with the standards. Removing this arbitrary market share assumption results in an additional 20.5 GWh per year of lost savings.

F. Additional Factors that Further Reduce Energy Savings.

In addition to the issues described above, a number of additional factors that have not been taken into account in our calculations will further reduce energy savings from that required under the 2013 code. The potential lost energy savings from these factors should also be estimated and disclosed before the Commission considers approving this code change.

(1) Failure to Take into Account Disparate Effect on Different Function Areas.

The Lighting Alteration Savings Analysis fails to take into account that function area types whose LPD maximums have been reduced by more than 35% since the 1998/2001 code are much more likely to utilize the newly proposed 35% lighting power reduction compliance path than function areas whose LPD maximums have been reduced by less than 10% since the 1998/2001 code. Under the 2016 Code proposal, retrofits will have two options for avoiding multi-level, daylighting and demand response lighting control requirements: (1) installing alterations that use less than 85% of the LPD maximum or (2) reducing overall power consumption by 35%. Under the 2013 Code, only the 85% LPD option was available to avoid full lighting control requirements. Because building owners will most often select the option that is the easiest and cheapest to meet, not all function areas will select the 35% lighting power reduction compliance path at an equal rate. The rate that different function areas select the 35% lighting power reduction compliance path will have a significant effect on how much energy savings or losses will result from the adoption of this path.

For example, function areas such as office, retail and hotel occupancies (which collectively make up over 43% of the existing nonresidential building spaces) can reduce their power consumption by 35% from 1998/2001 code requirements and still not meet the 100% LPD requirement since the LPD requirement for each of these function areas has decreased by more than 35% since the 1998/2001 code. Accordingly, these function areas will use substantially more energy by

following the 35% pathway than by following the 100% LPD path (with full controls) or the 85% LPD path (with partial controls) currently allowed under the 2013 code. Moreover, 35% power reduction path will be much easier to meet for these function areas than either of the other, more energy efficient, pathways.

Function areas such as commercial storage, theatre or gym occupancies, on the other hand, would be significantly more energy efficient under the 35% lighting reduction pathway because their maximum allowed LPDs are the same as the maximum LPDs allowed in pre-2005 vintage lighting systems. Accordingly, it would be much easier for these function areas to avoid advanced control requirements by using the 85% LPD path (requiring a 15% LPD reduction) than by using the 35% power reduction path.

The assumption in the Analysis that each function area will use the 35% power reduction path at an equal rate is not credible. Instead, function areas that will be less energy efficient under the 35% power reduction path are much more likely to use that path than function areas that would be more energy efficient under the 35% power reduction path. This likely disparity in the rate that function areas use the 35% power reduction path will result in further significant lost energy savings over what would occur in the 2013 code. The potential lost energy savings from this disparity needs to be estimated and disclosed before the Commission considers approving this code change.

(2) Inherent Verification and Enforcement Issues.

The 35% power reduction path will also result in additional energy saving losses due to enforcement issues that are inherent with this approach. Verification and enforcement of the 35 percent reduction will be extremely difficult, because when a retrofit building permit is issued, the first site visit by an inspector is to inspect the rough installation, including any new wiring. At this stage of a construction project, the original lighting fixtures or components would already be gone so the baseline value of the existing luminaires could not be verified. This may lead to inaccurate or fraudulent estimates of the lighting power reduction since property owners and lighting contractors will have a strong economic incentive to claim that a 35 percent reduction has been achieved.

(3) Expansion of Scope of Existing Exemptions.

The 2013 Code provides a limited exemption from multi-level, daylighting and demand response control requirements for lighting alterations that result in an average lighting power density that is at least 85% less than the maximum watts per square feet allowed for the function area, and a complete exemption from any energy efficiency requirements where less than 10% of luminaires are altered – but these exemptions only apply if no walls or ceilings are moved and the occupancy type stays the same. As a result, most tenant improvement work is not eligible for this advanced control exemption. The 2016 proposal expands these exemptions to include all lighting alterations, including where the alteration moves walls or ceilings, or changes the occupancy type.

(4) New Partial Exemption from Acceptance Test Requirements.

The proposed 2016 Code language also exempts indoor and outdoor lighting retrofits from current acceptance test requirements where controls are added to 20 or fewer luminaires. This exemption will further reduce energy savings from what would be achieved through compliance with 2013 Code requirements. Studies have shown that without acceptance testing, the actual energy savings achieved by the installation of lighting controls may be less than half of what would be achieved with acceptance testing. The lost energy savings from this proposed exemption should be calculated and disclosed before the Commission considers approving this code change.

III. EVALUATION OF ENERGY SAVINGS CALCULATIONS

CEC proposes multiple changes to regulations for lighting alteration projects contained in the Title 24 Building Energy Efficiency Standards (2013 Standards). A comparison of the proposed changes to what is required in the 2013 California Energy Code is contained in Exhibits A-C of this report. In its supporting documentation, the California Energy Commission relies on a Lighting Alteration Savings Analysis and a report entitled Supporting Nonresidential Energy Impacts by Y. Zhang, July 2015. California Energy Commission staff have also provided me with a copy of the excel spreadsheet[1] on which the Lighting Alteration Savings Analysis is based and the supporting documents. They have also provided me with a document entitled Vintage Lighting Systems, which provides the average 2016 savings over vintage for lighting power densities (LPDs) and the weighted average 2016 savings over vintage for LPDs. (Exhibit D.)

The Lighting Alteration Savings Analysis compares the energy savings from lighting system alterations, luminaire modifications and lighting wiring alterations under the 2013 California Energy Code requirements with the energy savings from lighting system alterations, luminaire modifications and lighting wiring alterations under the proposed 2016 amendments. This Analysis concludes that these amendments would result in an additional 74 Gigawatt-hours (GWh) of energy savings per year as compared to the current 2013 Standards.

We have reviewed the Lighting Alteration Savings Analysis spreadsheet and the other supporting documentation and have identified several critical errors or omissions in the data. When these errors and omissions are corrected, the calculations show that the proposed 2016 lighting retrofit changes will result in a **net loss in energy savings of somewhere between 168 GWh and 209 GWh per year**. (See Exhibts E-G.) This will create a 2016 Standard for lighting alterations that **increases energy use** in California buildings and costs California rate payers millions over the life of their lighting systems.[2]

Our revised calculations are attached as Exhibits E and F.

---

[1] "Lighting alteration savings analysis 04292015 v32.xlsx"

[2] 168 GWh of electricity costs approximately $35,000,000 assuming an average commercial rate of $0.21 per KWh.

A. Proposal to Eliminate Multi-Level Lighting Controls Requirements for All Lighting Alteration Projects

The Lighting Alteration Savings Analysis incorrectly assumes that there would be no lost energy savings attributable solely to the elimination of multi-level controls. While this technology more easily enables use of occupancy controls and daylighting controls (and those savings should not be double counted), multilevel controls also enable task tuning, manual dimming/switching, and multiple levels of scheduled dimming. The CASE study on multilevel controls conducted to support the 2013 Standards speaks to this point and, in fact, only associates savings from task tuning to multilevel controls so as not to double count savings associated with other control strategies. After taking into account the lost savings associated with multi-level lighting control strategies such as task tuning (savings attributed to 2013 Standards in the Lighting Savings Analysis), the proposed elimination of this control requirement in the 2016 Standards results in **148 GWh per year of lost savings.**

B. Proposal to Eliminate Certain Lighting Control and Lighting Power Density Requirements for Lighting Alterations and Lighting Component Modifications that Achieve a 35% Power Reduction

The Lighting Alteration Savings Analysis estimates that the new proposed lighting alteration compliance option that eliminates certain lighting controls requirements if projects achieve a 35% reduction in lighting power will result in energy savings that are a 75% improvement over the 2013 Standards. A review of the underlying spreadsheet shows that this conclusion is based on an assumption that the allowed lighting power requirements contained in the 2016 Standards are, on average, 20% lower than allowed under lighting systems that were installed in compliance with the LPD requirements contained in the 1998/2001 code. This is not accurate.

Lighting power requirements vary depending on the type of function area. However, not every function area has reduced their lighting power requirements equally. For example, the maximum lighting power density (LPD) for retail areas under the pre-2005 Code is 2.00 watts per square feet. The LPD under the 2016 code is 1.20 watts per square feet, which is a reduction of 40%. The LPD for commercial storage, gyms, theaters, and restrooms did not change at all from pre-2005 Code to the 2016 code – in other words these function areas are 0% more efficient. The LPD for numerous other occupancies just changed marginally. The Lighting Alteration Savings Analysis use of an average 20% reduction is based the incorrect assumption that the number of retrofits under the 2016 code would be distributed among each type of occupancy equally.

Subsequent to this calculation, the CEC prepared a more accurate weighted lighting power density calculation based upon the percentage of total square footage of existing buildings represented by each occupancy type. (Exhibit D). Under this revised percentage, the CEC calculated that the average 2016 LPD savings over pre-2005 Code would be 27%, not 20%. However, the CEC failed to update this average in the Lighting Alteration Savings Analysis spreadsheet calculation of the energy impacts of the proposed 2016 Code changes. **Changing the average 2016 LPD savings over vintage LPD savings from 20% to 27% would reduce energy savings by approximately 63 gigawatt hours per year.** (See Exhibit G.)

However, this calculation likely overstates the losses that would occur from this code change because it assumes that all retrofits would be pre-2005 vintage.[3] Nonresidential lighting systems generally have a 10 to 15 year lifespan, so some percentage of the retrofits under the 2016 code would likely be 2005 Code compliant. An assumption that only pre-2005 vintage lighting systems will take advantage of the 35% power reduction pathway represents the worst case scenario. On the other hand, an assumption that the number of retrofits taking advantage of the 35% power reduction pathway would be equally distributed between 2005 vintage and pre-2005 vintage lighting systems is likely overly optimistic. Because most 2005 vintage lighting systems would have an easier time avoiding advanced lighting controls under the 85% LPD reduction pathway than under the 35% total power reduction pathway, it is likely that a much greater percentage of 1998/2001-Code vintage lighting systems would take advantage of the 35% power reduction pathway than 2005-Code vintage systems. Accordingly, we assume that the reasonable worst case scenario would assume that 75% of the systems taking advantage of the 35% power reduction pathway would be pre-2005 vintage and 25% would be 2005 vintage. As shown below, energy savings would be significantly less than calculated in the Lighting Alteration Savings Analysis spreadsheet under either the optimistic 50/50 scenario or the reasonable worst case scenario of 75/25.

Lighting systems complying with 1998/2001 standards will save 27% by complying with the 2013 requirements, while systems compliant with the 2005 standards will save 17% (using the weighted averages calculated by Commission staff). Assuming, optimistically, an equal distribution of systems complying with both code vintages, average savings associated with lighting alternations designed to the 2013 Standards as compared to past code requirements is 22%, 2% higher than CEC estimates. **Changing the average 2016 LPD savings over vintage LPD savings in the Lighting Alteration Savings Analysis spreadsheet calculation from 20% to 22% (reflecting the optimistic 50/50 scenario) would reduce energy savings by approximately 22 gigawatt hours per year.** (See Exhibit E.)

Assuming the reasonable worst case scenario that 75% of the systems taking advantage of the 35% power reduction pathway would be pre-2005 vintage and 25% would be 2005 vintage, the average savings associated with lighting alternations designed to the 2013 Standards as compared to past code requirements is 24.5%, 4.5% higher than CEC estimates. After updating the calculations to reflect the reasonable worst case scenario, the proposed 2016 code modifications pertaining to the 35% lighting power reductions compliance path results in **24 GWh per year less savings** than that estimated by the CEC.[4] **Changing the average 2016 LPD savings over vintage LPD savings in the Lighting Alteration Savings Analysis spreadsheet calculation from 20% to 24.5% (reflecting reasonably the reasonable worst case 75/25 scenario) would reduce energy savings by approximately 45 gigawatt hours per year.** (See Exhibit F.)

---

[3] For the purposes of this discussion, pre-2005 vintage lighting systems refer to lighting systems that are compliant with the 1998 or 2001 editions of the California Energy Code. The 2001 edition was superseded by the 2005 edition of the California Energy Code. 1998 and 2001 lighting power allowances are very similar or identical for all space types considered – so no distinction is made between these codes under this analysis.

[4] This reduced savings is based on also making the other additional corrections made to the calculations, which result in this change having less effect than it would if no other changes were made to the calculations. If those other corrections were not made, the reduction in savings would be even greater - 46 gigawatt hours per year instead of 24 gigawatt hours per year.

The actual lost energy savings from this code change would probably be even greater than the reasonable worst case scenario, because that scenario does not account for the likelihood that the function area types whose LPD maximums have been reduced by more than 35% since the 1998/2001 code are much more likely to utilize the 35% lighting power reduction compliance path than function areas whose LPD maximums have been reduced by less than 10% since the 1998/2001 code. Retrofits will have two options for avoiding advanced lighting control requirements: (1) reducing overall power consumption by 35% or (2) installing alterations that use less than 85% of the LPD maximum. It is reasonable to assume that these will comply with the option that is the easiest and/or cheapest to meet.

Function areas such as office, retail and hotel occupancies (which collectively make up over 43% of the existing nonresidential building spaces) can reduce their power consumption by 35% from 1998/2001 code requirements and still not meet the 100% LPD requirement since the LPD requirement for each of these function areas has decreased by more than 35% since the 1998/2001 code. Accordingly, these function areas will use substantially more energy by following the 35% pathway than by following the 100% LPD pathway (with full controls) or the 85% LPD pathway (with partial controls) currently allowed under the 2013 code. Moreover, the 35% power reduction path will be much easier to meet for these function areas than either of the other, more energy efficient, pathways.

Office area LPD is 1.30 watts/sf under the 1998/2001 code and 0.81 watts/sf under the 2016 code,[5] which is a reduction of 37.7%. In order avoid advanced controls under the 85% LPD pathway, an office lighting alteration would be required to limit LPD to no more than 0.69 watts/sf (0.81x.85). The 35% power reduction path, however, allows office lighting alterations to avoid advanced controls with an LPD of up to 0.845 watts/sf (1.3.00x0.65) – which exceeds both the 100% LPD maximum and the 85% LPD maximum. In other words, office lighting alterations can avoid advanced lighting controls despite using 22.5% more energy than would be required to avoid advanced lighting controls under the 2013 code (0.69x122.5%=0.845). Office areas make up 22.1% of all existing nonresidential building space covered under these provisions.

Retail area LPD is 2.00 watts/sf under the 1998/2001 code and 1.20 watts/sf under the 2016 code, which is a reduction of 40%. In order avoid advanced controls under the 85% LPD pathway, a retail lighting alteration would be required to limit LPD to no more than 1.02 watts/sf (1.20x.85). The 35% power reduction path, however, allows retail lighting alterations to avoid advanced controls with an LPD of up to 1.3 watts/sf (2.00x0.65) – which exceeds both the 100% LPD maximum and the 85% LPD maximum. In other words, retail lighting alterations can avoid advanced lighting controls despite using 27.5% more energy than would be required to avoid advanced lighting controls under the 2013 code (1.02x127.5%=1.3). Retail areas make up 15.7% of all existing nonresidential building space covered under these provisions.

Hotel area LPD is 2.20 watts/sf under the 1998/2001 code and 1.40 watts/sf under the 2016 code, which is a reduction of 36.4%. In order avoid advanced controls under the 85% LPD pathway, a hotel lighting alteration would be required to limit LPD to no more than 1.19 watts/sf (1.40x.85).

[5] See Exhibit D (document prepared by CEC staff).

The 35% power reduction path, however, allows hotel lighting alterations to avoid advanced controls with an LPD of up to 1.43 watts/sf (2.20x0.65) – which exceeds both the 100% LPD maximum and the 85% LPD maximum. In other words, hotel lighting alterations can avoid advanced lighting controls despite using 20% more energy than would be required to avoid advanced lighting controls under the 2013 code (1.19x120%=1.43). Hotel areas make up 5.5% of all existing nonresidential building space covered under these provisions.

Accordingly, it is likely that almost all hotel, office and retail retrofits will use the cheaper and easier 35% lighting power reduction compliance path. This pathway effectively increases the maximum LPD for these function areas while at the same time greatly reducing control requirements.[6]

On the other hand, commercial storage, theatre or gym function areas (whose LPD requirements have not been reduced at all since the 1998/2001 code) would have to reduce their LPD to 65% of the maximum LPD if they were to use the 35% lighting power reduction compliance path, yet could obtain essentially the same benefits by reducing their LPD to 85% of the maximum LPD. Accordingly, it is unlikely that any of these occupancies would use the 35% lighting power reduction compliance path instead of the easier 85% LPD compliance path.

Under a worst case scenario that assumes each retrofit seeking to avoid advanced controls will use the least rigorous compliance path available, the only retrofits that would use the new 35% lighting power reduction compliance path would be those that would not be able to more easily meet the 85% LPD compliance path. Under that scenario, every retrofit that uses the new 35% lighting power reduction compliance path would use more energy than it would have under the 2013 code which requires either full controls or partial controls and 85% LPD.

Even assuming that some retrofits will take the 35% pathway even though they could install systems with more LPD under the 85% pathway, some additional adjustment is necessary to account for the likelihood that functions areas such as office, retail and hotel are much more likely to use this pathway than function areas such as commercial storage. For the purposes of our ultimate energy savings loss calculations, we have not included this adjustment in our final energy savings loss calculations. However, a reasonable adjustment for this variable would be to use the 27% worst case scenario level. As discussed above, **this would reduce energy savings by 63 gigawatt hours per year or more**. (See Exhibit G.)

Our analysis also does not account for potential enforcement issues related to the 35% lighting power reduction compliance path. The 35 percent reduction is unlikely to be meaningfully verifiable or enforceable, because when a retrofit building permit is issued, the first site visit by an inspector is to inspect the rough installation, including any new wiring. At this stage of a construction project, the original lighting fixtures or components would already be gone so the baseline value of the existing luminaires could not be verified. This could lead to inaccurate or fraudulent estimates of the lighting power reduction since property owners and lighting

[6] On a policy level, the Commission should consider why it would provide such a tremendous loosening of standards for hotel, retail and office function areas (which make up almost half of existing buildings), but not to other function areas. This appears to be a massive gift to these specific business interests.

contractors will have a strong economic incentive to claim that a 35 percent reduction has been achieved.

C. Existing Buildings Utilizing Automatic Shutoff and Multi-Level Lighting Controls

The Lighting Alteration Savings Analysis overestimates the fraction of existing lighting systems that already utilize automatic shutoff and multi-level lighting controls. The CEC workbook comments state "there is no way to know" how many existing systems utilize automatic shutoff controls and therefore the calculations assume 50% of existing systems already utilize the controls, and reduce the applicable market share accordingly for this measure. They then estimate that the same share of buildings utilize multi-level lighting controls.

The 50% assumption is false. It substantially underestimates the savings attributed to the 2013 automatic shutoff and multi-level controls requirements, and therefore underestimates the lost savings due associated with the proposed 2016 Standards.[7]

The California Appliance Saturation Survey issued by Itron on behalf of the CPUC in 2014, surveyed ~1400 commercial businesses on what types of lighting controls they had installed. This report essentially replaces the 2006 California Commercial End-Use Survey, a report often referenced in building energy consumption calculations. Only about 10-30% of large businesses, which made up less than 10% of the sample set, had some form of auto shutoff control or building energy management system typically capable of providing such control. All other businesses had 0% and 20%. Therefore 20% is a much more accurate (albeit still optimistic) estimate of existing businesses that utilize auto shut off controls.

After updating this value from 50% to 20%, the proposed 2016 requirements results in an additional **50 GWh per year of lost savings**.

D. Regulated, Existing Building Stock

The Lighting Alteration Savings Analysis underestimates the fraction of total commercial floor space applicable to the 2013 standards by improperly rounding down a reconciliation factor, which thereby underestimates the total lost savings due to elimination of 2013 controls measures. The CEC workbook utilizes a factor of 0.91 hardcoded in multiple cells, to reconcile the CBECS building data to staff building stock calculations. The actual factor needed to reconcile is 0.916. This rounding error results in about **0.5 GWh per year of lost savings.**

E. Project Category Market Share

The Lighting Alteration Savings Analysis utilizes different market share assumptions to calculate savings attributed to the 2016 proposed Standards and the current 2013 Standards. CEC

[7] This section describes savings lost due to errors in estimation of the fraction of existing building stock utilizing these controls. It details the relative difference between savings at different market shares, and it does not include savings noted in section *Proposal to Eliminate Multi-level Lighting Controls Requirements for All Lighting Alteration and Lighting Component Modifications*, which is the absolute savings lost from going from use of controls (2013 Standards) to no use of multi-level controls (2016 Standards) at an assumed market share of 50% of existing buildings.

calculates assume the 2016 proposed standards will affect a 3% bigger market share than the 2013 Standards, distributing this difference across multiple project and subproject categories using hardcoded derating factors. CEC does not provide justification to support how the proposed 2016 Standards will increase market share of regulated projects. In fact, the only clear effect on the market share due to the proposed 2016 Standards is that they will increase the number of exempt lighting component modifications due to the increase in project threshold (40 to 70 luminaires) as previously discussed.

After setting the market shares equal for both the proposed and existing standards, estimated savings of the 2016 Standards are **reduced by an addition 20.5 GWh per year**.

IV. ADDITIONAL CHANGES THAT MAY NEGATIVELY IMPACT ENERGY SAVINGS

A. New Exemption for Alterations that Change the Area of the Enclosed Space or Change the Occupancy Type or Increase the Lighting Power in the Enclosed Space.

Currently, alterations that the change the area of the enclosed space (generally tenant improvement work), or change the occupancy type or increase lighting power, must install all controls, including area, automatic shutoff, multi-level, daylighting and (where applicable) demand response controls. The 2013 Code provides no exemptions to these requirements.

1. New 85% Power Allowance Reduction.

The 2016 Code proposal provides that alterations that change the area of the enclosed space or change the occupancy type or increase the lighting power in the enclosed space are exempt from the 2013 requirements to install multi-level controls, automatic daylight controls and demand response controls if the lighting power is less than or equal to 85% of the power allowance. Under the 2013 Code, the 85% power allowance pathway did not apply to these types of alterations.

2. New 10% Exemption.

The 2016 Code exempts alterations that change the area of the enclosed space or change the occupancy type or increase the lighting power in the enclosed space from all Title 24 compliance requirements if the alterations involve less than 10% of existing luminaires. Under 2013 Code, alterations of less than 10% of existing luminaires were still subject to control requirements if the alteration changed the area of the enclosed space, changed the occupancy type or increased the lighting power. Now luminaire alterations may move walls and ceilings or increase lighting power and avoid all controls and LPD requirements as long as the alterations involve less than 10% of the existing luminaires.

The lost energy savings from these measures should be calculated and disclosed before the Commission considers approving these changes.

B. New Partial Exemption from Acceptance Test Requirements

In addition to creating exemptions from current lighting control requirements, the proposed 2016 Code language also exempts indoor and outdoor lighting retrofits from current acceptance test requirements where controls are added to 20 or fewer luminaires. This exemption will further reduce energy savings from what would be achieved through compliance with 2013 Code requirements.

Acceptance testing, which has been required by Title 24 since 2005, is necessary to ensure that assumed paper energy savings translate to actual energy savings. Studies have found that the gap between the expected energy efficiency savings of HVAC and lighting control installations and the energy savings actually realized when evaluated has been as much as 51% and 63%.[8]

This gap is particularly prevalent with the installation of advanced lighting controls. An evaluation of Title 24 acceptance testing effectiveness found that automatic daylighting controls failed in 7 out of 7 tests, and occupancy sensors failed in 2 out of 3 tests. All of the failures were due to design, installation, and/or calibration issues that would not have been identified without acceptance testing.[9]

As these studies show, without acceptance testing, the actual energy savings achieved by the installation of lighting controls may be less than half of what would be achieved with acceptance testing. While these studies are limited in size, they represent the best available evidence on the impact of acceptance testing. The lost energy savings from this proposed exemption should be calculated and disclosed before the Commission considers approving this code change.

V. LOST SAVINGS WILL COMPOUND EVERY YEAR

Under our revised calculations (which still don't take into account all likely losses from the proposed amendments), we estimate that the proposed 2016 amendments to the lighting retrofit requirements will result in lost energy savings of somewhere between 168 and 209 gigawatt hours each year. (See Exhibits E-G.) The total lost energy savings, however, will compound each year. Since nonresidential lighting systems typically have a useful lifespan of approximately 10 to 15 years, this means that retrofits installed each year under the 2016 code may use 2,090 to 3,135 more gigawatt hours of energy over their lifespan than if installed under the 2013 code. Assuming that the 2016 code is effective for three years, this means that retrofits installed under

---

[8] See Energy Division, California Public Utilities Commission, *Energy Efficiency Evaluation Report for the 2009 Bridge Funding Period* (January 2011). http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/2009_Energy_Efficiency_Evaluation_Report.htm; Lutz, Al and Vishy Tirumalashett, ACEEE Summer Study Proceedings, *Measure by Measure: the Real Reasons for Gaps in Claimed and Evaluated Savings* (2012), http://aceee.org/files/proceedings/2012/data/papers/0193-000134.pdf#page=1.

[9] Tyler, Matthew, John Farley and Eliot Crowe. Evaluation of Title 24 Acceptance Testing Enforcement and Effectiveness. PECI, September 2011. http://www.cacx.org/PIER/documents/T24_Acceptance_Testing_Final_Report.pdf.

the 2016 code will use, in total, approximately 6,270 to 9,405 more gigawatt hours of energy over their lifespan than retrofits installed under the 2013 code.

VI. CONCLUSION

The Lighting Alteration Savings Analysis relied upon to support the proposed lighting retrofit amendments fail to accurately disclose the potential for these amendments to result in substantial lost energy savings. These lost savings will be particularly acute in retail, office and hotel occupancies, which make up close to half of the retrofit market.

EXHIBIT A

Comparison of 2013 and Proposed 2016 Lighting System Alteration Requirements: Proposed § 141.0, subdivision (b)2.I

2013 Lighting System Alteration Requirements:

I. Lighting System Alterations that Change the Area of Enclosed Space, Change the Occupancy Type, or Increase Lighting Power.

Lighting System Alterations (of any size) that change the area of the enclosed space, change the occupancy type, or increase the lighting power must comply with the following requirements (See 2013 Code, Table 141.0-E.):

(1) Install §130.1(a) Area Controls;

(2) Install §130.1(b) Multi-Level Controls;

(3) Install §130.1(c) Shut-Off Controls;

(4) Install §130.1(d) Automatic Daylight Controls;

(5) Install §130.1(e) Demand Response Controls (limited to alterations of buildings greater than 10,000 sq. feet and to spaces with a lighting power density of 0.5 watts per square feet or greater);

(6) Comply with the requirements of §130.0(d) (which requires controls to comply with §110.9 standards); and

(7) Comply with the lighting power allowance requirements of §140.6.

II. Other Lighting System Alterations that Alter More than 10% of Existing Luminaires.

Lighting System Alterations that do not change the area of the enclosed space or the occupancy type or increase the lighting power, but that alter more than 10% of the existing luminaires have to comply with one of the following:

A. If lighting power is between 85% and 100% of the lighting power allowance, the alterations must comply with the lighting power allowance requirements of §140.6 and install the following controls: (1) §130.1(a) Area Controls; (2) §130.1(b) Multi-Level Controls; (3) §130.1(c) Shut-Off Controls; and (d) §130.1(d) Automatic Daylight Controls. (See 2013 Code, Table 141.0-E.)

B. If lighting power is less than or equal to 85% of the lighting power allowance, the alterations must comply with the lighting power allowance requirements of §140.6 and install the following controls: (1) §130.1(a) **Area Controls**; (2) §130.1(c) **Shut-Off Controls**; and **"Two Level Lighting Controls.**" (See 2013 Code, Table 141.0-E.)

III. Acceptance Test Requirements.

Lighting system alterations that include controls must comply with lighting control acceptance testing requirements. (See 2013 Code, §130.4.)

2016 Proposed Changes to 2013 Lighting System Alteration Requirements:

I. New Alternative 35% Power Reduction Compliance Pathway for Alterations.

The 2016 Code Proposal creates a new alternative compliance pathway that exempts applicable lighting alterations from otherwise applicable control and power allowance requirements. The new pathway applies to any lighting system alterations where (1) existing luminaires are replaced with new luminaires; (2) the work *does not include* adding, removing or replacing walls or ceilings along with redesign of the lighting system; and (3) the replacement luminaires collectively have at least 35% lower rated power than the existing luminaires being replaced.

Alterations taking the new 35% power reduction pathway are required to install area and automatic shutoff controls, but are exempt from multi-level and daylighting Control requirements and are not required to meet any lighting power allowance requirements.

II. New Exemption for Alterations that Change the Area of the Enclosed Space or Change the Occupancy Type or Increase the Lighting Power in the Enclosed Space.

Currently, alterations that the change the area of the enclosed space (generally tenant improvement work), or change the occupancy type or increase lighting power, must install all controls, including area, automatic shutoff, multi-level, daylighting and (where applicable) demand response controls. The 2013 provides no exemptions to these requirements.

A. New 85% Power Allowance Reduction. The 2016 Code proposal provides that alterations that change the area of the enclosed space or change the occupancy type or increase the lighting power in the enclosed space are exempt from the 2013 requirements to install multi-level controls, automatic daylight controls and demand response controls if the lighting power is less than or equal to 85% of the power allowance. Under the 2013 Code, the 85% power allowance pathway did not apply to these types of alterations.

B. **New 10% Exemption.** The 2016 Code exempts alterations that change the area of the enclosed space or change the occupancy type or increase the lighting power in the enclosed space from all Title 24 compliance requirements if the alterations involve less than 10% of existing luminaires. Under 2013 Code, alterations of

less than 10% of existing luminaires were still subject to control requirements if the alteration changed the area of the enclosed space, changed the occupancy type or increased the lighting power. Now luminaire alterations may move walls and ceilings or increase lighting power and avoid all controls as long as the alterations involve less than 10% of the existing luminaires.

III. Deletion of Section 130.1(a)(4) Area Control Requirements.

The 2013 Code requires that alterations subject to area control requirements shall comply with all requirements of Section 130.1(a). The 2016 Code exempts all alterations from compliance with Section 130.1(a)(4), which requires that, in addition to the requirements in Section 130.1(a)1, 2, and 3: (A) General lighting shall be separately controlled from all other lighting systems in an area; (B) Floor and wall display, window display, case display, ornamental, and special effects lighting shall each be separately controlled on circuits that are 20 amps or less; and (C) When track lighting is used, general, display, ornamental, and special effects lighting shall each be separately controlled.

IV. Acceptance Test Exemption. Exempts lighting system alterations from existing acceptance test requirements where lighting controls are added to control 20 or fewer luminaires.

EXHIBIT B

Comparison of 2013 and Proposed 2016 Luminaire Modification Exemptions: Proposed § 141.0, subdivision (b)2.J and Proposed Deletion of Existing Table 141.0-F

2013 Lighting Component Modification Requirements:

I. **Forty (40) Luminaire Threshold for Title 24 Compliance.** Lighting component modifications are not subject to Title 24 requirements if they total less than 40 luminaire modifications-in-place per building space per year.

II. **Modification Control Requirements.** Modifications of 40 or more luminaire modifications-in-place must comply with the lighting power allowance requirements of §140.6 and follow one of the following two control requirement paths:

A. If lighting power is between 85% and 100% of the lighting power allowance, the modifications must install the following controls: (1) §130.1(a) Area Controls; (2) §130.1(b) Multi-Level Controls; (3) §130.1(c) Shut-Off Controls; (4) §130.1(d) Automatic Daylight Controls. In addition, the controls must comply with the requirements of §130.0(d) (which requires controls to comply with §110.9 standards). (See Table 141.0-E.)

B. If lighting power is less than or equal to 85% of the lighting power allowance, the modifications must install the following controls: (1) §130.1(a) Area Controls; (2) §130.1(c) Shut-Off Controls; and (3) "Two Level Lighting Controls" (or multi-level controls). (See Table 141.0-E.)

III. **Acceptance Testing Requirement.** Acceptance testing is required for all lighting controls installed as part of the modification requirements. (See 2013 Code, §130.4.)

2016 Proposed Changes to 2013 Luminaire Modification Requirements:

I. **Title 24 Compliance Threshold Increased from 40 to 70 Luminaires.** Under the 2016 proposal, the threshold for applying Title 24 to lighting modifications is raised from *40 to 70* luminaire modifications-in-place *and eliminates the per year requirement*, meaning that a building owner could modify 69 luminaires every month without triggering any energy efficiency requirements.

II. **Elimination of Daylight and Multi-level Control Requirements for All Modifications.** The 2016 Code only requires luminaire modifications to install Area Controls and Shut-Off Controls. (These controls are required for modification under the current 2013 Code if lighting power is greater than 85% of the lighting power allowance.

For modifications with lighting power 85% or less than the lighting power allowance, this eliminates the current requirement to install two level lighting controls.)

III. Modifications Allowed to Exceed Lighting Power Allowance. Under the 2016 proposal, modifications may exceed the lighting power allowance in Section 140.6 as long as the modified luminaires collectively have at least 35% lower rated power compared to the original luminaires prior to modification. In contrast, the 2013 Code requires modification to meet the lighting power allowance even if compliance requires more than a 35% reduction in rated power from the existing lighting. The 2016 Code caps the required reduction at 35% even if the lighting power allowances are not met.

IV. Elimination of Certain Area Control and Automatic Shut-Off Control Requirements for All Modifications.

A. **Deleted Area Control Requirements.** The 2013 Code requires that luminaire modifications subject to area control requirements shall comply with all requirements of Section 130.1(a). The 2016 Code exempts all modifications from compliance with Section 130.1(a)(4), which requires that: (A) General lighting shall be separately controlled from all other lighting systems in an area; (B) Floor and wall display, window display, case display, ornamental, and special effects lighting shall each be separately controlled on circuits that are 20 amps or less; and (C) When track lighting is used, general, display, ornamental, and special effects lighting shall each be separately controlled.

B. **Deleted Automatic Shut-Off Control Requirements.** The 2013 Code requires that luminaire modifications subject to automatic shut-off control requirements shall comply with all requirements of Section 130.1(c). The 2016 Code exempts all modifications from compliance with numerous provisions of Section 130.1(c), including 130.1, subdivisions (c)(1)(d) [separate controls form general, display, ornamental, and display case lighting], (c)(6)(B) [Library book stack aisle occupancy sensors], (c)(6)(C) [corridor and stairwell occupancy sensors], (c)(7)(A) [hotel motel corridor and stairwell occupancy sensors], and (c)(8) [hotel/motel guest room occupancy sensors].

V. Acceptance Test Exemption. Exempts luminaire modifications from existing acceptance test requirements where lighting controls are added to control 20 or fewer luminaires.

EXHIBIT C

Comparison of 2013 and Proposed 2016 Lighting Wiring Alteration Exemptions: Proposed § 141.0, subdivision (b)2.K

The 2016 Code lighting retrofit 15 day language proposal exempts lighting wiring alterations from existing control requirements, demand response requirements and acceptance test requirements.

2013 Lighting Wiring Alteration Requirements:

Lighting Wiring Alterations (1) that add a circuit feeding luminaires, (2) that replace, modify, or relocate wiring between a switch or panelboard and luminaires, or (3) that install or replace lighting control panels, panelboards, or branch circuit wiring must comply with all of the applicable requirements of Section 110.9, 130.1, and 130.4. Section 130.1 requires installation of the following controls: (1) §130.1(a) **Area Controls**; (2) §130.1(b) **Multi-Level Controls**; (3) §130.1(c) **Shut-Off Controls**; (3) §130.1(d) **Automatic Daylight Controls**; (4) §130.1(e) **Demand Response Controls** (limited to alterations of buildings greater than 10,000 sq. feet and to spaces with a lighting power density of 0.5 watts per square feet or greater.) Section 110.9 contains additional multi-level and daylighting control requirements. Section 130.4 requires acceptance testing of lighting controls. (§141.0, subd. (b)2.k.)

2016 Proposed Changes to Lighting Wiring Alteration Requirements:

I. Eliminates Demand Response Control Requirements. The 2016 Code Proposal deletes the existing requirement for lighting wiring alterations to install demand response controls.

II. Replaces Multi-Level Controls Requirement with a Pre-Wiring Requirement. The 2016 Code Proposal deletes the existing requirement for lighting wiring alterations to install multi-level controls and replaces it with a requirement to pre-wire for two-level controls.

III. Creates New Exemption From Daylight Control Requirements. The 2016 Code Proposal exempts lighting wiring alterations from existing daylight control requirements where less than 20 luminaires are located within the primary sidelit daylit zone and the skylit daylit zone.

IV. Eliminates Certain Area Control and Automatic Shut-Off Control Requirements for All Lighting Wiring Alterations.

A. **Deleted Area Control Requirements.** The 2013 Code requires that lighting wiring alterations shall comply with all the area control requirements of Section 130.1(a). The 2016 Code exempts all lighting wiring alterations from compliance with Section 130.1(a)(4), which requires that, in addition to the requirements in Section 130.1(a)1, 2, and 3: (A) General lighting shall be separately controlled from all other lighting systems in an area; (B) Floor and wall display, window display, case display, ornamental, and special effects lighting shall each be separately controlled on circuits that are 20 amps

or less; and (C) When track lighting is used, general, display, ornamental, and special effects lighting shall each be separately controlled.

B. **Deleted Automatic Shut-Off Control Requirements.** The 2013 Code requires that lighting wiring alterations shall comply with all the automatic shut-off control requirements of Section 130.1(c). The 2016 Code exempts all modifications from compliance with numerous provisions of Section 130.1(c), including 130.1, subdivisions (c)(1)(d) [separate controls form general, display, ornamental, and display case lighting], (c)(2) [prohibition on countdown timer switches], (c)(5) [areas where occupant sensors must shut off all lighting], (c)(6) [additional occupancy sensor requirements for warehouses, libraries, corridors and stairwells]; (c)(7) [parking garages and hotel/motel stairwells and corridors], and (c)(8) hotel/motel guest room occupancy sensors].

V. Acceptance Test Exemption. Exempts lighting wiring alterations from existing acceptance test requirements where lighting controls are added to control 20 or fewer luminaires.

Area Category Method - Lighting Power Density (Watts/sf)						
	Standards Vintage					Percentage of total square footage
Function Areas:	**1998 and 2001**	**2005**	**2008**	**2013**	**2016**	
Auditorium	2.00	1.50	1.50	1.50	1.40	1.5%
Classroom, Lecture	1.60	1.20	1.20	1.20	1.20	8.8%
Commercial Storage	0.60	0.60	0.60	0.60	0.60	13.8%
Corridors, Restrooms, Support	0.60	0.60	0.60	0.60	0.60	2.0%
Convention, Conference	1.50	1.40	1.40	1.40	1.20	1.5%
Dining	1.10	1.10	1.10	1.10	1.00	7.3%
Exercise, Gym	1.00	1.00	1.00	1.00	1.00	1.5%
Exhibit, Museum	2.00	2.00	2.00	2.00	1.80	1.5%
General Commercial High Bay	1.20	1.10	1.00	1.00	1.00	1.5%
General Commercial Low Bay	1.00	1.00	0.90	0.90	0.90	1.5%
General Commercial, Precision	1.50	1.30	1.20	1.20	1.20	1.5%
Grocery	1.60	1.60	1.60	1.20	1.20	1.5%
Hotel	2.20	1.50	1.50	1.50	1.40	5.5%
Library Reading Areas	1.20	1.20	1.20	1.20	1.10	1.5%
Library Stacks	1.50	1.50	1.50	1.50	1.50	1.5%
Lounge	1.10	1.10	1.10	1.10	0.90	1.5%
Malls	1.20	1.20	1.20	1.20	0.95	1.5%
Medical and Clinic	1.40	1.20	1.20	1.20	1.20	3.8%
Office	1.30	1.20	0.95	0.81	0.81	22.1%
Religious Worship	2.10	1.50	1.50	1.50	1.50	1.5%
Retail	2.00	1.70	1.60	1.20	1.20	15.7%
Theater Area	0.90	0.90	0.90	0.90	0.90	1.5%
Average LPDs	1.39	1.25	1.22	1.17	1.12	
Average 2016 Savings Over Vintage for LPDs	**19.7%**	**10.4%**	**8.2%**	**4.8%**		

Note 1: The 1998 and 2001 Standards LPDs are very similar

Note 2: Average life of retrofitted lighting system is 10 to 15 years

Percentage of total square footage	Area Category Method - Weighted LPD (Watts/sf)					
		Standards Vintage				
	Function Areas:	**1998 and 2001**	**2005**	**2008**	**2013**	**2016**
1.5%	Auditorium	0.030	0.023	0.023	0.023	0.021
8.8%	Classroom, Lecture	0.141	0.106	0.106	0.106	0.106
13.8%	Commercial Storage	0.083	0.083	0.083	0.083	0.083
2.0%	Corridors, Restrooms, Support	0.012	0.012	0.012	0.012	0.012
1.5%	Convention, Conference	0.023	0.021	0.021	0.021	0.018
7.3%	Dining	0.080	0.080	0.080	0.080	0.073
1.5%	Exercise, Gym	0.015	0.015	0.015	0.015	0.015
1.5%	Exhibit, Museum	0.030	0.030	0.030	0.030	0.027
1.5%	General Commercial High Bay	0.018	0.017	0.015	0.015	0.015
1.5%	General Commercial Low Bay	0.015	0.015	0.014	0.014	0.014
1.5%	General Commercial, Precision	0.023	0.020	0.018	0.018	0.018
1.5%	Grocery	0.024	0.024	0.024	0.018	0.018
5.5%	Hotel	0.122	0.083	0.083	0.083	0.077
1.5%	Library Reading Areas	0.018	0.018	0.018	0.018	0.017
1.5%	Library Stacks	0.023	0.023	0.023	0.023	0.023
1.5%	Lounge	0.017	0.017	0.017	0.017	0.014
1.5%	Malls	0.018	0.018	0.018	0.018	0.014
3.8%	Medical and Clinic	0.053	0.045	0.045	0.045	0.045
22.1%	Office	0.287	0.265	0.210	0.179	0.179
1.5%	Religious Worship	0.032	0.023	0.023	0.023	0.023
15.7%	Retail	0.314	0.267	0.251	0.188	0.188
1.5%	Theater Area	0.014	0.014	0.014	0.014	0.014
	Weighted Average LPD for each Vintage	**1.39**	**1.21**	**1.14**	**1.04**	**1.01**
	Average 2016 LPD Savings Over Vintage LPDs	27%	17%	11%	3%	0%
	85% of 2016 LPDs	**0.86**	**0.86**	**0.86**	**0.86**	**0.86**
	70% of Vintage LPDs (30% reduction)	**0.97**	**0.85**	**0.80**	**0.73**	
	65% of Vintage LPDs (35% reduction)	**0.90**	**0.79**	**0.74**	**0.68**	

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

LBNL-5095E

A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings

Alison Williams, Barbara Atkinson, Karina Garbesi, and Francis Rubinstein

Energy Analysis Department
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

Erik Page

Erik Page & Associates, Inc.

September 2011

This work was supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, Building Technologies Program under Contract No. DE-AC02-05CH11231.

.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.

ABSTRACT

Researchers have been quantifying energy savings from lighting controls in commercial buildings for more than 30 years. This study provides a meta-analysis of estimates of energy savings identified in the literature—240 savings estimates from 88 papers and case studies, categorized into daylighting strategies, occupancy strategies, personal tuning, and institutional tuning. Beginning with an overall average of savings estimates by control strategy, this paper adds successive analytical filters to identify potential biases introduced to the estimates by different analytical approaches. Based on the meta-analysis, the best estimates of average energy savings potential are 24% for occupancy, 28% for daylighting, 31% for personal tuning, 36% for institutional tuning, and 38% for multiple approaches. The results suggest that simulations significantly overestimate (by at least 10%) the average savings obtainable from daylighting in actual buildings.

Key Words: Daylighting, occupancy sensors, controls, tuning

1. INTRODUCTION

Lighting systems have the largest potential of any known appliance to reduce United States energy use (Desroches and Garbesi 2011). Lighting represents approximately one-third of electricity use in commercial buildings and more than one-half in lodging and retail (U.S. Department of Energy). As a result, there is significant interest in reducing lighting energy use through more efficient lighting systems, including controls. The National Electrical Manufacturers Association (NEMA) has argued that controls have greater potential for energy savings in major applications than an increase in source efficacies (U.S. Department of Energy 2011b). However, lighting controls are not incorporated in federal energy conservation standards and are only partially incorporated through state and local building codes.[1] While energy savings from some system components, such as replacing T12s with T8s, can be fairly easily quantified and guaranteed, savings from controls that turn lights off or down when not needed depend on numerous factors including application, site orientation and occupation, building design, interior reflectances, occupant behavior, and tuning and configuration during installation and commissioning, making savings less easy to predict. With current estimates of the installed capacity of lighting controls systems very low—only 2% of lit commercial buildings in the United States have daylighting sensors and only 1% have an energy management and control systems for lighting, according to the U.S. Department of Energy 2003 Commercial Buildings Energy Consumption Survey (CBECS)—the potential for technical potential for energy savings appears large.

Researchers have been quantifying energy savings from lighting controls in commercial buildings for more than 30 years, but no comprehensive research review of the studies on controls has been done before. This makes it hard to understand the big picture of the opportunities of controls because the individual studies have been very diverse in their goals, methods, coverage, and results. Some studies, such as those regarding U.S. Environmental Protection Agency programs, present data from monitoring of actual installations in numerous buildings all in one paper (e.g. VonNeida et al 2000). Other studies, such as those by the National Research Council Canada and Florida Solar Energy Center, present results from lab tests or experiments with just one or two control spaces and experimental spaces (e.g. Parker

[1] ASHRAE 90.1, the national model building code, is updated every three years and includes several controls requirements in ASHRAE 90.1-2010 including automatic shutoff controls and photocells in certain space types. However, states have until 2013 just to update their codes to meet ASHRAE 90.1-2007, and some states still meet only ASHRAE 90.1-2001 (U.S. Department of Energy 2011a).

et al 1996). Some studies separate the effects of controls from the effects of other lighting efficiency measures, while others do not. Some studies are designed to identify the influence of other factors, such as window glazing or orientation, on energy savings obtained from controls. Some studies focus on specific space types, while others report savings by buildings or across buildings without noting or reporting on savings by space types within buildings.

A few papers have provided limited overviews of lighting controls studies. Three of these reviews focused solely on occupancy sensors; the number of reports or individual energy savings estimates referenced by these papers range from seven to 35. VonNeida et al (2000) presented industry estimates of lighting energy savings for occupancy sensors by building space type, which ranged from 5% to 90%. The authors then presented results from their own study on 60 buildings with lighting savings ranging from 17% to 60%. The Lighting Research Center (2003) compiled 26 case studies and claims by manufacturers to recommend energy saving estimates for occupancy sensors for the U.S. Department of Energy. The recommendations based on the data were 25% to 40% depending on the use of space. Guo et al (2010) reviewed the performance of occupancy-based control systems from seven previous studies, with energy savings ranging from 3% to 86%.

The two reviews of savings from systems other than occupancy sensors provide only one to six savings estimates per control type. Southern California Edison (2008) produced a report on the "Office of the Future," which referenced several studies that provided energy savings for daylighting, occupancy sensors, and personal controls in open offices; vacancy sensors in private offices; and occupancy sensors in corridors. The overall range of savings was 6% to 80%. The Advanced Lighting Guidelines On-Line Edition (New Buildings Institute 2011) presents a table of lighting energy savings by space type (private office, open office, and classroom) and controls type (multilevel switching, manual dimming, daylight harvesting, and occupancy sensors); the range of lighting energy savings is 6% to 70% across 11 categories of space types and controls types.

These previous studies reported a very broad range of results for particular contexts using a subset of data existing in the literature. This paper describes a comprehensive literature review and analysis of energy savings from all types of lighting controls studied in commercial buildings. The purpose of this meta-analysis is to derive average energy savings per control type based to the extent possible on all available data. While these studies do not generally use common parameters, we utilize a range of analytical filters to estimate the savings by control type and building type and to isolate the effect of controls from those of other lighting system modifications.

2. METHODOLOGY

2.1 LITERATURE SEARCH

Our investigation of lighting controls savings potential began with a literature search of consultant reports, research papers, professional organization publications, industry literature, conference proceedings, and report databases. The team also consulted with California utilities, lighting manufacturers, controls manufacturers, the California Energy Commission, and the lighting controls division of the National Electrical Manufacturers Association (NEMA). We used the reference lists in the reports identified in this phase to find additional sources. If a paper presented only secondary data on energy savings from controls, as with some of the work cited in the introduction, we did not include it in our analysis. Instead, we expanded our search to identify the primary data sources and included them where available and appropriate.

To be included in the analysis, a paper needed to provide energy savings in percentage terms from lighting controls studies or present baseline and test case energy use from which we could calculate percentage savings. In total, we identified 88 papers that met these criteria. Of these, 40 were research papers published in a peer-reviewed journal or presented at a conference in which papers are reviewed, and 48 were self-published reports or case studies. While not all of those papers classified as reviewed were technically peer-reviewed, we refer to them as such throughout this paper for simplicity.

Reviewed publications included conference proceedings of the American Council for an Energy-Efficient Economy (ACEEE) (8), conference proceedings and journal articles of the Illuminating Engineering Society of North America (IESNA) (6), and journal articles from *Energy and Buildings* (5), *Lighting Research and Technology* (4), *Leukos* (3), and *Solar Energy* (3). We also included several consultant reports. The most represented non-industry authors came from the Lighting Research Center (11), the National Research Council Canada (9), Lawrence Berkeley National Laboratory (LBNL) (9), the California Lighting Technology Center (CLTC) (6), the Florida Solar Energy Center (5), and the Heschong Mahone Group (3). The most represented industry case studies included those of WattStopper (11), Sensor Switch (2), and Lutron (2).

2.2 DATA ORGANIZATION

We compiled data from the 88 papers into a searchable database in an Excel spreadsheet format. Each row of the spreadsheet represented a unique estimation of energy savings from controls. Every paper was represented by at least one row, but multiple rows were used if the paper presented energy savings for more than one control configuration or space type**.** A single row often combined multiple data points from the source study to yield a representative average savings. For example, in some cases we entered a minimum and maximum savings from the source and calculated the average savings. In other cases, we averaged over other variables such as window orientation, blind use, glazing, or time delay of occupancy sensors. A single control configuration might comprise multiple rows, if the paper included savings based on significantly different baselines (i.e. lights full on all day versus occupancy profile). However if a paper presented two different savings numbers, one for core hours and one for 24 hours, we retained only the core hour value in order to avoid double counting savings from essentially the same scenario, while retaining arguably the most useful savings number. Ultimately this process yielded 240 rows of unique controls-related energy savings estimates from the 88 papers and a database that includes more than 40 independent columns.

We based the primary data organization on the four major controls strategies defined in Table 1.

TABLE 1. Major lighting controls strategies

Strategy	**Definition**	**Relevant Technologies**
Occupancy	Adjusting light levels according to the presence of occupants	occupancy sensors, time clocks, energy management system
Daylighting	Adjusting light levels automatically in response to the presence of natural light	photosensors, time clocks[1]
Personal tuning	Adjusting individual light levels by occupants according to their personal preferences; applies, for example, to private offices, workstation-specific lighting in open-plan offices, and classrooms	dimmers, wireless on-off switches, bi-level switches, computer-based controls, pre-set scene selection
Institutional tuning	(1) Adjustment of light levels through commissioning and technology to meet location-specific needs or building policies; or (2) provision of switches or controls for areas or groups of occupants; examples of the former include high-end trim dimming (also known as ballast tuning or reduction of ballast factor), task tuning, and lumen maintenance	dimmable ballasts, on-off or dimmer switches for non-personal lighting

[1] Note: Time clocks are often used for daylighting control in exterior applications, and while they in theory could be used in interior spaces, they rarely are. None of the 88 studies reviewed included interior time clocks for daylighting control.

If a study tested multiple control strategies in combination, where possible, we presented data for each individual control strategy on separate rows. Depending on the study, this data might represent a fraction of the total savings, with all savings strategies totaling to the savings from the combination actually installed, or might represent the savings there would have been if the strategy had been implemented alone. We did not attempt to standardize this data. Some papers did not provide this level of data, so savings are presented for control strategies in combination on a single row. For a few studies that reported savings for controls both independently and in combination, we included the combination data on its own row in addition to the separate rows for each individual strategy. As we never calculate savings across control strategies, this does not result in double counting.

We included multiple additional fields to characterize the details of the control strategies. The most important fields include whether the control system used a clock or a sensor; whether the control was dimming, on-off, or both; and whether the control was automatic or manual. Any variation on these control strategies was determined to be a different control configuration and its results were presented on a different row. We also included a field for time delay for off response; some studies varied this, and results are averaged from the minimum and maximum time delay tested and presented in a single row.

We also tracked building type, space type, and luminaire and lamp technology. As previously mentioned, we had savings fields available for minimum and maximum as well as average. We also recorded the energy savings determination method for both the baseline and the test case—monitoring, calculation, simulation, and so on—as well as a text description with more details. We also included a detailed description of the baseline.

We recorded additional details regarding the savings, including whether they were for lighting controls only (as opposed to including savings from luminaire or lamp retrofits), whether the savings were only of lighting energy use or total building energy use, and whether the savings were given in energy or another unit deemed equivalent to energy (such as power for a test case in which hours of use did not

change). Report authors were not always clear about these important distinctions, but we used our best judgment to ascertain what each study represented. We also noted whether the data were from an actual installation (lab or field) or were estimated from a simulation or calculation.

For all studies we made our best effort to fill in all applicable variables. All reported variables were entered, and we made educated guesses based on other provided information for some variables not explicitly shown in a study. If we did not think we had enough information to determine a variable for a study with good confidence, we left that field blank. These database fields enabled us to identify unique control strategies and filter the data for desired characteristics.

2.3 COVERAGE

By control type

While we attempted to identify studies representing all available control types, the majority of the literature provided savings for daylighting and occupancy strategies. Figure 1 shows the percentages of the 240 rows of data that each control type represents. The smaller pie shows the most common groups of multiple strategies.

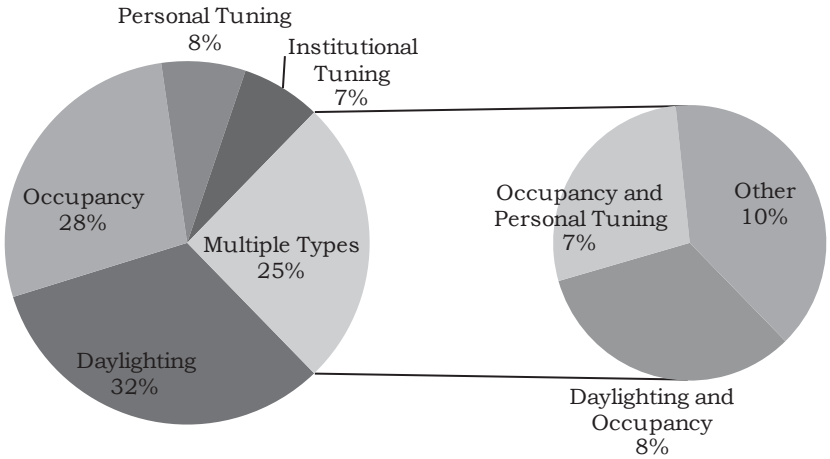

Fig. 1. Data by control type (n=240).

By building type

To obtain as complete sectoral coverage as possible, we made specific attempts to find studies in under-represented building types. Table 2 shows the coverage by building type with the building types ordered by their percentage of commercial lighting energy use, according to the 2003 Commercial Buildings Energy Consumption Survey (CBECS) (US Department of Energy). Most of the studies cover office and education building types; we do have some coverage in most categories with a high percentage of lighting use. For some studies, the building type was difficult to classify based on the information provided, so we made our best guess. Some of the missing coverage is expected; for example,

occupancy is generally the only control strategy used in the lodging sector. While data are missing for five of the 14 categories, these constitute less than 20% of total lighting energy use in the commercial sector. On the other hand, a significant number of data points are available only for the top four categories, which together constitute an estimated 58% of commercial building energy use.

TABLE 2. Coverage by building type: number of rows for each control type (alone or in combination). (Percent commercial lighting energy use from CBECS 2003.)

Building Type (Reported by itself or in combination with other building types)	Percent Commercial Lighting Energy Usage (CBECS 2003)	Occupancy	Daylighting	Personal Tuning	Institutional Tuning
Office	25%	76	70	18	31
Warehouse	12%	10	4	1	-
Lodging	11%	7	-	-	-
Education	10%	22	33	13	-
Retail (other than Mall)	10%	2	4	2	3
Healthcare Inpatient	7%	2	2	1	1
Service	6%	-	-	-	-
Food Service	4%	-	-	-	-
Food Sales	4%	-	-	-	-
Public Assembly	2%	2	1	-	-
Healthcare Outpatient	2%	5	-	-	-
Public Order and Safety	2%	-	-	-	-
Religious	1%	-	-	-	-
Other	5%	8	3	-	-

2.4 DATA ANALYSIS OVERVIEW

As a starting point, we calculated overall average energy savings by control type for all studies in the spreadsheet, irrespective of exactly what the savings represented. As mentioned previously, each row in our spreadsheet included an average savings either directly from the paper, calculated from a minimum and maximum provided in the paper, or calculated based on a range of other variables reported on, such as window orientation and occupancy sensor delay time. As such, we calculated the overall average savings for the meta-analysis as a simple average of the average savings in each row.

We then applied a series of progressive filters to the data, each building on the former, in order to screen out data points with significantly different characteristics. For the first filter, we screened out savings data that included not only savings from controls but also from lamp or luminaire retrofits. This filter left us with data points that represented savings from lighting controls only.

For the next filter, we examined what the savings represented, as we wanted to include studies that represented lighting energy savings only. We removed data points that represented savings as a fraction of total building energy or included heating, ventilation, and air conditioning (HVAC) savings as opposed

to lighting savings only. We also removed data points that represented a non-comparable savings type, such as wasted light hours and energy costs. In some cases we determined that the presented units were equivalent to energy; for example if occupancy sensors saved X% of lighting hours and there was no apparent change to power, the savings were considered equivalent to energy savings.

Finally, we examined the remaining studies for significant differences between savings from actual installations and from simulations. We filtered out any savings points that were not from actual installations—either lab or field. This last filter had the effect of removing outliers and likely provides more realistic savings. We also compared savings from each of the progressive scenarios—lighting controls only, lighting energy savings only, and actual installations only.

3. ANALYTICAL FILTERS AND RESULTS

3.1 OVERALL

As mentioned previously, we began by calculating an unfiltered, unadjusted average savings by control type for all data in our matrix. Figure 2 shows the average savings by control strategy as well as the standard deviation and minimum and maximum values. For individual control types, average savings range from 30% for occupancy to 41% for daylighting. Note that the institutional and personal tuning sample sizes are small. Throughout this paper, the savings figures for each filter will be shown with the control strategies in the same order to demonstrate changes between filters, while an overall comparison will be shown at the end of the paper.

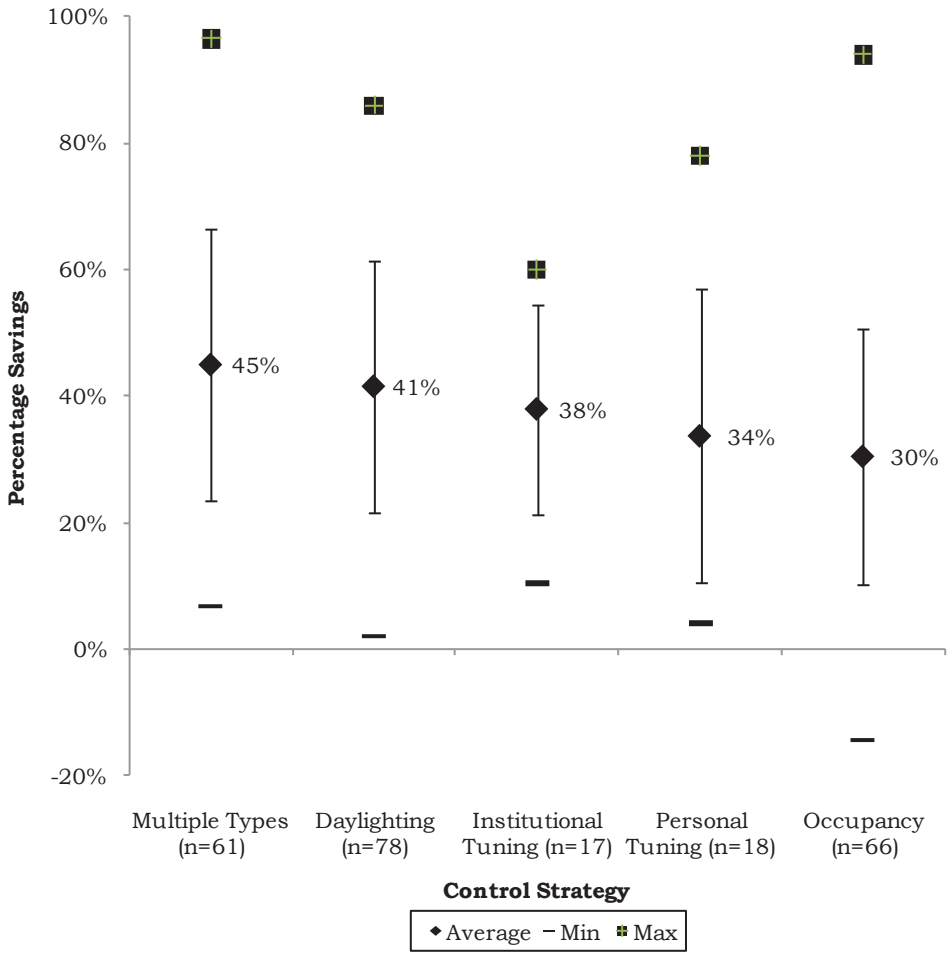

Fig. 2. Average savings (%) by control type – unfiltered; error bar shown represents one standard deviation.

The savings shown in Fig. 2 represent a wide range and include cases where the savings are negative. Throughout this analysis, we checked for outliers in the dataset in an effort to identify data that would not represent realistic potential energy savings and to narrow the range as appropriate. In the overall data, there appear to be outliers on the low end. However, these are generally from actual installations, and, in the negative case, occupants had previously been diligent about turning off lights but no longer did so. We believe this provides a legitimate potential result that may occur with occupancy sensor installation. Some other low savings numbers occur from strategies implemented in combination with other strategies, so that the savings attributed to any one strategy may be smaller than they would be if implemented alone. However, we think that many of the numbers on the high end are actually outliers, and we review the maximum savings after each filter to identify whether outliers have been removed. Note that we relied on the filtering process to remove outliers rather than removing any arbitrarily.

We also present savings by building type, as shown in Table 3. Because some studies provided data for multiple building types that we were unable to disaggregate, the table below only averages savings from building types reported alone. Therefore, this table is not comprehensive of all data in the study. Note that sample sizes are only robust for some control strategies within office and education.

TABLE 3. Average savings for each control type by building type

Building Type	Occupancy	Daylighting	Personal Tuning	Institutional Tuning	Multiple Types
Office	23% (n=32)	38% (n=42)	38% (n=15)	38% (n=15)	43% (n=42)
Warehouse	35% (n=6)	28% (n=1)	-	-	63% (n=3)
Lodging	48% (n=7)	-	-	-	-
Education	31% (n=9)	49% (n=29)	6% (n=2)	-	46% (n=11)
Retail (other than Mall)	5% (n=1)	29% (n=3)	-	60% (n=1)	69% (n=1)
Healthcare Inpatient	-	-	-	-	55% (n=2)
Public Assembly	36% (n=2)	36% (n=1)	-	-	-
Healthcare Outpatient	23% (n=1)				
Other	7% (n=1)	18% (n=1)	-	-	-

We checked for differences in savings between peer-reviewed and non-peer-reviewed papers to identify any possible quality issues in non-reviewed papers. Table 4 shows the results of the analysis. We did not find any significant differences between these categories. However, many of the sample sizes are low. Nevertheless, we do not believe sufficient evidence exists to filter on this variable, choosing instead to rely on other filters for our analyses.

TABLE 4. Average savings by control type for peer-reviewed and non-peer-reviewed papers

Control Type	Reviewed	Not Reviewed	Two-tailed P value*
Occupancy	28% (n=31)	33% (n=35)	0.3101
Daylighting	43% (n=63)	35% (n=15)	0.1636
Personal Tuning	36% (n=13)	27% (n=5)	0.4727
Institutional Tuning	43% (n=11)	28% (n=6)	0.1407
Multiple Types	50% (n=28)	41% (n=33)	0.1006

*Values <0.05 would be considered statistically significant at 95%.

3.2 SAVINGS FOR LIGHTING CONTROLS ONLY

Many of the studies reported data for comprehensive lighting retrofits that included both lighting controls and lamp or luminaire replacements (or delamping, the removal of lamps from luminaires that remain in place). In many cases, the studies did not disaggregate the energy savings just attributable to the controls. Because we wanted to focus on the savings potential that lighting controls provide, we filtered out all studies that did not disaggregate lighting controls savings from overall savings, including other types of lighting retrofits. This filter retained 86% of all rows: 91% of peer-reviewed rows and 78% of non-peer-reviewed rows. Fig. 3 shows the average savings following this first filter. Savings range

from 28% for occupancy to 39% for daylighting, representing a very small correction. Note that this filter does not remove many of the high outliers.

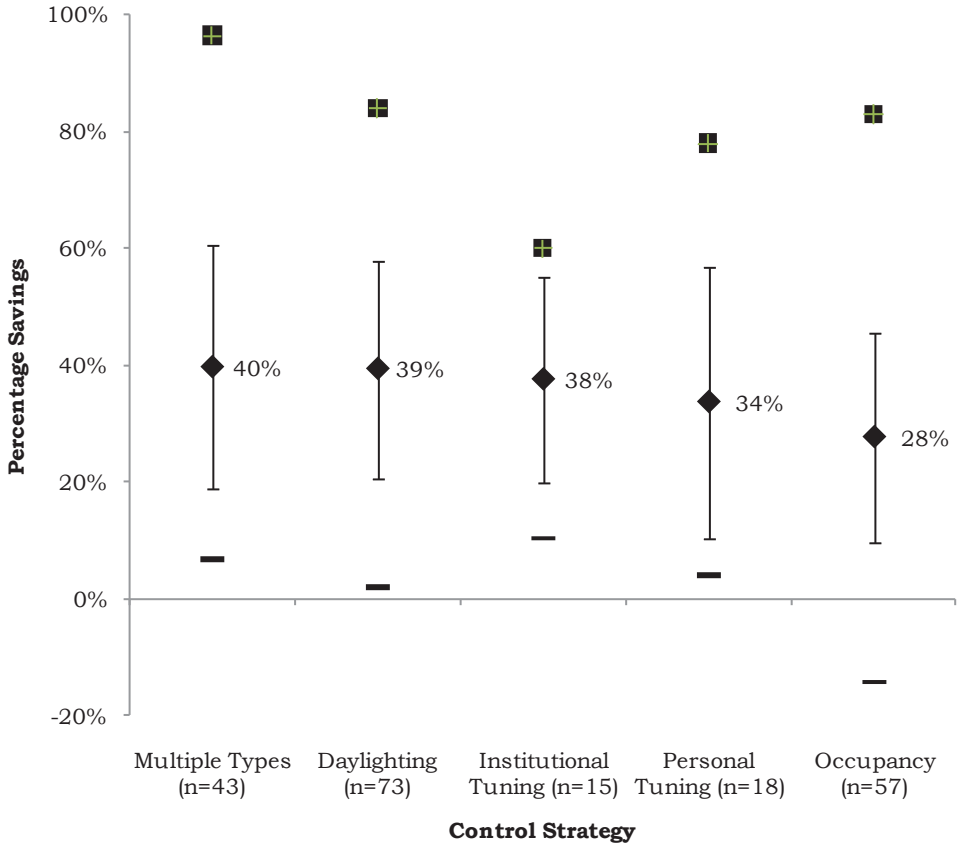

Fig. 3. Energy savings for lighting controls only – first filter; symbols as shown in Fig. 2.

3.3 SAVINGS FOR LIGHTING ENERGY ONLY

We next looked at what the savings numbers represented, attempting to identify all savings reported as lighting energy savings or as something equivalent. We originally believed that this would eliminate many data points, as only 150 of the original 240 records reported savings explicitly as energy. Many studies used other descriptors such as lighting hours, power, or energy per area. However, we reviewed the reports to determine whether these data were equivalent to energy. For example, average power can be equivalent to energy if hours of use do not change. In the end, we determined that most studies reported in units equivalent to energy. Therefore with this filter, we removed only nine rows, including savings as a percentage of wasted light hours, energy costs, total building energy, or energy per workstation.

Note that within energy savings, savings may still represent different things (i.e. annual vs. daily, weekday core hours only vs. 24/7). However, we did not attempt to filter or standardize further on this variable. Many of the papers did not provide clear information on all details, and many different hour ranges were used for core hours. In addition, in some building types, evaluating savings from core hours may account for nearly all the savings, while, in other building types, savings may accrue mostly after hours, making a 24-hour baseline important. With these examples, it does not seem critical to use only studies with certain definitions of energy savings.

The savings from the second filter are shown in Fig. 4. Savings range from 26% for occupancy to 39% for daylighting, again representing only a small correction. This filter removes major outliers for occupancy only, but some high values remain in other categories.

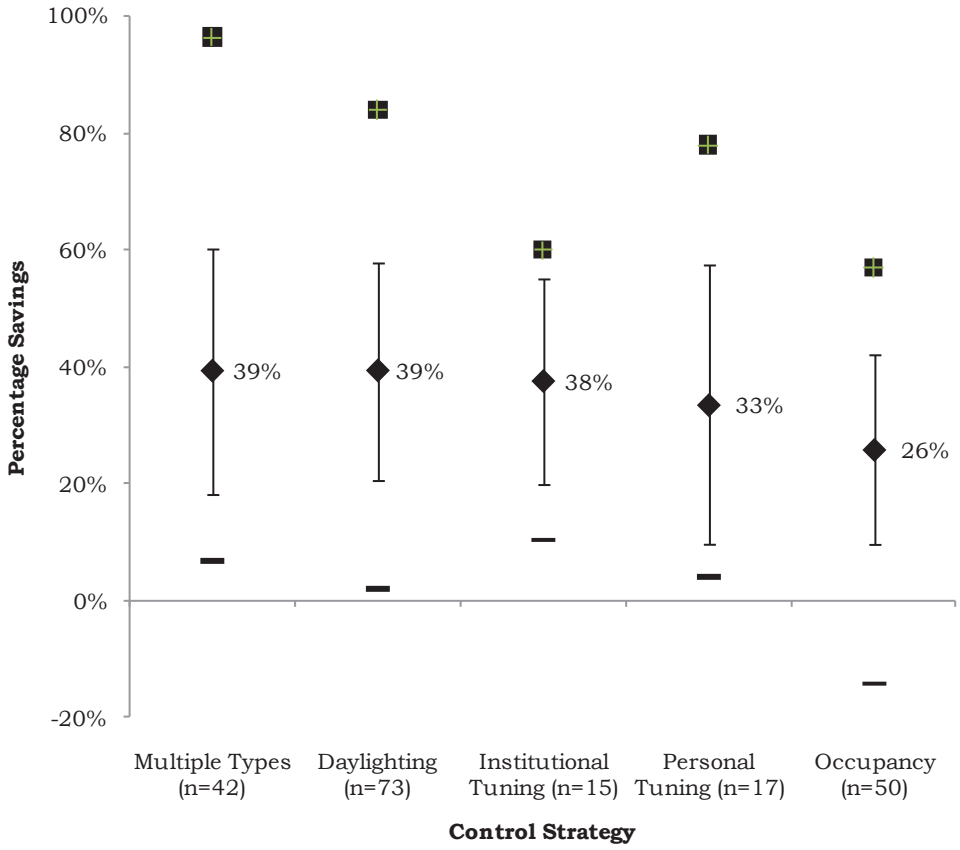

Fig. 4. Energy savings for lighting controls and lighting energy only – second filter; symbols as shown in Fig. 2.

3.4 SAVINGS FOR ACTUAL INSTALLATIONS ONLY

For the final filter, we wanted to address savings by how they were calculated. In theory, studies that monitor both the baseline and the test case should be most reliable. Studies that monitor only the test case and back-out the baseline may partially misrepresent savings by not capturing things like changes in behavior after controls installation. Studies that monitor the baseline and calculate or simulate a test case may over-represent savings by reporting what are essentially theoretical (maximum potential) savings, as are estimates based on completely simulated studies. Table 5 shows the breakdown of savings estimates based on these parameters, categorized into the overarching themes of actual installations and simulations/calculations.

TABLE 5. Savings basis for actual installations and simulated or calculated installations

Savings Basis	**Number of Rows – Actual Installation**	**Number of Rows – Simulated or Calculated**
Monitored **(with calculated baseline)**	86	-
Calculated/Simulated **(from a monitored baseline)**	-	26
Simulated **(test case and baseline)**	2*	33
Monitored/Metered **(test case and baseline)**	37	-
Calculated **(test case and baseline)**	-	5
Unknown	8	-
TOTAL	**133**	**64**

*These two data points represent actual installations for which the savings data was estimated from a simulation rather than monitoring.

To simplify analysis and prevent reduction to small sample sizes, we looked at the difference between savings from the two major categories shown in Table 5: actual installations of controls and scenarios in which the presence of controls was simulated. Figure 5 shows this analysis.

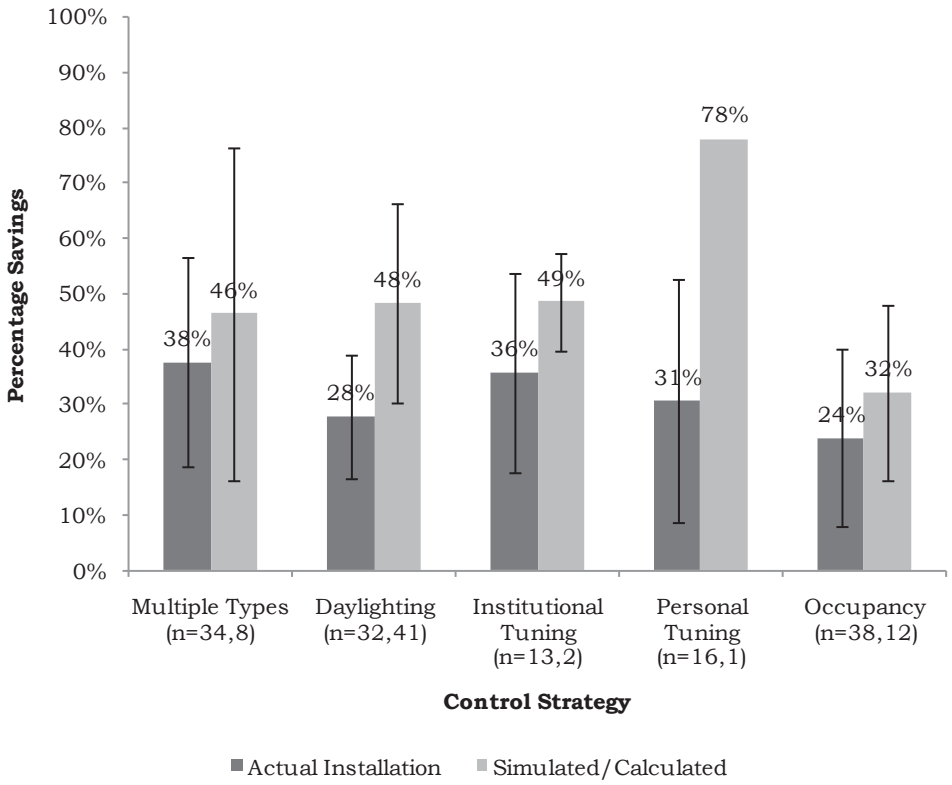

Fig. 5. Comparison of energy savings for actual installations and simulated or calculated installations.

For daylighting, savings from actual installations appear to be significantly lower than those from simulations ($p<0.0001$). Sample sizes may be too small for the other categories to identify significant differences. Because of the significant difference for daylighting and the strong possibility that simulated studies over-represent savings, we filtered on this variable. Fig. 6 shows the average savings and other statistics following this final filter. Note that the averages in this figure are equivalent to the average savings from actual installations shown in Fig. 5. Savings range from 24% for occupancy to 36% for institutional tuning. Most notable, this filter clearly reduced the savings for daylighting, down to 28%. The filter removed 40% of peer-reviewed rows and only 17% of non-peer-reviewed rows, as simulations tend to be published in peer-reviewed literature. This filter removes many of the high outliers. Although some high values remain, because they come from actual installations, we believe that they represent real savings potential.

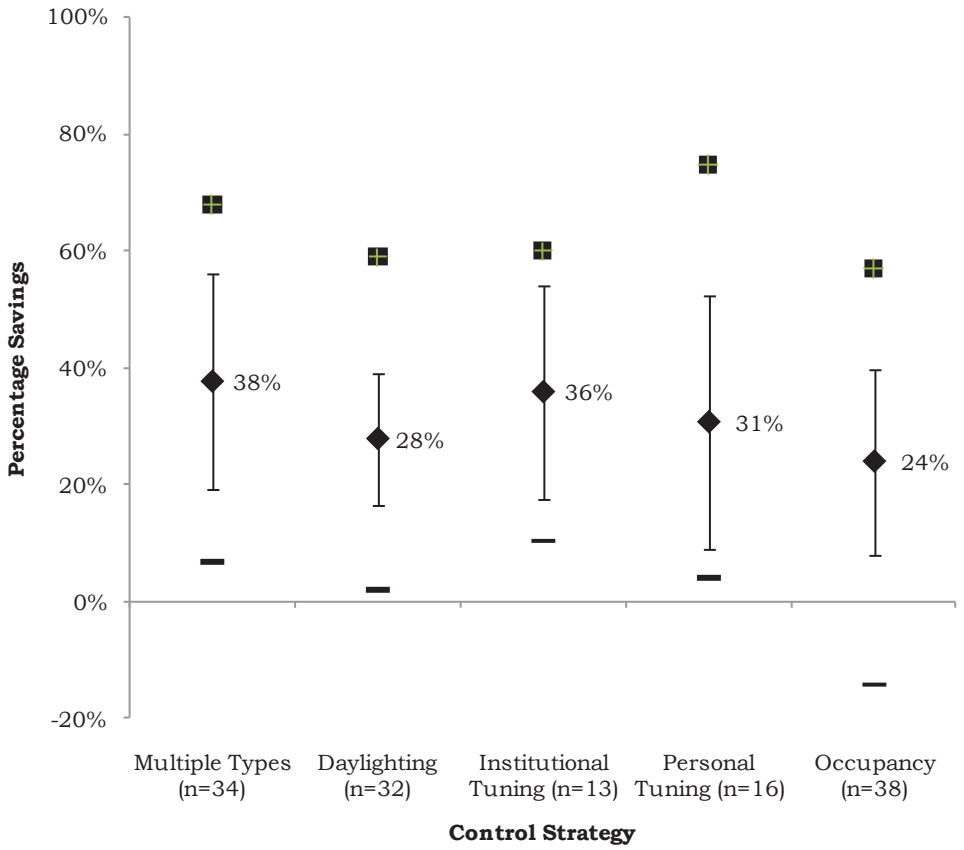

Fig. 6. Energy savings for lighting controls and lighting energy in actual installations – final filter; symbols as shown in Fig. 2.

In this final cut, we again checked for significant differences between savings from reviewed papers and savings from non-reviewed papers. Table 6 shows that the only significant difference was for multiple types (although note that sample sizes are small for all control strategies). Three very low non-reviewed data points for multiple types come from a single paper with a highly efficient lighting system as baseline. This, along with the disparate nature of combinations of control strategies, may be the reason for this significant difference. We do not believe this indicates any quality issues, particularly since savings are higher for the reviewed papers.

TABLE 6. Comparison of savings for reviewed and non-reviewed papers

Control Type	Reviewed	Not Reviewed	Two-tailed P-value*
Occupancy	24% (n=20)	23% (n=18)	0.8493
Daylighting	29% (n=20)	26% (n=12)	0.4687
Personal Tuning	33% (n-12)	24% (n=4)	0.4934
Institutional Tuning	42% (n=8)	26% (n=5)	0.1268
Multiple Types	43% (n=20)	30% (n=14)	**0.0428**

*Values <0.05 considered statistically significant.

Table 7 provides a final cut of savings by building type. However, note that, with this filter, there are not enough savings data left to provide reliable estimates for most building types.

TABLE 7. Energy savings by building type – final filter

Building Type (Alone)	Occupancy	Daylighting	Personal Tuning	Institutional Tuning	Multiple Types
Office	22% (n=23)	27% (n=18)	35% (n=13)	36% (n=11)	40% (n=24)
Warehouse	31% (n=4)	28% (n=1)	-	-	-
Lodging	45% (n=2)	-	-	-	-
Education	18% (n=5)	29% (n=7)	6% (n=2)	-	34% (n=7)
Retail (other than Mall)	-	29% (n=3)	-	60% (n=1)	-
Healthcare Inpatient	-	-	-	-	35% (n=1)
Public Assembly	36% (n=2)	36% (n=1)	-	-	-
Healthcare Outpatient	23% (n=1)	-	-	-	-
Other	7% (n=1)	18% (n=1)	-	-	-

3.5 COMPARISON OF ENERGY SAVINGS ACROSS FILTERS

Viewing the savings from all the filtered scenarios at once shows a general downward trend in energy savings as well as a reduction in the error band in some cases, as can be seen in Fig. 7. Figure 8 highlights an especially strong downward trend for the daylighting savings estimates, which began with a filtered average of 39% and was reduced to 28% in the final filter. Savings from occupancy strategies also declined over the analysis, but only from 28% to 24%. In this case, savings declined steadily through each filter. We believe that the final filter represents the best conservative estimate of controls energy savings achievable in the field.

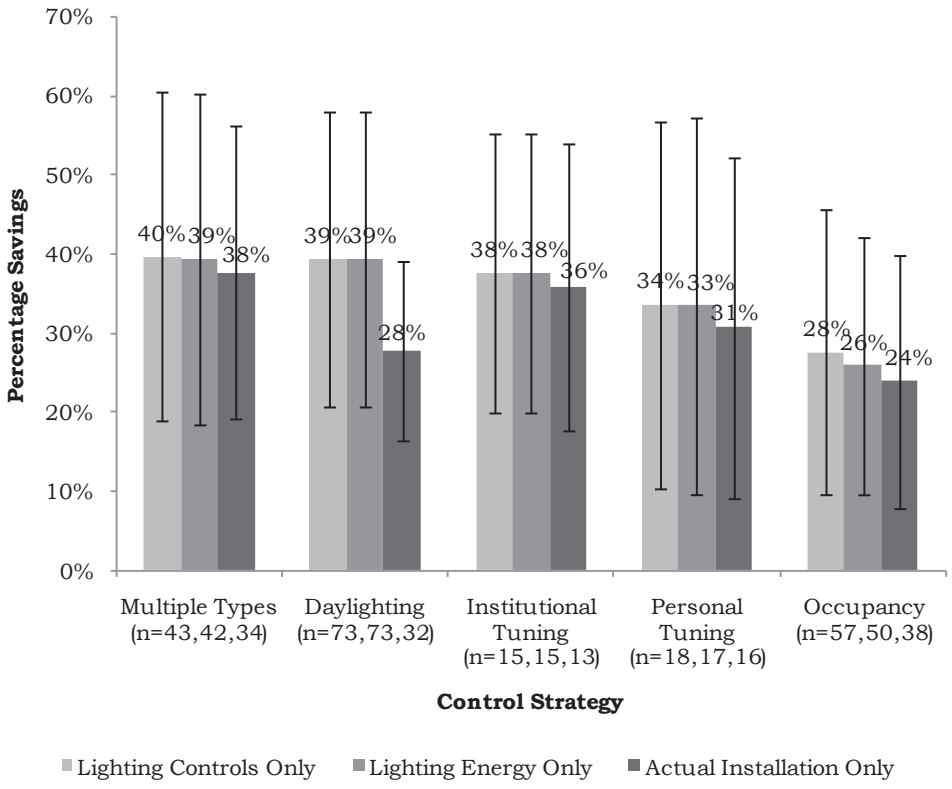

Fig. 7. Comparison of energy savings from first filter to final filter. (Note that we do not show the overall unfiltered results here; because it includes savings from non-controls-related measures, it is not relevant to the final analysis).

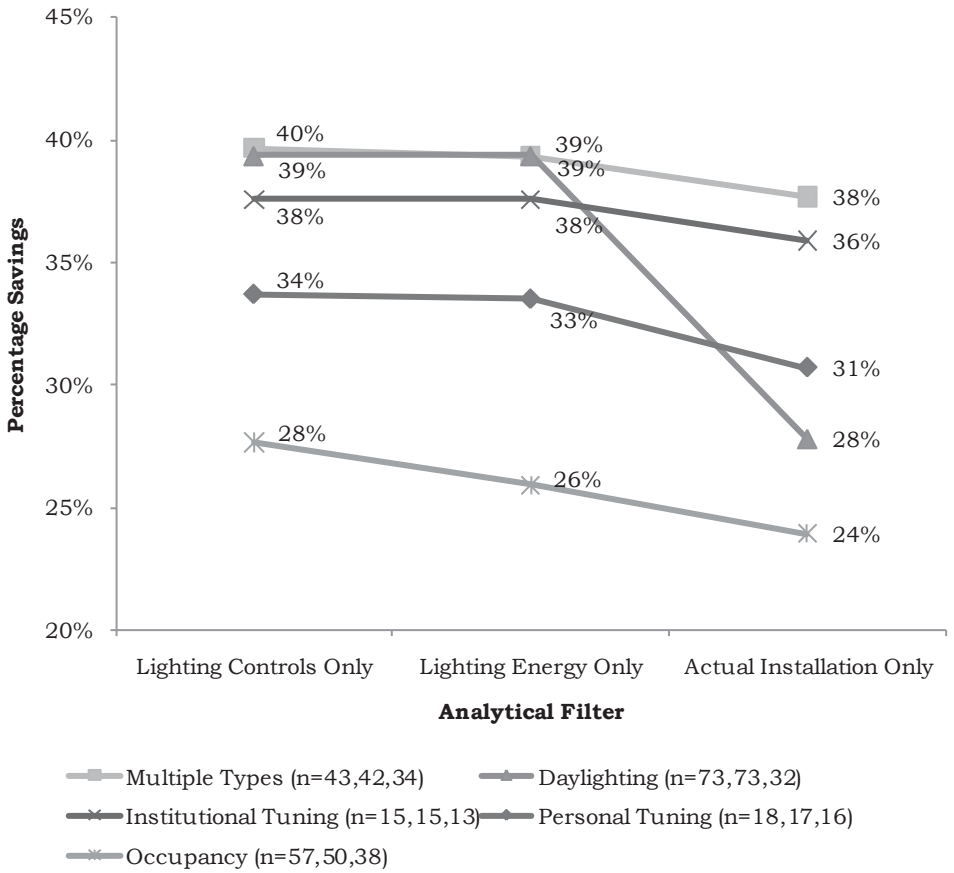

Fig. 8. Comparison of energy savings from first filter to final filter.

4. DISCUSSION AND CONCLUSIONS

This paper examined to the greatest extent possible the entire body of evidence on the energy impacts of lighting system controls used in commercial buildings. To arrive at the best estimates of the impacts of different controls, we applied a series of filters to screen out data points with significantly different characteristics and to remove possible sources of bias in the data. Interestingly, we found no effect from peer-reviewed versus non-peer-reviewed literature and therefore did not filter on this variable. The first two filters we used screened out data points that include savings from non-controls lighting technology and that report savings in something not equivalent to lighting energy. These filters did not create a large impact on overall savings.

The biggest single effect from filtering was the final filter, which screened out data points that were not based on actual installations: We found that simulations appear to overestimate savings achievable in the field, especially for daylighting. This result is not surprising, as daylight in a building is affected by so many factors (building orientation, location, use, weather, occupancy, blinds, reflectances, commissioning, etc.). This indicates that energy policy and savings estimates should not be based on simulations alone, but should include field measurement or at least downward adjustment of savings predicted from simulations.

This comprehensive meta-analysis provides strong evidence that lighting controls do on average capture significant energy savings—between one-quarter and one-third of lighting electric energy, depending on the individual control strategy, and up to nearly 40% for buildings in which multiple controls strategies are used. While these results may have limited value from a predictive standpoint, viewed in aggregate, they build confidence that lighting control strategies can and do provide significant energy savings in commercial building applications. This finding has significant implications for energy policy. As mentioned previously, controls penetration is very low, federal energy conservation standards do not include lighting controls, and state and local building codes only partially address them. Our findings indicate that policies that increase the use of lighting system controls are among the most potent approaches to reducing U.S. energy use.

ACKNOWLEDGEMENT

The work described in this article was funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, Building Technologies Program under Contract No. DE-AC02-05CH11231.

REFERENCES

ADM Associates, Inc. 2002. Lighting controls effectiveness assessment: final report on bi-level lighting study. Heschong Mahone Group. 78 p.

Atif MR, Galasiu AD. 2003. Energy performance of daylight-linked automatic lighting control systems in large atrium spaces: report on two field-monitored case studies. Energy and Buildings 35(5):441-461.

Birt B, Newsham GR. 2009. Energy savings from photosensors and occupant sensors/wall switches on a college campus. Proceedings of the Lux Europa 11th Annual Lighting Conference. p 731-738.

Bisbee, D. 2010. Customer Advanced Technologies Program technology evaluation report: HID Labs SmartPOD. Sacramento Municipal Utility District. Report # ET09SMUD1012. 12 p.

Bodart M, De Herde A. 2002. Global energy savings in offices buildings by the use of daylighting. Energy and Buildings 34: 421-429.

Bourgeois D, Reinhart C, Macdonald I. 2006. Adding advanced behavioural models in whole building energy simulation: a study on the total energy impact of manual and automated lighting control. Energy and Buildings 38(7):814-823.

Boyce PR, Eklund NH, Simpson SN. 2000. Individual lighting control: task performance, mood, and illuminance. J Illum Eng Soc. Winter 2000: 131-142.

California Lighting Technology Center. Hybrid smart wall switch & bathroom vanity luminaire. < http://cltc.ucdavis.edu/content/view/671/357/> Accessed 2011 01 July.

California Lighting Technology Center. 2007. Lighting research program project 4.1 hotel and institutional bathroom lighting. [CEC] California Energy Commission Public Interest Energy Research Program. CEC-500-2007-141-A10. CEC Contract No. 500-01-041. 62 p.

California Lighting Technology Center, Western Cooling Efficiency Center, Emerging Technology Associates, Inc. 2010. San Diego Gas & Electric Emerging Technologies Program: hotel guest room energy controls. San Diego Gas and Electric Company. 33 p.

California Utilities Statewide Codes and Standards Team. 2011. Draft measure information template – guest room occupancy controls: 2013 California Building Energy Efficiency Standards. Pacific Gas and Electric Company, Southern California Edison, SoCalGas, SDG&E. 44 p.

California Utilities Statewide Codes and Standards Team. 2011. Draft measure information template – lighting retrofits: 2013 California Building Energy Efficiency Standards. Pacific Gas and Electric Company, Southern California Edison, Sempra Utilities. 117 p.

Carrière LA, Rea MS. 1984. Lighting energy consumption in an office building having manual switches. Building Research Note No. 221. 18 p.

Chung TM, Burnett J. 2001. On the prediction of lighting energy savings achieved by occupancy sensors. Energy Engineering 98(4): 6-23.

Clanton & Associates, Inc. Wireless lighting control: a life cycle cost evaluation of multiple lighting control strategies. Daintree Networks. 26 p.

Deru M, Pless SD, Torcellini PA. 2006. BigHorn Home Improvement Center energy performance. ASHRAE Transactions. 112(2):349-366.

*Desroches L-B, Garbesi K. 2011. Max tech and beyond: maximizing appliance and equipment efficiency by design. Lawrence Berkeley National Laboratory. 60 p.

Doulos L, Tsangrassoulis A, Topalis F. 2007. The impact of colored glazing and spectral response of photosensors in the estimation of daylighting energy savings. Proceedings of the 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century. p 279-283.

Emerging Technology Associates, Inc. 2010. Advanced lighting control system assessment final report: Veteran Administration Medical Center San Diego. San Diego Gas & Electric. 20 p.

Encelium. Case study: University Health Network Toronto General Hospital. Encelium. 2 p.

Energy Solutions. 2009. Advanced lighting controls for demand side management (energy efficiency assessment). San Francisco: Pacific Gas and Electric Company Emerging Technologies Program. 67 p.

Energy Studies in Buildings Laboratory University of Oregon. 2006. Daylight dividends: field test shade control and DaySwitch: final report on DaySwitch demonstration project. Lighting Research Center. Purchase Order No P0052476. 33 p.

Figueiro MG, Rea MS, Rea AC, Stevens RG. 2002. Daylight and productivity: a field study. Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings 8:69-78.

Floyd DB, Parker DS. 2005. Field commissioning of a daylight-dimming lighting system. Proceedings of the Right Light Tree 3rd European Conference on Energy Efficient Lighting. 7 p.

Floyd DB, Parker DS, Sherwin JR. 1996. Measured field performance and energy savings of occupancy sensors: three case studies. Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings 4:97-105.

Floyd DB, Parker, DS, McIlvaine JER, Sherwin JR. 1995. Energy efficiency technology demonstration project for Florida educational facilities: occupancy sensors. Tallahassee: Florida State Department of Education. FSEC-CR-867-95. 28 p.

Galasiu AD, Newsham GR. 2009. Energy savings due to occupancy sensors and personal controls: a pilot field study. Proceedings of Lux Europa 2009, 11th European Lighting Conference. p 745-752.

Galasiu AD, Atif MR, MacDonald RA. 2004. Impact of window blinds on daylight-linked dimming and automatic on/off lighting controls. Solar Energy 76(5):523-544.

Galasiu AD, Newsham GR, Suvagau C, Sander DM. 2007. Energy saving lighting control systems for open-plan offices: a field study. Leukos 4 (1):7-29.

Granderson J, Gaddam V, DiBartolomeo D, Li X, Rubinstein F, Das S. 2010. Field-measured performance evaluation of a digital daylighting system. Leukos 7(2):85-101.

*Guo X, Tiller DK, Henze GP, Waters CE. 2010. The performance of occupancy-based lighting control systems: a review. Lighting Res Technol 42:415-431.

Heschong Mahone Group, Inc. 2005. Sidelighting photocontrols field study. Southern California Edison Co, Pacific Gas and Electric Company, Northwest Energy Efficiency Alliance. HMG Job 0416. 186 p.

Heschong Mahone Group, Inc. 2003. Daylight and retail sales. [CEC] California Energy Commission. P500-03-082-A-5. CEC Contract No. 400-99-013. 86 p.

Heschong Mahone Group, Inc. 2003. Windows and classrooms: a study of student performance and the indoor environment. [CEC] California Energy Commission. P500-03-082-A-7. CEC Contract No. 400-99-013. 131 p.

International Facility Management Association, Lawrence Berkeley National Laboratory. 2005. Lighting research program case studies. [CEC] California Energy Commission Public Interest Energy Research Program. CEC-500-2005-141-A26. CEC Contract # 500-01-041. 8 p.

Jennings J, Colak N, Rubinstein F. 2001. Occupancy and time-based lighting controls in open offices. Proceedings of the Illuminating Engineering Society of North America 2001 Annual Conference. 28 p.

Jennings JD, Rubinstein FM, DiBartolomeo D. 2000. Comparison of control options in private offices in an advanced lighting controls testbed. J Illum Eng Soc 29: 39–60.

Jones CC, Richman E. 2005. Lighting business case: a reporting analyzing lighting technology opportunities with high return on investment energy savings for the federal sector. US Department of Energy. PNNL 15341. Contract DE-AC05-76RL01830. 64 p.

Kapsis K, Tzempelikos A, Athienitis AK, Zmeureanu RG. 2010. Daylighting performance evaluation of a bottom-up motorized roller shade. Solar Energy 84(12):2120-2131.

Koyle B, Papamichael K. 2010. Dual-loop photosensor control systems: reliable, cost-effective lighting control for skylight applications. Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings 9:157-166.

Lee ES, Selkowitz SE. 2005. The New York Times headquarters daylighting mockup: monitored performance of the daylighting control system. Energy and Buildings 38(7):914-929.

Leslie R, Raghavan R, Howlett O, Eaton C. 2005. The potential of simplified concepts for daylight harvesting. Lighting Research and Technology 37(1):21-40.

Li DHW, Lam TNT, Wong SL. 2006. Lighting and energy performance for an office using high frequency dimming controls. Energy Conversion and Management 47(9-10):1133-1145.

Li DHW, Cheung KL, Wong SL, Lam TNT. 2010. An analysis of energy-efficient light fittings and lighting controls. Applied Energy 87(2):558-567.

Lighting Research Center. 2008. T5 fluorescent high-bay luminaires and wireless testing controls. Field Test DELTA 3:1-12.

Lighting Research Center. 2004. Daylight Dividends Case Study: Harmony Library Fort Collins, Colorado. Rensselaer Polytechnic Institute. 14 p.

Lighting Research Center. 2004. Daylight Dividends Case Study: Smith Middle School, Chapel Hill, NC. Rensselaer Polytechnic Institute. 12 p.

Lighting Research Center. 2004. Daylight Dividends Case Study: TomoTherapy Incorporated, Madison, Wis. Rensselaer Polytechnic Institute. 12 p.

Lighting Research Center. 2003. Integrated skylight luminaire. Field Test DELTA 1:1-12.

*Lighting Research Center. 2003. Reducing barriers to use of high efficiency lighting systems final report year 2: March 2002- January 2003. US Department of Energy. 107 p.

Lighting Research Center. 1997. Sacramento Municipal Utility District Customer Service Center. DELTA Portfolio Lighting Case Studies 2(2):1-12.

Lighting Research Center. 1997. Sony Disc Manufacturing Springfield, Oregon. DELTA Portfolio Lighting Case Studies 2(1):1-12.

Lighting Research Center. 1995. 450 South Salina Street Syracuse, New York. DELTA Portfolio Lighting Case Studies 1(3):1-12.

Lutron. Case study: The Energy Foundation, San Francisco, CA. Lutron Electronics Co, Inc. 6 p.

Lutron. Case study: Georgian College, Ontario, Canada. Lutron Electronics Co, Inc. 4 p.

Maniccia D, Rutledge B, Rea MS, Morrow W. 1999. Occupant use of manual lighting controls in private offices. Journal of the Illuminating Engineering Society 28(2): 42-56.

Moore T, Carter DJ, Slater A. 2003. Long-term patterns of use of occupant controlled office lighting. Lighting Research and Technology 35(1):43-59.

Moore T, Carter DJ, Slater AI. 2002. A field study of occupant controlled lighting in offices. Lighting Research and Technology 34(3):191-205.

Mukherjee S, Birru D, Cavalcanti D, Shen E, Patel M, Wen Y-J, Das S. 2010. Closed loop integrated lighting and daylighting control for low energy buildings. Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings 9:252-269.

*New Buildings Institute. 2011. Advanced Lighting Guidelines. <http://algonline.org/index.php>. Accessed 2011 10 August.

Newsham GR, Aries M, Mancini S, Faye G. 2008. Individual control of electric lighting in a daylit space. Lighting Research and Technology 40(1):25-41.

Nilsson P-E, Aronsson S. 1993. Energy efficient lighting in existing non-residential buildings: a comparison of nine buildings in five countries. Energy 18(2):115-122.

Parker DS, Schrum L, Sonne JK, Stedman TC. 1996. Side-by-side testing of commercial office lighting systems: two-lamp fluorescent fixtures. Proceedings of the Tenth Symposium on Improving Building Systems in Hot and Humid Climates. 9 p.

Pigg S, Eilers M, Reed R. 1996. Behavioral aspects of lighting and occupancy sensors in private offices: a case study of a university office building. Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings 8:161-171.

[PIER] Public Interest Energy Research Program. 2008. IOU Partnership Draft Case Study: Bi-level stairwell lighting system. PIER. 4 p.

[PIER] Public Interest Energy Research Program. 2008. IOU Partnership Draft Case Study: Integrated Classroom Lighting System (ICLS). PIER. 4 p.

Reinhart CF. 2002. Effects of interior design on the daylight availability in open plan offices. Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings 3:309-322.

Richman EE, Dittmer AL, Keller JM. 1994. Field analysis of occupancy sensor operation: parameters affecting lighting energy savings. U.S. Department of Energy. PNL-10135. Contract DE-AC06-76RLO 1830. 39 p.

Roisin B, Bodart M, Deneyer A, Dherdt PD. 2008. Lighting energy savings in offices using different control systems and their real consumption. Energy and Buildings 40(4):514-523.

Rubinstein F, Enscoe A. CA. 2010. Saving energy with highly-controlled lighting in an open-plan office. J Illum Eng Soc 7(1). 15 p.

Rubinstein F, Karayel M. 1982. The measured energy savings from two lighting control strategies. IEEE Transactions on Industry Applications 20(5):1189-1197.

Rubinstein F, Verderber R. 1990. Automatic lighting controls demonstration. [LBL] Lawrence Berkeley Laboratory. LBL-28793. 70 p.

Rubinstein F, Colak N, Jennings J, Neils D. 2003. Analyzing occupancy profiles from a lighting controls field study. Lawrence Berkeley National Laboratory. 4 p.

Rubinstein F, Jennings J, Avery D, Blanc S. 1998. Preliminary results from an advanced lighting controls testbed. Proceedings of the IESNA 1998 Annual Conference. 20 p.

Schrum L, Parker DS, Floyd DB. 1996. Daylight dimming systems: studies in energy savings and efficiency. Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings 4:311-319.

Sensor Switch. Community profiles: Middlesex Community College. Sensor Switch. 1 p.

Sensor Switch. State profiles: national distribution warehouse. Sensor Switch. 1 p.

Southern California Edison. 2009. Two-way connectivity with a lighting system as a demand response resource. Southern California Edison. DR 07.04 Report. 51 p.

*Southern California Edison. 2008. Office of the Future Phase II report: the 25% solution. The Office of the Future Consortium. ET 08.01. 72 p.

*U.S. Department of Energy. 2003 CBECS detailed tables. <http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03>. Accessed 2011 August 10.

*U.S. Department of Energy. 2011a. Building Energy Codes Program. < http://www.energycodes.gov/>. Accessed 2011 August 16.

*U.S. Department of Energy. 2011b. Energy efficiency program: test procedure for lighting systems (luminaires). Federal Register 76(150):47178-47180.

VonNeida B, Maniccia D, Tweed A. 2000. An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems. Proceedings of the Illuminating Engineering Society of North America 2000 Annual Conference. p 433-459.

Washington State University Extension Energy Program. 2011. Final report E3T Emerging Technology Assessment: Bi-level office lighting with occupancy sensors. Bonneville Power Administration. WSUEEP11-003. 68 p.

The WattStopper, Inc. Case study: 851 Target stores use occupancy sensors from The Watt Stopper to save energy. Santa Clara: The WattStopper, Inc. 1 p.

The WattStopper, Inc. Case study: Adobe Systems saves $15,000 in one month on energy costs by using Isolé plug load controls. Santa Clara: The WattStopper, Inc. 1 p.

WattStopper. 2010. Case study: Controls contribute to 40% energy savings in Kaiser Permanente warehouse. WattStopper. 2 p.

The WattStopper, Inc. Case study: Estimates show Southern Wine and Spirits will save 55% in lighting costs. Santa Clara: The WattStopper, Inc. 1 p.

The WattStopper, Inc. Case study: Lighting controls find a place in PG&E's energy saving plans. Santa Clara: The WattStopper, Inc. 1 p.

WattStopper. 2008. Case study: Miro Controls save energy and support marketing efforts in lighting showroom. WattStopper. 2 p.

The WattStopper, Inc. Case study: Rhode Island College slashes energy costs in classrooms and library with Watt Stopper occupancy sensors. Santa Clara: The WattStopper, Inc. 1 p.

The WattStopper, Inc. Case study: Watt Stopper contributes to "gold" LEED award for California state office building. Santa Clara: The WattStopper, Inc. 1 p.

WattStopper. 2007. Case study: Watt Stopper/Legrand helps NRG Systems realize big savings. WattStopper. 3 p.

The WattStopper, Inc. Case study: The Watt Stopper occupancy sensors reduce university library load by 30%. Santa Clara: The WattStopper, Inc. 1 p.

The WattStopper, Inc. Case study: Watt Stopper sensors a targeted part of energy conservation measures at Uintah Basin Medical Center. Santa Clara: The WattStopper, Inc. 1 p.

Yang I-H, Nam E-J. 2010. Economic analysis of the daylight-linked lighting control system in office buildings. Solar Energy 84(8):1513-1525.

*References marked with an asterisk were used as background only; as they are not primary sources of energy savings estimates, they were not included in the meta-analysis.