CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Measure Information Template – Indoor Lighting Controls

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team, October 2011

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Indoor Lighting Controls

2011 California Building Energy Efficiency Standards

[California Utilities Statewide Codes and Standards Team, October 2011]

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FIGURES

1. Overview

a. Measure Title	Indoor Lighting Controls
b. Description	The intention of this code change proposal is to reduce the lighting energy used in offices (open, private and overall). The approach that we have taken is to reduce lighting power densities to the extent possible, and to facilitate the achievement of these reduced LPDs, in part, through a Power Adjustment Factor (PAF) for occupancy controls in open offices. In contrast to mandating such controls, this approach gives the lighting designer the flexibility to meet or exceed the allowed LPD through means other than occupancy controls, for instance by using highly efficient lighting technology (third generation or high-output T8 in efficient fixtures) or by using task ambient lighting. The proposed measure will reduce the LPD for office buildings as follows: ◆ The LPD for office buildings under the complete building method will be reduced from 0.85 W/sf to 0.8 W/sf. ◆ The LPD for open offices under the area category method will be reduced from 0.9 W/sf to 0.75 W/sf. ◆ The LPD for private offices under the area category method will be reduced from 1.1 W/sf to 1.0 W/sf. Table 146-C will provide new PAFs for occupancy sensors in open offices for control group sizes of 1, 2 and 4 workstations (125 sf, 250 sf, and 500 sf). Hourly weekday and weekend occupancy schedules will be provided in the ACM Manual. These controls are only one of the several means designers can use to achieve the proposed lower LPDs; Task/Ambient and high efficiency luminaires are two additional approaches, as described in this report. The PAF for manual dimming in Table 146 (c) will be retained. In spaces with primary sidelit daylight area <250 sf, the proposed language includes a requirement for a manually actuated switch *located within the daylit area*. This switch must be manually actuated in order to switch on the lighting, and must switch off automatically. While automatic daylighting controls are not required by code in such a situation, spaces voluntarily using automatic daylighting controls will be exempted from the switch requirement.

<table>
<tr><td>c. Type of Change</td><td>
Mandatory Measure: Section 131(c) will be modified to accommodate for spaces with primary sidelit daylight area <250 sf, a switch within the daylit area that must be manually actuated in order to switch on the lighting in the primary sidelit daylight area. Exceptions will be spaces that voluntarily use automatic daylighting controls.
Prescriptive Requirement: LPD for office buildings in the complete building method of Section 146 Subsection (c) will be reduced from 0.85 W/sf to 0.8 W/sf. LPDs for offices >250sf in the area category method will be reduced from 0.9 W/sf to 0.75 W/sf. LPDs for office <250sf will be reduced from 1.1 W/sf to 1.0 W/sf.
Compliance Option Additional lighting occupancy schedules have been developed for office spaces >250 sf (open offices). Hourly weekday and weekend occupancy schedules (calculated by multiplying the baseline by (1-PAF)) will be added to Table N2-8 of the ACM Manual under four new categories –

‘lights (%) uncontrolled’, and
‘lights in open office with at least one occupancy sensor per 125 sf’
‘lights in open office with at least one occupancy sensor per 250 sf’
‘lights in open office with at least one occupancy sensor per 500 sf’

The existing hourly occupancy schedule for ‘lights (%) uncontrolled’ will be retained for other commercial spaces and buildings. Similarly, hourly occupancy schedules will also be added for manual dimming alone and a combination of manual dimming and the three occupancy control granularities.
Modeling For office spaces >250 sf, the new occupancy schedules added to Table N2-8 of the ACM Manual for open office lighting will be used to model lighting in open office performance calculations.
</td></tr>
<tr><td>d. Energy Benefits</td><td>
The percentage savings in open offices over an average week from each of the occupancy control options is as follows:
<table>
<tr><th>Workstations per occupancy sensor</th><th>1</th><th>2</th><th>4</th></tr>
<tr><td>Approx. area per occupancy sensor (sf)</td><td>125</td><td>250</td><td>500</td></tr>
<tr><td>Calculated lighting energy savings</td><td>52%</td><td>40%</td><td>23%</td></tr>
<tr><td>PAFs (tuned down from savings)</td><td>0.40</td><td>0.30</td><td>0.20</td></tr>
</table>
The total energy savings from the office lighting power density (LPD) reductions are as follows. Note that these values have <u>not</u> been adjusted downward to take into account any required photocontrols, because the percentage of floor area in which photocontrols are required is unknown. The savings <u>have</u> been adjusted downward in private offices to account for a 25% reduction in load due to the existing requirement for vacancy sensors.
</td></tr>
</table>

	Electricity Savings (kWh/yr)	Demand Savings (kW)	TDV Electricity Savings
Per Small Model Office Building			
Private offices (25% of office space)	250	0.08	$ 957
Open offices (45% of office space)	2018	0.48	$ 4,119
Per Large Model Office Building			
Private offices (25% of office space)	946	0.28	$ 3,614
Open offices (45% of office space)	7622	1.82	$ 15,560
Savings per square foot (of total office new construction)			
Private offices (25% of office space)	0.028	0.000008	N/A
Open offices (45% of office space)	0.224	0.000053	N/A

The total energy savings from the daylight switch requirement are as follows. These values assume that 10% of the open office area is affected by the requirement for a mandatory switch.

	Electricity Savings (kWh/yr)	Demand Savings (kW)	TDV Electricity Savings
Per Small Model Office Building			
Open offices (45% of office space)	421	0.079	$ 880
Per Large Model Office Building			
Open offices (45% of office space)	1589	0.30	$ 3,324
Savings per square foot (of total office new construction)			
Open offices (45% of office space)	0.047	0.0000088	$ 0.10

Total Electric Energy Savings (GWh)	**Total Gas Energy Savings (MMtherms)**	**Total TDV Savings ($)**	**Total TDV Energy (kBTU)**
From office LPD reductions			
14.7	0	$8,603,000	96,700,000
From the requirement for a manual switch in daylit zones			
2.7	0	$321,000	3,600,000

e. Non-Energy Benefits	Studies indicate non-energy benefits from manual dimming/switching controls, such as increased occupant satisfaction. Surveys employed in the Galasiu et al. (2007) study indicated this was likely due to individual dimming control, although use of this control beyond an initial preferred setting was rare. Escuyer and Fontoynont (2001) indicates that manual dimming was more likely to produce conscious satisfaction than automatic dimming alone (Similar indications from Boyce et al. (2003), Newsham et al. (2008))

f. Environmental Impact

The proposed change does not have any potential adverse environmental impacts. Because the proposed energy measure will reduce electricity use, this will reduce electricity generation, and thereby have a small reduction in mercury emissions from coal-burning power plants, and in water consumption from electricity generation. However, because the primary benefit is energy reduction, these environmental benefits are not considered here, and all material uses are shown as No Change (NC).

Materials Consumption

The proposed change has no impacts associated with reduced lighting power densities, and an unknown (but small) impact associated with the increased use of occupancy sensors in open office. For details of the materials impact see Section 3.13.

	Mercury	Lead	Copper	Steel	Plastic	Others (Identify)
Statewide impact	Not calculated—the only materials impact would be from occupancy sensors, which is a voluntary measure.					

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

Water Consumption

	On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Year)
Per Unit Measure	Not Applicable
Per Prototype Building	NC

Water Quality Impacts

	Mineralization (calcium, boron, and salts	Algae or bacterial Buildup	Corrosives as a Result of PH Change	Others
Impact (I, D, or NC)	NC	NC	NC	NC
Comment on reasons for your impact assessment				

Air Quality

In lbs/Year, Increase, (Decrease), or No Change (NC)[3]:

	NOX	SOX	CO	PM10	CO2
LPD Reduction					
per square foot	0.000040	0.00024	0.000058	0.000019	0.15
per small model office building	0.36	2.2	0.52	0.17	1313
per large model office building	1.4	8.1	2.0	0.63	4961
Daylight switch					
per square foot	0.000007	0.000044	0.000011	0.0000035	0.027
per small model office building	0.067	0.40	0.10	0.031	244
per large model office building	0.25	1.5	0.37	0.12	920

g. Technology Measures	**Measure Availability and Cost:** Technology to satisfy the proposed measure is readily available from a wide variety of manufacturers, ensuring competitive pricing. Occupancy controls have been commercially available for several decades. Both passive infra-red and ultrasonic occupancy sensors are widely accepted in office buildings, have been acknowledged to save energy successfully, and are frequently required by codes. The principal manufacturers include: Cooper Controls Greengate, Hubbell, Leviton, Lightolier, Lutron, SensorSwitch, Square D and Wattstopper. These manufacturers supply distributors throughout the state who coordinate with electricians and contractors. There is adequate supply available to meet the requirements of this measure; of the nearly three dozen distributors contacted, all were prepared to fill orders next day. A thorough market survey effort (San Diego Gas and Electric, 2009) discovered that at least eight distinct models are available to serve this measure's purpose. Individual models of occupancy sensor may have to be fitted with lenses and/or shrouds to ensure that the detection angle of the sensor matches the intended coverage area. We have confirmed that appropriate lenses and shrouds are readily available from several manufacturers. **Useful Life, Persistence and Maintenance:** The Energy Commissions cost-effectiveness methodology requires all lighting controls to be assessed assuming a 15-year measure life. We have no reason to believe that any of the equipment or components this study is based on, would have useful lives or persistence shorter than 15 years.
h. Performance Verification of the Proposed Measure	The Nonresidential Appendices already contain an appropriate Acceptance Test in section 'NA7.6.2 Occupancy Sensor Acceptance'. This language already requires verified occupancy sensor performance in the field. No additions or modifications to this section are deemed necessary. However, we propose that this same language should be added to the description of new PAFs in the Nonresidential Manual– '*In open offices/spaces with partition height less than the ceiling height, shielding or lenses shall be employed to confine the view of the occupancy sensor to the intended coverage area*'.

<table>
<tr>
<td>i. Cost Effectiveness</td>
<td>Life cycle costing was performed for the power adjustment factors for occupancy sensors in open offices. Savings were based solely on lighting energy savings, and did not include secondary HVAC savings from reduced lighting. 2013 TDV costs in $/kWh for nonresidential buildings over a 15 year life cycle were applied to half the LPD (0.9 W/sf from Title 24 2008 area category method) in an open office after accounting for 15% savings from dimming ballast or multilevel switching proposed by the Controllable Lighting CASE Study in their third stakeholder meeting that happened on June 23rd 2010 at the UC Davis California Lighting Technology Center. The savings in $/sf were translated to savings in dollars for 1, 2, and 4 workstations at 125 sf per workstation. The measures proved cost effective based on both calculated savings and the more conservative proposed PAFs, i.e., in each case the TDV value of the savings is higher than the measure cost.
<table>
<tr><th></th><th>A</th><th>B</th><th>C=A+B</th><th>D</th><th>E=D/C</th></tr>
<tr><th></th><th>Ceiling Occupancy Sensor ($)</th><th>Labor ($)</th><th>Total Cost ($)</th><th>TDV Savings from PAFs ($)</th><th>Benefit to Cost Ratio</th></tr>
<tr><td>One workstation per control group</td><td>$49.91</td><td>$66.22</td><td>$116.13</td><td>$151.47</td><td>1.3</td></tr>
<tr><td>Two workstations per control group</td><td>$49.91</td><td>$66.22</td><td>$116.13</td><td>$223.65</td><td>1.9</td></tr>
<tr><td>Four workstations per control group</td><td>$49.91</td><td>$66.22</td><td>$116.13</td><td>$296.39</td><td>2.6</td></tr>
</table>
Figure 1. Cost Effectiveness Summary
</td>
</tr>
<tr>
<td>j. Analysis Tools</td>
<td>The benefits can be quantified using the standard reference methods for offices such as eQUEST/DOE-2 or EnergyPlus. No additional tools are required for the proposed measures.</td>
</tr>
<tr>
<td>k. Relationship to Other Measures</td>
<td>The savings calculated for this measure assume that 15% of lighting energy savings area already achieved by the Controllable Lighting CASE Study proposal that will mandate tuning of a dimming ballast or multilevel switching.</td>
</tr>
</table>

2. Methodology

This section describes the methodology that we followed to assess the savings, costs, and cost effectiveness of the proposed code change. The key elements of the methodology were as follows:

- Literature review of savings from occupancy controls
- Analysis of field data on occupancy patterns
- Development of open office lighting layouts
- Calculation of new lighting power density (LPD) allowances
- Calculation of power adjustment factors (PAFs) for occupancy controls
- Calculation of revised lighting schedules for the Alternative Compliance Method (ACM) Manual
- Calculation of savings from locating manual switches within primary sidelit daylight areas
- Savings Analysis
- Cost Analysis
- Cost effectiveness analysis

This work was publicly vetted through our stakeholder outreach process, which, through in-person meetings, webinars, email correspondence and phone calls, requested and received feedback on the direction of the proposed changes. The stakeholder meeting process is described at the end of the Methodology section.

2.1 Literature Review of Technical Viability and Savings from Occupancy Controls and Manual Dimming in Open Offices

We reviewed close to 30 published papers to investigate the energy and non-energy benefits of occupancy and manual controls and the interaction of occupants with such controls (see Literature Review in Appendices).

2.2 Analysis of Field Data on Occupancy Patterns

In order to understand occupancy controls and occupant behavior we utilized field-measured, one-minute interval, workstation-level occupancy data in open office settings. We obtained this data from two studies, in three buildings, that had minute-by-minute, field-measured, workstation-level occupancy data in open office settings for multiple weeks.

Using these studies we grouped the occupants' workstations into logical groupings based their physical locations, to predict the savings from occupancy sensor control when the lighting for several workstations was controlled by the same occupancy sensor.

2.3 Development of Open Office Lighting Layouts

The CASE team developed a series of lighting layouts, luminaire schedules and control schedules to meet IES recommended practices for typical offices. These layouts were intended to reflect both typical practice and advanced practice. These layouts were used as the basis for much of the other work done for this CASE study, and have also been used for costing and savings calculations for other CASE studies.

2.4 Calculation of New Lighting Power Density (LPD) Allowances

Based on the open office lighting layouts, we derived average lighting power density values for open offices. We used these values in combinations with breakdowns of the percentage of floor area given over to different types of space within offices to calculate a revised Complete Building Method LPD for offices.

2.5 Calculation of Power Adjustment Factors (PAFs) for Occupancy Controls

Using the analysis of field data on occupancy patterns described above, we developed an hourly analysis of the percentage savings from occupancy controls, across the three buildings, for each of four different control group sizes (1,2,4 and 8 workstations). From this savings analysis we calculated both single-figure and hourly Power Adjustment Factors (PAFs) for occupancy sensor control of workstation lighting at various group sizes, for inclusion in Section 146 of Title 24.

2.6 Calculation of Revised Lighting Schedules for The Alternative Compliance Method (ACM) Manual

Using baseline lighting energy use schedules from the same research study that was used to develop the lighting schedules in Title 24 ADM (2002), and adjusting these schedules in line with the single-value and hourly PAFs, we developed new lighting schedules for open offices for the ACM Manual.

2.7 Calculation of Savings from Locating Manual Switches Within Primary Sidelit Daylight Areas

We assessed the potential savings from locating manual wall switches within the primary sidelit daylight area itself, rather than having the switch mounted elsewhere in the space. The rationale for this approach is that people are less likely to switch on the lighting in the primary daylit area if they have to a). Walk over to the switch, and b). Actuate the switch while standing in a brightly daylit area.

Our approach to estimating the savings from this measure was to review research papers on the relationship between the illuminance in a space and the probability of people switching the lights on. We derived a predictive model based on prior research and then applied this to an annual daylighting simulation of a typical daylit space to calculate the expected savings.

2.8 Energy Savings Analysis

Using the California Energy Commission's 2011 cost-effectiveness methodology, we calculated energy savings using time-dependent valuation (TDV) assuming a 15-year measure life and the proposed change in the lighting schedule.

2.9 Cost Analysis

To develop cost estimates, we combined data from equipment manufacturers and distributors with equipment costs and labor rates provided by RS Means (2010)

2.10 Cost Effectiveness Analysis

We calculated the cost-effectiveness for this proposed PAF by comparing the calculated TDV savings with the calculated measure costs. We also estimated of the resulting annual statewide savings. The cost-effectiveness calculation is a direct comparison between:

- Measure costs per square foot (for equipment and labor)
- Measure savings per square foot over the 15-year measure life, calculated using the 2013 TDV method

For the revised lighting power densities (LPDs) for the area category and whole building method, we have based the proposed revisions on typical practice, and have shown that the proposed LPDs can be met using several lighting design approaches.

Because not every lighting / controls approach is appropriate in every office space, we have not attempted to demonstrate that any particular approach is always cost-effective and must be used as the basis for the proposed LPDs; instead we have shown that a range of approaches can be used to meet the target.

For the proposed Power Adjustment Factors (PAFs) for occupancy sensors in open offices, cost-effectiveness in not required to be proven because the PAF is optional. However, we have taken the step of showing cost-effectiveness, to provide further support for the proposed LPD reductions, which can be seen in conjunction with the proposed PAF as a means of meeting reduced LPDs.

2.11 Statewide Savings Analysis

The statewide estimate of savings was based on new construction square footage forecasts by building type, obtained from the California Energy Commission, together with estimates of the typical hours of use and lighting power density of egress lighting, as obtained from our data analysis.

2.12 Stakeholder Meeting Process

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at one of three public Lighting Stakeholder Meetings.

At each meeting, the utilities' CASE team invited feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodes.com. Stakeholder meetings were held on the following dates and locations:

- First Lighting Stakeholder Meeting: March 18th, 2010, Pacific Energy Center, San Francisco, CA

- Second Lighting Stakeholder Meeting: September 21st 2010, California Lighting Technology Center, Davis, CA
- Third Lighting Stakeholder Meeting: February 24th, 2011, UC Davis Alumni Center, Davis CA

In addition to the Stakeholder Meetings, a Stakeholder Work Session was held on December 8th, 2010 to allow detailed review of this and other lighting topics.

3. Analysis and Results

This section presents the analysis and results of the methodology explained in the previous section.

3.1 Literature Review

A detailed discussion of each of the papers reviewed for this study is shown in Appendix I—Literature Review. Key findings are provided below.

3.1.1 Savings from Occupancy Sensors in Open Offices

We were able to find several papers that indicated that occupancy sensors in open offices are a viable approach to energy savings and are well accepted by occupants(Rubinstein 2009, Escuyer and Fontoynont 2001, Jennings et al. 2000, Maniccia et al. 1998, Galasiu et al. 2007). These studies also produced a consistent picture of the magnitude of savings that can be achieved using occupancy sensors, as described in Section 3.2.

3.1.2 Savings from Manual Controls in Open Offices

For (personal) manual dimming controls in open offices, the data were sparse. Several studies showed that manual dimming created potential conflicts between occupants over the control of the luminaires (and/or reluctance on the part of occupants to use the dimming controls for fear of irritating their colleagues). This effect is documented best in the series of studies by Moore et al. (2002-2004).

Of all the published research that was used for this study, only three papers had information on manual switching/dimming controls. The scatter plot developed based on this information contained only six data points. Due to insufficient availability of existing data, a reliable estimate of savings for manual controls could not be calculated.

The results of the studies varied significantly in terms of the predicted magnitude of savings from dimming; this was due in part to the very different approaches taken by the different research teams in terms of how the control systems were set up, and what interfaces were provided. Therefore, we were not able to estimate savings from manual dimming, accurately. Consequently we have proposed to simply retain the existing power adjustment factor (PAF) for manual dimming in open offices.

3.2 Analysis of Field Data on Occupancy Patterns

In order to understand occupancy controls and occupant behavior we utilized field-measured, one-minute interval, workstation-level occupancy data in open office settings. We obtained this data from two studies on three buildings. Two of the buildings were the small and large commercial office buildings from the low-ambient lighting CASE project lead by HMG, sponsored by PG&E (PG&E 2009a,b). The third building was a Federal facility that was the subject of a detailed investigation into open office lighting by LBNL. LBNL performed the data analysis of this building.

To calculate savings from occupancy controls, we combined workstations into groups of varying sizes, based on the layout of each building. The analysis is based on all the workstations in the group being controlled by the same occupancy sensor (see Figure 2), so for each group we calculated the amount of time for which *all* of the workstations in the group were unoccupied, because the occupancy sensor would only shut off the lighting once *all* the occupants had left the zone. Savings were based on the resulting fraction of normally-occupied hours during which lights could be switched off by the occupancy sensor. The lighting energy savings results from the three separate buildings were then combined to arrive at averaged occupancy schedules and savings schedules, relative to a baseline lighting energy use schedule from the bi-level lighting baseline study (ADM 2002).

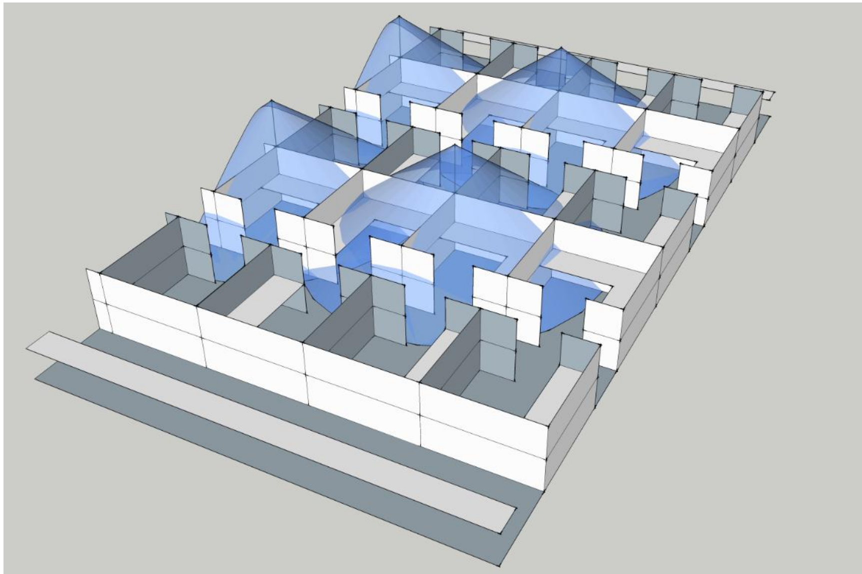


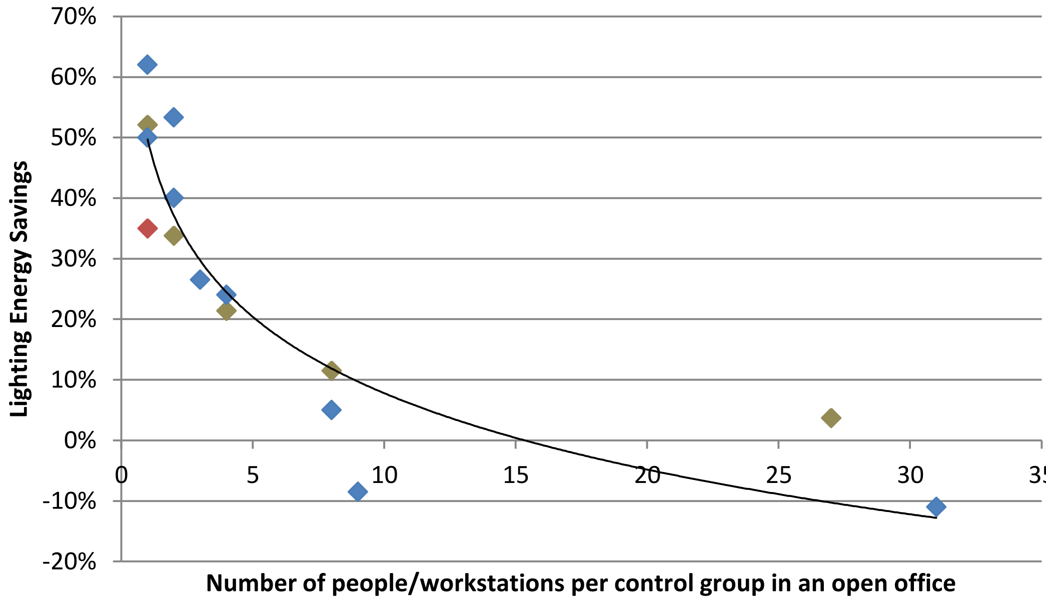
Figure 2. Schematic of Workstation Groupings for Occupancy Sensor Control

Figure 3 shows a scatter plot of the lighting energy savings, relative to each building's own baseline schedule. Each point on the graph represents the calculated savings from a particular control group size. The orange point is derived from one of the studies that was reviewed in the Literature Review task (see Section 3.5.2). This was the only secondary study for which we were able to use the savings data directly.

The scatter plot shows a very consistent picture of how savings from open office occupancy sensors vary according to the control group size; i.e., savings are high for small control group sizes, and diminish rapidly as the control groups expand. This makes us confident that the achieved savings in practice will be close to the calculated savings.

The rate of reduction in savings as group size increases is not as great as would be predicted mathematically, which indicates that there are "real-world" effects at work, for instance that people who sit together take lunch together, arrive and leave together, and attend the same meetings at the same time.

For two of the data points, the savings were negative. This is because that particular building had central time clock control, and a detailed analysis of the data showed that some of the occupants were arriving at work before the lighting was switched on. Therefore if the lighting had been controlled by occupancy sensors, it would actually have switched on earlier in the day and used more energy. The negative savings from these spaces results in the trend line to dip below zero at a control group size of 15 workstations.



Source Studies: Rubinstein (2009) PG&E (2009a,b) Galasiu (2007)

Figure 3. Occupancy Sensor Control Group Size vs Lighting Energy Savings

3.3 Development of Open Office Lighting Layouts

The CASE team worked to develop a combination of six luminaire layouts and five options for controls. Due to the complexity and size of the lighting plans, the full layouts are provided in an attached file.

The CASE team developed lighting layouts for a 34,000 sf typical office building in which some of the open offices were located at the periphery and some in the core (see Figure 5). The plans and furniture layout of the building are taken directly from a real project that was chosen because it contains a combination of topologies, i.e. in one part of the building the open offices are at the periphery, while in another part private offices are at the periphery. This model therefore combines many common space configurations in one single building model.

Lighting design was limited to the open office part of the floor plan and consisted of the following six luminaire options:

- Typical office fixtures – Suspended Luminaires
- Typical office fixtures – Recessed Luminaires
- Task/Ambient – Suspended Luminaires
- Task/Ambient – Recessed Luminaires
- High Efficiency – Suspended Luminaires
- High Efficiency – Recessed Luminaires

The controls options were:

- Title 24 baseline (time sweep shut-off system)

- Manual dimming of overhead luminaires
- Occupancy sensor control—basic (6-9 workstations per sensor)
- Occupancy sensor control—medium resolution (6 workstations per sensor)
- Occupancy sensor control—fine resolution (2 workstations per sensor)

The “typical” fixtures are “high performance T8” fixtures, i.e. they are compliant with the CEE “high performance” standard. This is because starting July 2012, the new Federal lamp standard (10 CFR Part 430) will require T8 lamps to meet 92 lm/W, which is equivalent to the current CEE High Performance T8 standard (DOE 2009).

The “high efficiency” options were chosen to represent typical high-end practice. They use single-lamp fixtures with high output lamps, to maximize the photometric efficiency of the fixtures. These fixtures incur a small increase in price over the “typical” fixtures but were chosen by Clanton and Associates to represent the top end of typical lighting design practice, rather than representing exceptional “bleeding edge” design Note that the price of these fixtures was not taken into account in the cost-effectiveness calculations, because we are not basing the proposed LPD reductions on the use of these fixtures.

The “task ambient” options assume that LED task lights are provided, which require 0.13 W/sf. The ambient component provides 20-25fc and the task lights bring the illuminance up to the 30-50fc footcandle range in the task area.

Figure 4 shows a summary of the luminaire types, ballast specifications, LPD and illuminances for the six open office lighting options discussed in the report. The open office lighting models include a wide array of luminaire layouts, controls layouts, and cut sheets for both luminaires and controls.

Open Office Area, [sf]	21,680

Scenario	*Luminaire Type*		*Input Watts per Luminaire, [W or W/ft]*	*Luminaire Quantity, [unit or lf]*	*Total Watts, [W]*	*Ballast Factor*	*Light Loss Factor (LDD * LLD)*	*Initial Lumens per Lamp*	*Installed LPD, [W/sf]*	*Average Maintained Illuminance on Desk Surfaces, [fc]*	*Average Initial Illuminance on Desk Surfaces, [fc]*
T24 Baseline - Recessed SK-1 Series	General Overhead	RF1	72	221	15,912	0.71	0.903	3,100	0.87	43.9	48.7
		RF4	28	47	1,316	0.88	0.817	1,710			
		RF5	28	58	1,624	0.88	0.817	1,710			
T24 Baseline - Suspended SK-2 Series	General Overhead	PF1	47	344	16,168	0.71	0.903	3,100	0.90	42.2	45.8
		RF4	28	67	1,876	0.88	0.817	1,710			
		RF4a	28	32	896	0.88	0.817	900			
		RF5	28	23	644	0.88	0.817	1,710			
Task/Ambient - Recessed SK-3 Series	General Overhead	RF2	47	222	10,434	0.71	0.903	3,100	0.51	40.0 (43.3 total at task areas, 25.9 ambient)	46.1 (49.7 total at task areas, 28.7 ambient)
		RF4b	20	7	140	0.88	0.817	1,150			
		RF5a	20	28	560	0.88	0.817	1,150			
	Task	TL1	11	151	1,691	1.00	0.808	479	0.13		
		TL2	7	151	1,027	1.00	0.808	270			
Task/Ambient - Suspended SK-4 Series	General Overhead	PF2	47	330	15,510	0.71	0.903	3,100	0.75	41.1 (44.2 total at task areas, 27.3 ambient)	47.3 (51.22 total at task areas, 30.2 ambient)
		RF4b	20	16	320	0.88	0.817	1,150			
		RF5a	20	17	340	0.88	0.817	1,150			
	Task	TL1	11	151	1,691	1.00	0.808	479	0.13		
		TL2	7	151	1,027	1.00	0.808	270			
High Efficiency - Recessed SK-5 Series	General Overhead	RF3	72	151	10,872	0.71	0.903	3,100	0.52	40.5	44.8
		RF4b	20	15	300	0.88	0.817	1,150			
		RF5a	20	8	160	0.88	0.817	1,150			
High Efficiency - Suspended SK-6 Series	General Overhead	PF3	94	151	14,194	0.71	0.903	3,100	0.68	42.7	47.4
		RF4b	20	15	300	0.88	0.817	1,150			
		RF5a	20	8	160	0.88	0.817	1,150			

Figure 4. Summary of Performance for Office Lighting Model

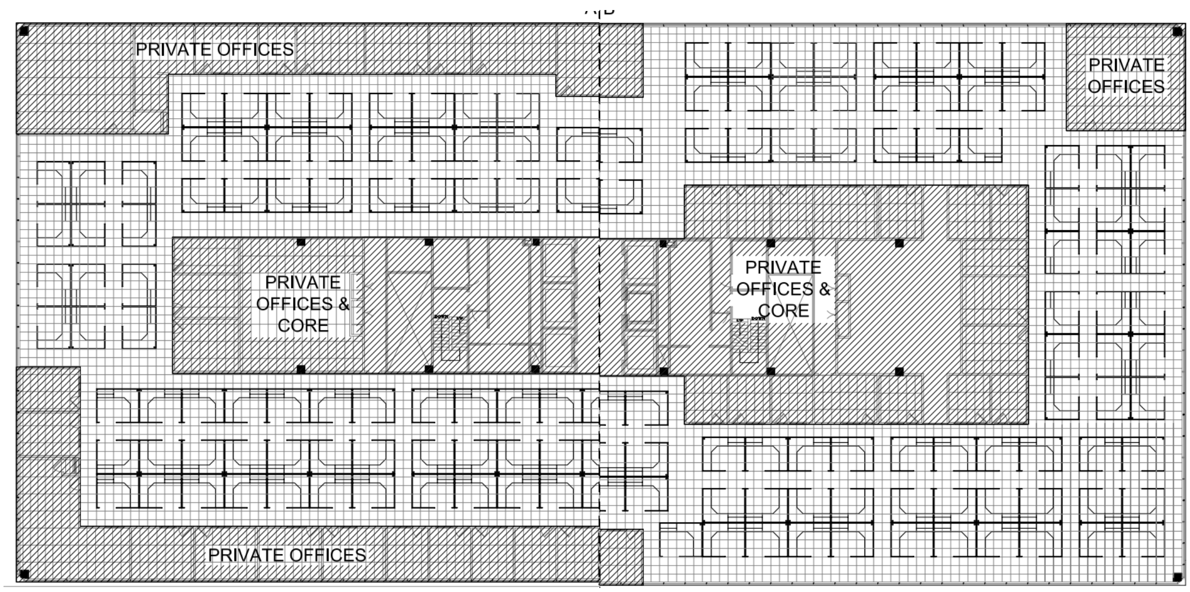


Figure 5. Open Office Model, Showing Office Locations and Furniture Layout

3.4 Calculation of New Lighting Power Density (LPD) Allowances

This section describes how we calculated revised LPDs for the Area Category Method and for the Complete Building Method, based on the open office layouts described above.

We propose that the lighting power density (LPD) allowance for general lighting in open offices should be reduced from 0.9 W/sf to 0.8 W/sf, and that the use-it-or-lose-it allowance for task lighting be increased from 0.2 W/sf to 0.3 W/sf. Therefore the total allowed lighting power in open offices is unchanged, at 1.1 W/sf.

3.4.1 Revised LPDs for Open and Private Offices under the Area Category Method

Figure 6 shows the LPD values that were developed for each of the luminaire layouts described above. We calculated a “system efficacy” (lighting power density per footcandle), and multiplied this by a target illuminance of 30fc. We took this approach because there are so many possible options for luminaire layouts and space geometries that it would be arbitrary to choose a single luminaire spacing (for instance 10’x8’) as the basis for the lighting power density calculation. The target illuminance of 30fc was chosen to ensure that workspaces can meet the IES’s recommended range of 30-50fc average illuminance, without using additional task lighting in most cases.

Figure 6 shows that all the luminaire types can easily provide adequate illuminance in the large open office within the 0.75 W/sf proposed LPD.

For details on the performance of the luminaires used for the models, see Section 3.3.

	Lighting Power Density (W/sf)	**Maintained illuminance on desk surface (fc)**	**System efficacy (W/sf per maintained footcandle)**	**LPD at 30 fc (W/sf)**
Typical office fixtures, recessed	0.87	43.9	0.0198	0.59
Typical office fixtures, suspended	0.9	42.2	0.0213	0.64
Task Ambient (Recessed Overhead + LED Task)	0.51 + 0.13	40	0.0128(1)	0.38
Task Ambient (Suspended Overhead + LED Task)	0.75 + 0.13	41.1	0.0182(1)	0.55
High Efficiency Recessed	0.52	40.5	0.0128	0.39
High Efficiency Suspended	0.68	42.7	0.0159	0.48

(1). These values are calculated using only the wattage of the ambient (overhead) luminaires, not the task luminaires, since the task luminaire power is exempt from the calculation of actual lighting power density in Title 24 Section 146.

Figure 6. Large Model Office LPDs for Various Luminaire Types

In real spaces, the achieved illuminances depend on various factors such as space geometry, partitions, surface reflectances, and luminaire reflector/diffuser options. To ensure that the proposed Area Category LPDs are sufficient to provide recommended illuminance levels, even in small rooms that are photometrically less efficient to light, we calculated the effect of decreasing room size (i.e., decreasing Room Cavity Ratio) on the LPD required to meet the target illuminance. We chose four room sizes—a small 80sf private office, a 250sf two-person room (the smallest room that qualifies as “open office” under the Area Category Method), a 500sf four-person room, and a 2,500sf large open office. We chose these sizes, in part, because they equate to the thresholds for the new proposed power adjustment factors for occupancy controls.

Figure 7 shows the coefficients of utilization for the suspended and recessed fixture types used in the large office lighting model, along with the lighting power densities required to achieve the target illuminances. The final three rows (in gray) show the LPDs required to meet the target illuminance, when the lighting takes advantage of the proposed PAFs. For the open office spaces, this means the proposed PAFs for occupancy sensors (where the occupancy sensors control half the lighting in that space), and for the private office this means the existing PAF of 0.25 for occupancy sensing and manual dimming.

			Fixture type	
	Size of space	**Room Cavity Ratio**	**Suspended fixture**	**Recessed fixture**
Coefficient of utilization at 80/50/20	Private office	8	0.34	0.38
	2-person office	5	0.47	0.51
	4-person office	3.5	0.57	0.61
	2,500sf office	1.5	0.75	0.76
LPD required, no PAFs	Private office	8	1.40 W/sf	1.17 W/sf
	2-person office	5	1.01 W/sf	0.87 W/sf
	4-person office	3.5	0.84 W/sf	0.74 W/sf
	2,500sf office	1.5	0.64 W/sf	0.59 W/sf
LPD required, with occ sensor PAF	Private office	8	1.05 W/sf	0.88 W/sf
	2-person office	5	0.86 W/sf	0.74 W/sf
	4-person office	3.5	0.75 W/sf	0.66 W/sf
	2,500sf office	1.5	0.64 W/sf	0.59 W/sf

Figure 7. LPDs Required to Achieve 30fc on Desk Surface

The last three rows of Figure 7 show that both luminaire types can provide adequate illuminance in what Title 24 refers to as “open offices” (>250sf) using the proposed open office LPD of 0.75 W/sf, except for the suspended luminaire in the two-person office. In this case, additional task lighting would be required for the task areas to reach recommended illuminances, and/or the building could comply under the Complete Building Method instead of the Area Category Method.

The fourth-from last row of Figure 7 shows that the recessed luminaire can provide adequate illuminance in private offices using the proposed allowance of 1.0 W/sf, but that the “typical” recessed luminaire cannot—it requires 1.05 W/sf to achieve 30fc. Therefore, in this very small office it would require a task light to increase the illuminance to the target level.

Note that all the values in Figure 7 are based on the “typical” office fixtures, and that lower LPDs can be achieved with the “high efficiency” fixtures, or with low ambient / task lighting. Also note that the illuminance target of 30fc is a *maintained illuminance* (i.e. after several years of dirt deposition—the initial illuminance would be much higher).

In addition to the LPD allowance for general lighting, Section 146 in Title 24 2008 allows up to 0.2 W/sf of task lighting to be installed without having to be included in the “actual lighting power density” (LPD) of the space. To determine whether this allowance should be revised, we looked to PG&E’s field studies on Task-Ambient lighting (PG&E 2009a, 2009b) which contain an analysis of task lighting options for open offices. These studies found that task lighting using conventional (fluorescent) lighting rather than LED lighting may require up to 0.3 W/sf, so we have proposed an increase in the task lighting allowance to encourage the use of LED lighting. Figure 8 summarizes the existing LPDs and proposed changes with their locations in Section 146.

Location in Title 24	Contents	Title 24 2008	Proposed Title 24 2013
Table 146-F	Offices > 250 sf LPD	0.9	0.75
Table 146-F	Office ≤ 250 sf LPD	1.1	1.0
Section 146(a)	Task lighting LPD exception	0.2	0.3

Figure 8. Existing and Proposed LPDs in Section 146

3.4.2 Revised LPD for the Complete Building Method

To calculate the proposed complete building method LPD for office buildings, California-specific large offices were broken down by space-type. Large offices were the basis for this calculation because most of the square footage of open office areas in the state is located in large office buildings rather than small ones. The space-type breakdown shown in Figure 9 was sourced from Table 6.2 of the Database of Energy Efficiency Resources 2005 final report (Itron 2005). The DEER report in turn sources it from the CaNCCalc Building Energy Efficiency Measure Analysis Software (NCC).

The proposed 2013 LPDs under the Area Category Method's open and private office LPDs were applied to these breakdown percentages to arrive at the proposed 'office buildings' LPD for the Complete Building Method, as shown in Figure 9.

Area Type	Area (sf)	% Area	2008 Area Category LPD (W/sf)	Proposed 2013 Area Category LPD (W/sf)
Conference Room	7,000	4%	1.2	1.2
Copy Room	3,500	2%	0.6	0.6
Corridor	17,500	10%	0.6	0.6
Lobby	8,750	5%	1.1	1.1
Mechanical/Electrical	7,000	4%	0.7	0.7
Private Office	43,750	25%	1.1	1.0
Open Office	78,750	45%	0.9	0.75
Restrooms	8,750	5%	0.6	0.6
Total/Area-weighted building-level LPD	175,000	100%	**0.91**	**0.82**

Figure 9. Complete Building Method LPD Calculation

Figure 9 shows that the office building average LPD is mainly determined by the private and open offices which make up a total of 70% of the floor area. Support spaces have a lower LPD of 0.6 W/sf and make up approximately 17% of the floor area, whereas conference rooms and lobbies have a higher LPD and make up 9% of the floor area. The purpose of the Complete Building Method is to provide designers with an easier compliance path in return for a slightly lower lighting power density, so the 2008 Complete Building LPD of 0.85 W/sf is below the area-averaged LPD of 0.91 W/sf. Similarly, for 2013 we propose a Complete Building LPD of 0.80 W/sf, which is slightly below the area-averaged value of 0.82 W/sf.

3.5 Calculation of Power Adjustment Factors (PAFs) for Occupancy Controls

This section describes in detail how we calculated hourly savings from occupancy sensors that control a small zone of workstations. The process involved first calculating hourly percentage savings, and then using those hourly savings in conjunction with a common baseline to calculate single-figure Power Adjustment Factors (PAFs) to capture the average annual savings.

As explained earlier in the report, only buildings with field measured one-minute interval data/state of change occupancy information at a workstation level over multiple weeks were useful for the development of Annual PAFs and hourly Occupancy Schedules. This is because the measured occupancy information at a workstation level was required to simulate the hypothetical presence of different control group sizes and develop savings estimates for lighting energy.

Hence the following buildings from various studies were considered:

No. of Buildings	Source Study
1	*Saving Energy with Highly Controlled Lighting* (Rubinstein 2009)
2	*Low Ambient Office Lighting Studies* (PG&E 2009a,b)
1	*Energy Saving Lighting Control Systems for Open-Plan Offices: A field Study* (Galasu et al. 2007)[1]

Figure 10. Studies and Buildings Considered for Detailed Analysis

3.5.1 Rubinstein 2009 'Saving Energy with Highly-Controlled Lighting in an Open-Plan Office Study.

This study was originally conducted by LBNL, and we worked together with LBNL to re-analyze their occupancy data in a way more suited to this study. We gratefully acknowledge the help of Francis Rubinstein and Abby Enscoe of LBNL in supporting this study.

Description of Lighting System and Controls

The study took place in 86 cubicles in an open office of a federal office building. The lighting was a highly controlled workstation-specific retrofit, a direct/indirect pendant luminaire with three (3) 32-watt tubular fluorescent lamps. Each luminaire had two DALI ballasts, one for the two lamps facing down (task lighting) and one for the single lamp facing upward (ambient lighting) to the ceiling.

The luminaires had a fixture-integrated occupant sensor that switched lamps on and off according to individual cubicle occupancy. All the ballasts were initially programmed to default settings with specified power levels and timeouts (at default, luminaires operate at 92W and have a 20 minute timeout at 92W and a 10 minute timeout at 61W before fading off). A lighting controller (Lumenergi Lighting Measurement Control System (LMCS)) recorded the power level commanded to each ballast at 2 minute intervals. There were also built-in photosensors, which were not activated during this study due to low levels of available daylight.

[1] This study was reviewed and considered but was not included in the PAF and Occupancy Schedule calculations because the authors could not share detailed measured workstation level occupancy information for technical and administrative reasons.

The baseline case, called "GSA Retrofit" and installed on another floor in the same building, conforms to the current GSA lighting standard and is typical of GSA retrofits in the past five years. Energy use for GSA the retrofit was calculated rather than measured. Layout, daylight levels, surface materials, and type of work performed were largely identical in the two areas. Occupants in both areas worked for GSA. In the GSA retrofit system, pendant-mounted, direct/indirect luminaires with on-off switching controls at the room level only and a one-lamp cross section were installed in continuous rows, with 8 ft spacing between rows. Luminaires had 32 watt T-8 lamps and GE Ultramax normal ballasts, with an input power of 53 watts per 8ft length of luminaire. Lights were assumed to stay on for 16 hours a day. This is an unusually long time for a luminaire to remain on, but the hours were verified by direct circuit monitoring during the 2007 pilot study and made the office an ideal place to save energy with workstation luminaires.

Reported Savings

GSA building had a calculated daily energy use of 13.3 W-h/sf/day prior to the retrofit. After the retrofit, the average daily lighting energy use was 7.9 W-h/sf /day, which is approximately a 40% reduction.

Energy use was studied over 32 days. The installed LPD was 1.23 W/sf, lighting power peaked at approximately 0.72 W/sf during the middle of the day, and the average LPD during working hours (6am-6pm) was 0.52 W/sf. Security and custodial rounds, in which very short occupancy periods turned lights on for specified timeouts (typically 30 minutes), caused power density spikes in the evening.

Adjusted Savings

LPD and savings reported directly in the studies that we reviewed have been adjusted because they are relative to a higher baseline than would be used in new construction under Title 24, and because the occupancy sensors controlled only the downward fraction of the luminaire.

We calculated the "fraction of installed lighting power" that was on for every minute using the occupancy/power level logged by the ballast at 2 minute intervals over the 32 days[2]. Then we applied these fractional savings to the new construction baseline energy use. This analysis was carried out for control group sizes of 1, 2, 4, 8, 27 and 81 workstations. Occupants were logically organized into control groups based on adjacency and shared luminaires, as outlined in Section 3.2.

The field data results (based on occupancy) indicated that there was a lot of lighting energy use late in the evening, therefore the baseline energy consumption was adjusted downward to take account of the automatic shutoff controls that a Title 24 2008 minimally-compliant building would have. The factors for this modification for shutoff controls were derived from ADM (2002) open office baseline, which is the same source of data used for the Title 24 lighting schedule in the Alternative Compliance Method (ACM) Manual. After 6p.m., energy use was adjusted downward so that it did not exceed the same hourly value in the ACM schedule.

Figure 11 shows the average energy use and savings for various control group sizes. The values are adjusted to include a 30-minute occupancy sensor time delay (in line with the maximum allowed under Title 24 Section 119). The adjusted baseline was based on an assumption that any amount of occupancy in the open office would cause all the lights to remain turned on (either by occupancy

[2] LBNL performed this simulation; they already had the logged data setup for simulation using Matlab software.

sensors or by manual override of a time sweep system). Therefore, in this building the control group with 81 workstations was the baseline schedule.

Control group size (# of workstations)	**1**	**2**	**4**	**8**	**27**	**81 (all)**
Average Energy Use (full load hours, weekdays only)	7.3	10.1	12.0	13.5	14.7	15.2
Savings relative to building's own baseline (all workstations controlled together) (full load hours, weekdays only)	7.9	5.2	3.3	1.8	0.6	0.0

Figure 11. GSA Building - Savings results (simulated) for various control group sizes, average weekday

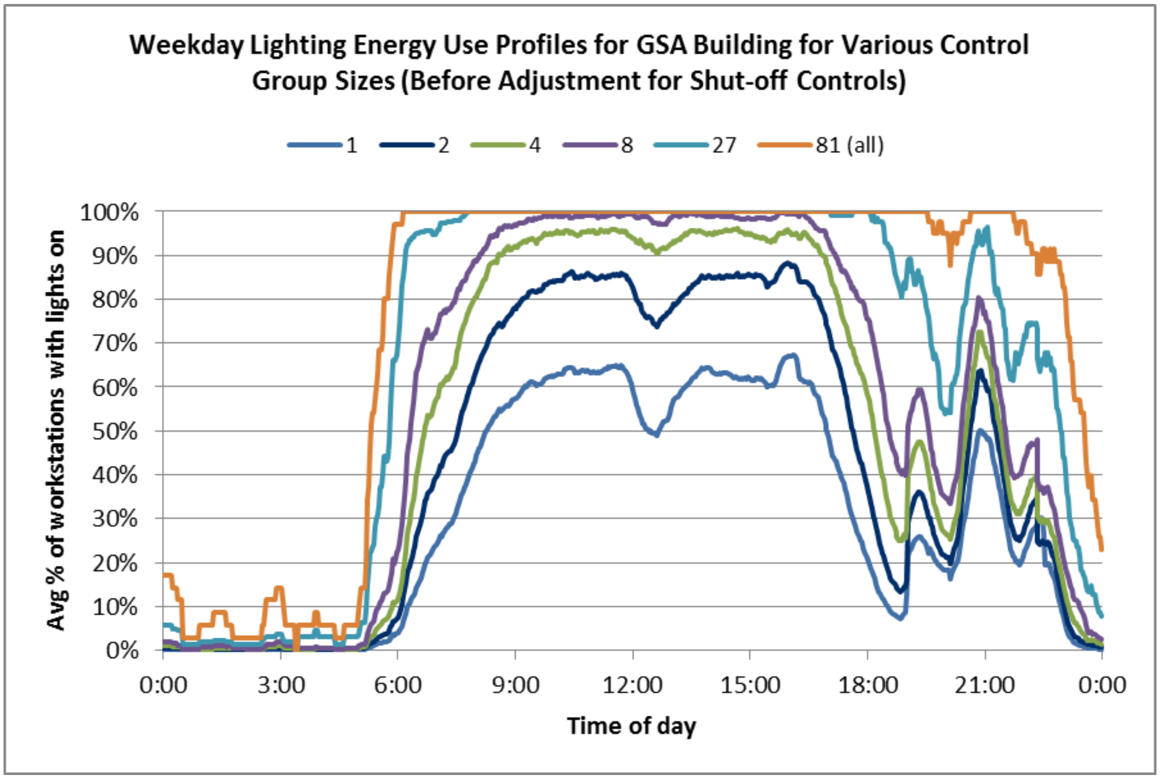


Figure 12. Simulation results before adjustment for shutoff controls

Figure 12 and Figure 13 show the 'average percentage of workstations with lights on' calculated for the 32 weekdays included in the field measurement period, based on this occupancy for hypothetical control group sizes of 1, 2, 4, 8, 27, and 81 workstations. This result for each control group size is averaged over all the 32 weekdays. The figures show a progressive decrease in lighting energy use as the number of people in the control group decreases.

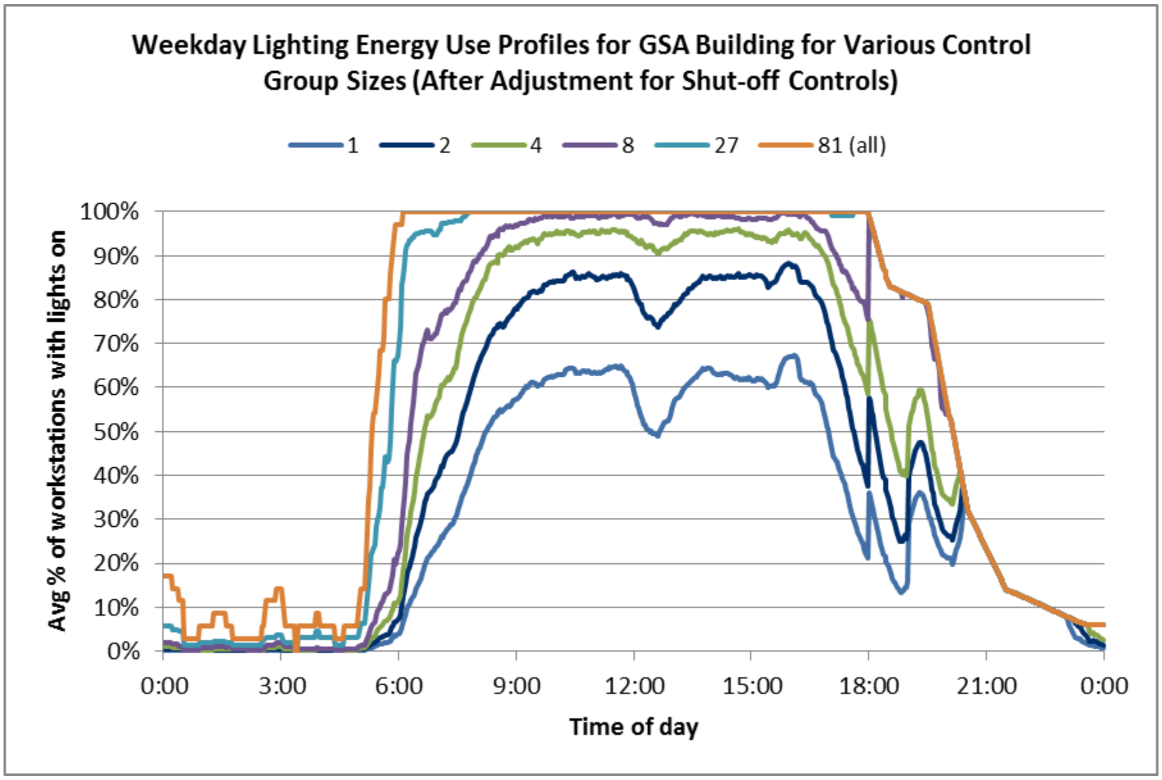


Figure 13. Simulation results after adjustment for shutoff controls

3.5.2 Galasiu et al. 'Energy Saving Lighting Control Systems for Open-Plan Offices: A Field Study'

Because we were not able to obtain sufficiently detailed information from the authors of the study, the results reported from this research were not included directly in the calculation of the PAFs and hourly schedules. They were used to corroborate the results from the others studies, and are discussed here because they support many of the conclusions from the other studies.

Description of Lighting System and Controls

A majority of workstations on the study floors had commercial direct-indirect luminaires suspended at about a foot below the ceiling and located centrally in each workstation. When fully on, the system provided an average illuminance of 42 fc in the center of the workstation at 34" above the floor (desktop height).

Each luminaire contained 3x32 W lamps. During the study, the field installation comprised a total of 195 luminaires distributed over three and a half floors in one building.

Each luminaire was connected by a network to a central control computer and to each occupant's desktop computer. The fixture also included an occupancy sensor and a photosensor. The lamp in the center of the luminaire was equipped with a static electronic ballast and directed the light mainly upward, providing constant general lighting around the open-plan space. During the study, these lamps were controlled centrally based on a daily schedule that kept them continuously at full power from 7:30 AM to 5 PM on workdays. Outside of these hours, the uplight lamps were turned on by an integrated sensor when sensing occupancy in the vicinity.

The two lamps at the sides directed the light mainly downward. The downlights were controlled during the study based on all of the following three control options:

- An integrated occupancy sensor (OS). It consisted of an infrared motion sensor mounted directly on the luminaire. On detecting vacancy, the sensor prompted the downlights to gradually dim down to zero and switch-off. When presence was detected, the downlights were automatically restored to the previously set lighting level.
- An integrated light sensor (LS), used to monitor the surrounding light levels and dim the downlights when sufficient light (from either daylight or neighboring electric light) was present to maintain the occupant preset light level. The light sensor consisted of a photocell mounted directly on the luminaire.
- Individual control (IC), consisting of an on-screen slider located on the occupants' desktop computers that allowed both on/off switching or dimming of the downlights to a preferred level.

Reported Savings

With all the three controls in operation, the lighting system saved an *additional* 42-47% of energy (on top of the 42% saved by the direct-indirect luminaires when they replaced a static ceiling-recessed system four years prior to the study). This translates to 70% claimed energy savings compared to the conventional lighting system.

The LBNL team used the occupancy data to calculate energy use in three hypothetical scenarios:

- Baseline energy use scenario (absence of controls during work-hours plus the additional time that the uplights were reported to have been on outside the scheduled hours when occupancy was detected)
- Energy use and power demand of each luminaire if only one control had been in operation.
- Energy use and power demand of each luminaire if a combination of two controls had been in operation.

The results showed that if the three lighting control systems had been installed separately:

- Occupancy sensors would have saved 35% if used alone (control group size of one person/workstation per occupancy sensor).
- Daylight harvesting would have saved 20% if used alone.
- Individual dimming would have saved 11% if used alone.

Note that these savings sum to more than the claimed total of 42-47% if they are simply added (or multiplied) together; this is because adding subsequent layers of control saves progressively less energy because those layers of control cannot save the same energy twice.

Adjusted Savings

Reported savings on this project were not adjusted, because sufficient hourly schedules and other baseline information were not available.

The authors were contacted for field measured occupancy information from the sensor or ballast that we could use to simulate the effect of multiple control group sizes and increase the density of the PAF scatter plot. We were told that the information could not be shared for technical and administrative reasons.

So the research reported on this building is used only as a guideline and not included directly in the calculation of PAFs and occupancy schedules.

3.5.3 PG&E 2009a High Efficiency Office: Low Ambient/ Task Lighting Pilot Project. Large Office Site Report

Description of Lighting System and Controls

The space had continuous row suspended T8 uplight fixtures. This was a before-and-after study, in which the fixtures were relamped part-way through the study, and the ambient illuminance reduced from 40fc to 19fc, and LED task lighting was added at each workstation. The intent of the study was to capture occupants' reactions to and opinions of the reduced ambient illuminance and the LED task lights, so the suspended fixtures were controlled by a timesweep system and the task lights were on manual control, i.e., the occupancy sensors were used only to log the presence and absence of occupants, not to control the lighting.

Reported Savings

Savings from this project were due only to the reduction in ambient illuminance; there was no attempt to save energy by using occupancy sensors.

Adjusted Savings

Measured occupancy information was collected in an open office at a workstation level in the "Large Office" building for the PG&E low ambient lighting project. This logged occupancy for 4 weeks included regular weekdays, furlough Fridays, Saturdays, Sundays, and a labor day holiday. While the measurement spanned 31workstations, 10 of these were vacant. The workstations that were vacant during the measurement period were included so as to capture realistic occupancy conditions in open offices. For weekday, Saturday and Sunday categories, this was interpolated into minute by minute occupancy for different control group sizes such as 1, 2, 4, 8 and 31 occupants. Occupants were logically organized into control groups based on adjacency and shared luminaires. Energy factors were developed from this occupancy information assuming a time delay of 10 minutes for the occupancy sensors.

The project's hourly energy baseline profile was developed from the actual energy use of the building (measured on site during the study period). This is the correct baseline for Title 24 2008 because the lighting in the study space had automatic shut-off controls (timesweep controls) compliant with Title 24 Section 131(d) and 119. Therefore the results did not need to be adjusted in this regard.

Note that the largest control group (31 workstations) shows negative energy savings, i.e., occupancy sensor control would have used *more* energy than the timesweep control, if the workstations had been grouped together and controlled by a single occupancy sensor. As can be seen in Figure 15, this is because some occupants were beginning their workday as early as 6 or 7am, before the timeclock system switched the lights on. This was possible because the study period was during the summer and many of the workstations were directly adjacent to windows.

Control Group Size	**1**	**2**	**4**	**8**	**31(all)**
Average Energy Use (full load hours)	4.3	5.2	6.5	8.2	9.5
Savings relative to Building's Own Baseline (time sweep control) (full load hours)	4.3	3.4	2.1	0.4	-1.0

Figure 14. Large Office Building - Savings results for various control group sizes, average week

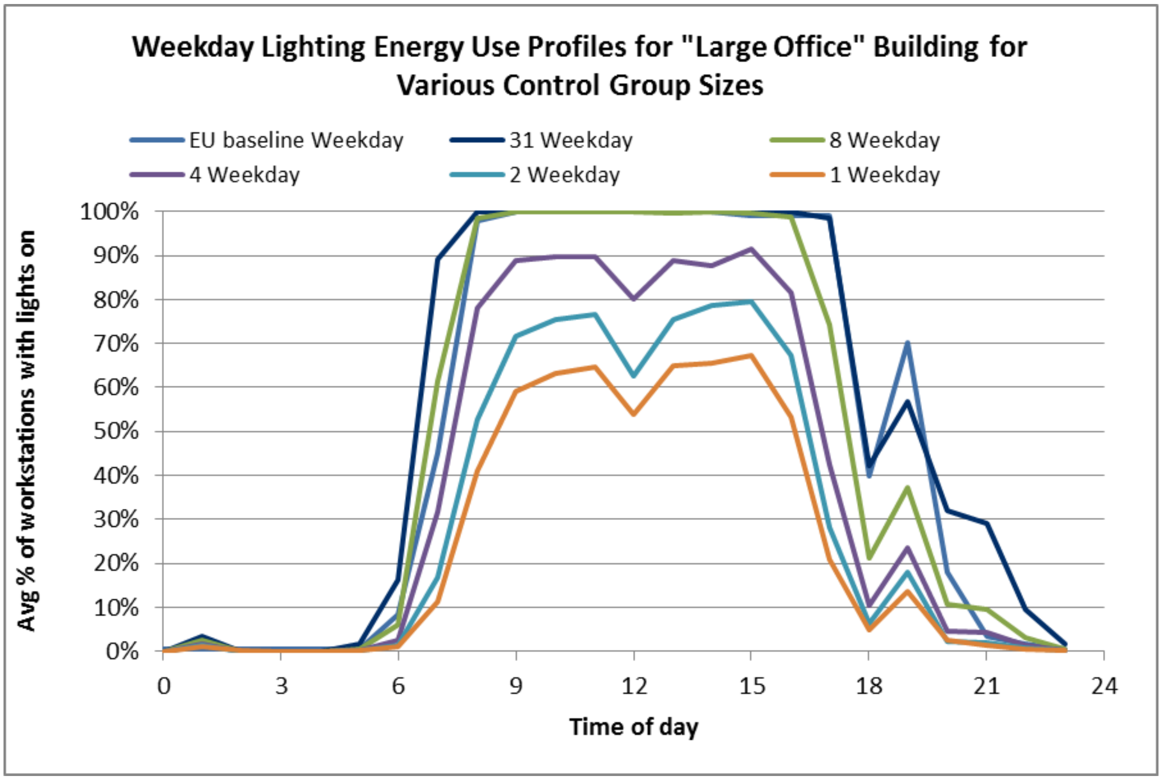


Figure 15. Weekday Profiles for Various Control Group Sizes on the "Large Office" Building Low Ambient Pilot Project

For weekdays, the results depicted in the chart indicate that the lighting energy use decreases progressively as the number of people in the control group decreases.

3.5.4 PG&E 2009a High Efficiency Office: Low Ambient/ Task Lighting Pilot Project. Large Office Site Report

Description of Lighting System and Controls

Not relevant to this project. Lighting energy savings developed were solely based on field measured occupancy and not on the existing lighting technology. The site only had time clock controls and no occupancy or manual controls in the open offices.

Reported Savings

Not relevant to this project. Lighting energy savings developed were solely based on field measured occupancy and not on the existing lighting technology. The site only had time clock controls and no occupancy or manual controls in the open offices.

Adjusted Savings

Measured occupancy information was collected in an open office at a cubicle level in the small office building for the PG&E low ambient lighting project. While the measurement spanned 13 open office workstations, one of them was vacant. The vacant cubicle was included so as to capture realistic occupancy conditions in open offices. The logged occupancy contained information for two weeks. For weekday, Saturday and Sunday categories, this was interpolated into minute by minute occupancy for different control group sizes such as 1, 2, 4, 9 and 13 occupants. Occupants were logically organized into control groups based on adjacency and shared luminaires. Energy factors were developed from this occupancy information assuming a time delay of 10 minutes for the occupancy sensors.

The project's hourly energy baseline profile was developed from kWh measured on site during the study period. The project already had shutoff controls, so no modification was needed in this regard.

Control Group Size	**1**	**2**	**4**	**9**	**13**
Average Energy Use (full load hours)	3.8	4.7	7.4	11.0	11.0
Savings relative to building's own baseline (time sweep control) (full load hours)	6.3	5.4	2.7	-0.9	-0.9

Figure 16. Small Office Building - Savings results for various control group sizes, average week

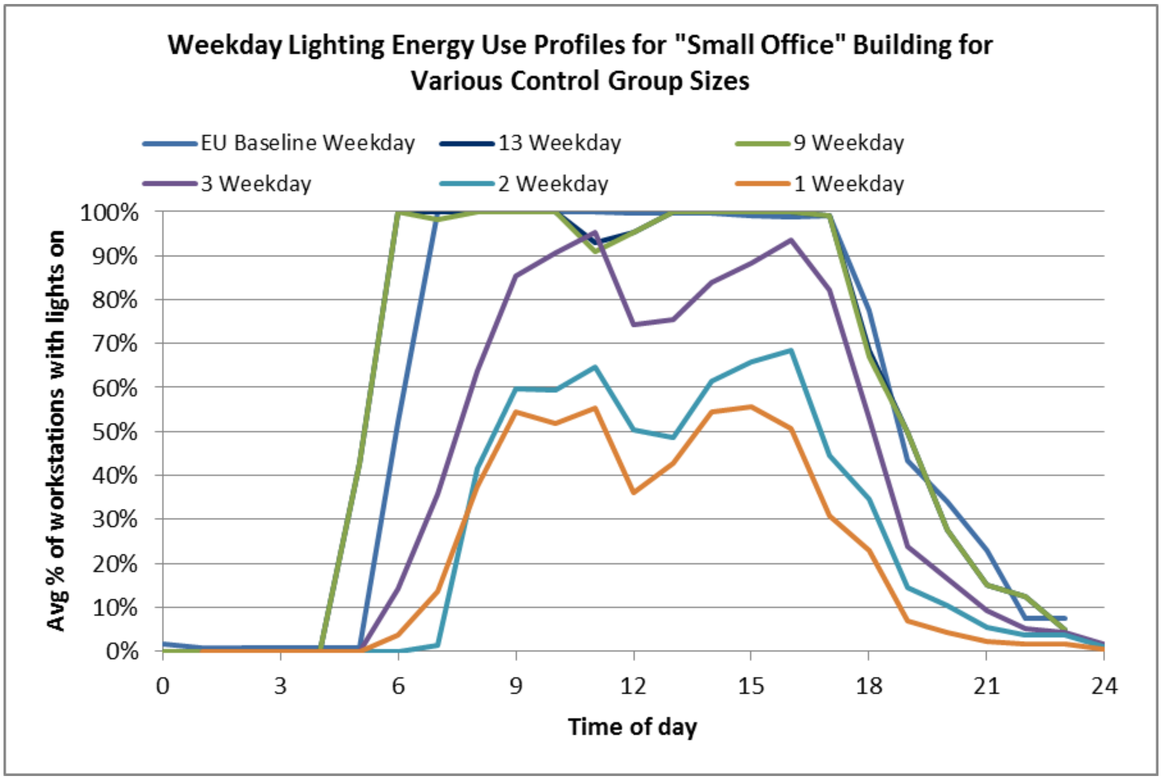


Figure 17. Weekday Profiles for Various Control Group Sizes on the "Small Office" Building Low Ambient Pilot Project

For weekdays, the results depicted in the chart indicate that the number of lights turned off, and hence energy savings, increase as the number of people in the control group decrease.

3.5.5 Development of PAFs for Occupancy Controls

This section describes how we developed single-figure PAFs for Table 146(C), and hourly schedules for the Alternative Compliance Method (ACM) Manual, based on the hourly energy use profiles summarized above for each building.

Using the data summarized above, we developed a baseline lighting schedules without occupancy controls, and a series of calculated schedules based on the use of occupancy sensors for various control group sizes for each building. For each hour, we calculated the average percentage reduction in lighting load due to occupancy sensors across the three buildings. These hourly values are shown in Figure 18.

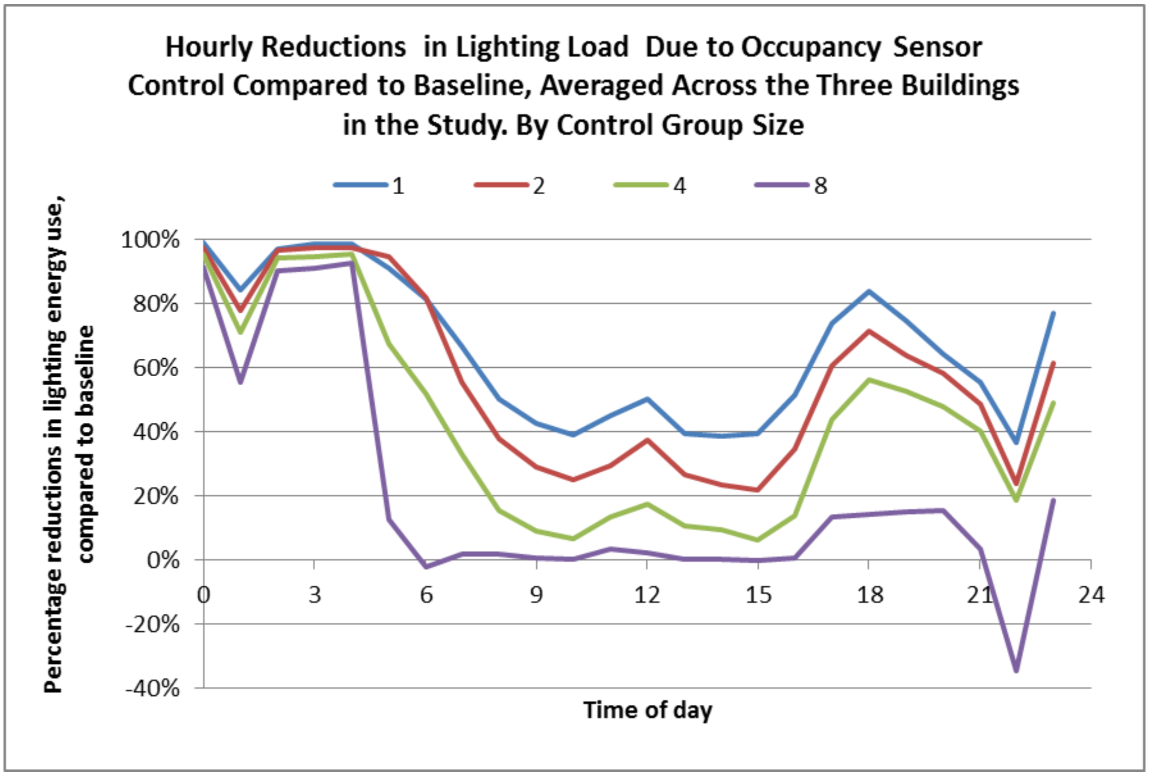


Figure 18. Hourly Reductions in Lighting Load due to Occupancy Sensor Control

Figure 18 shows that the percentage reductions in lighting load become erratic outside "working hours" (i.e., late at night and in the early morning); this is because both the baseline and the actual lighting energy use values are small, so a slight change in either one can produce a dramatic change in the percentage savings. For the group size of eight sensors, the "savings" value is negative at 10pm (22 hours), because the baseline energy use was actually lower than the actual energy use for that hour (see Figure 14 and Figure 15). Because of these erratic changes, and because the actual magnitude of savings was so small for these hours, we set the savings percentages to zero for the period 11p.m. to 5a.m., as shown in Figure 19. This hourly profile was the basis for the proposed hourly occupancy schedules for the ACM Manual, shown in Section 0.

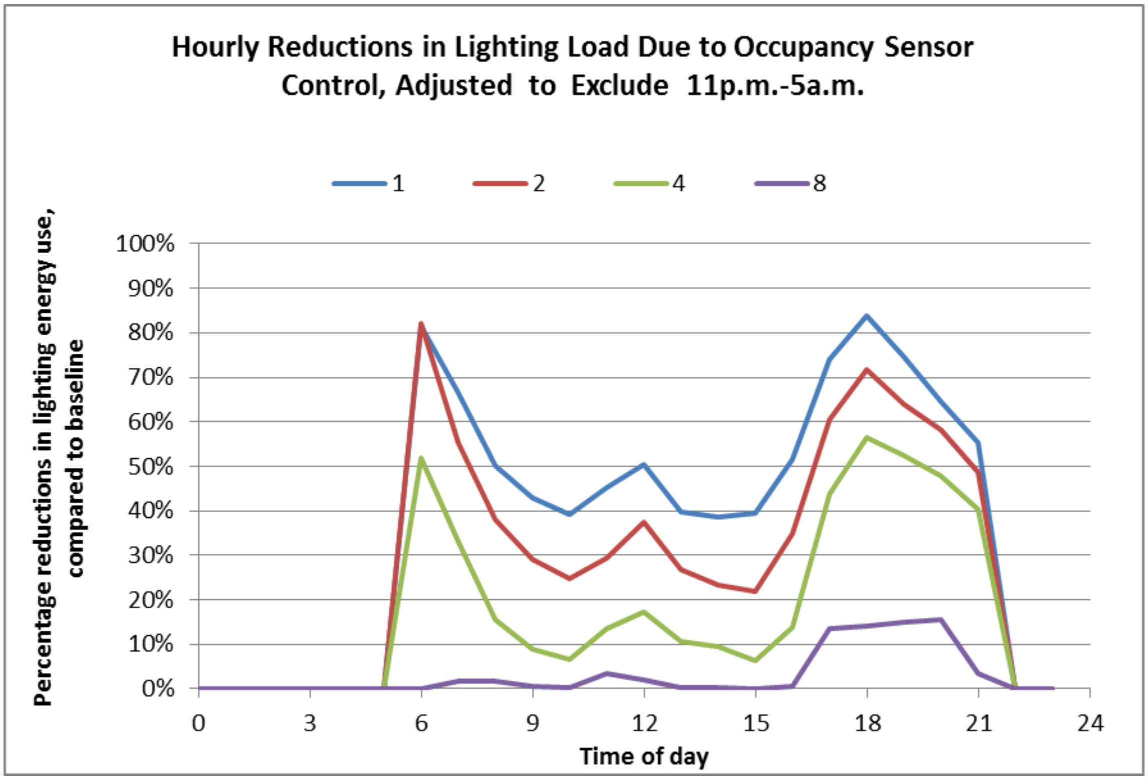


Figure 19. Hourly Reductions in Lighting Load due to Occupancy Sensor Control, Adjusted to Exclude Erratic Values

We used the hourly percentage reductions in lighting load shown in Figure 19 to calculate single-figure PAFs, for Title 24 Table 146(c). For each control group size (1,2,4,8):

$$\text{Power Adjustment Factor (PAF)} = \frac{\sum_{i=0}^{23} B_i.PR_i}{\sum_{i=0}^{23} B_i}$$

Where:

B_i = Baseline lighting energy use for hour i, averaged across the three buildings.

PR_i = Percentage reduction in lighting load at hour i, due to occupancy sensor control (see Figure 19).

The resulting "calculated" single-figure lighting energy reduction values are shown in Figure 20. These PAFs represent the estimated savings for a "tailored" grid of occupancy sensors, i.e. the sensors are located and shielded and adjusted to detect *only* occupants in the workstations over which they are mounted, and cannot "see" people walking past in adjacent corridors, or working in adjacent workstations. Because, even with a known furniture layout and accurate commissioning, the sensors are unlikely to work perfectly, we have proposed PAFs that are slightly lower than the calculated values.

Control Group Size	**1**	**2**	**4**	**8**
Calculated lighting energy reduction value	0.52	0.40	0.23	0.04
Proposed PAFs for "tailored" occupancy sensor grid	0.4	0.3	0.2	0

Figure 20.Calculated Lighting Reductions and Proposed PAFs

3.6 Calculation of revised lighting schedules for the Alternative Compliance Method (ACM) Manual

To calculate the schedules in the Alternative Compliance Method (ACM) manual, we used these proposed PAFs to adjust downward the hourly savings values (i.e., we reduced each hourly value in Figure 19 downward according to the ratio of "calculated reduction" to "proposed PAF" in Figure 20). The reduced hourly savings values were then applied to the proposed Title 24 2013 baseline for open offices to obtain the ACM schedules shown in Section 0.

3.7 Energy Savings

This section describes how energy savings (and the Time Dependent Valuation (TDV) of savings) were calculated, both for the proposed LPD reduction and for the proposed requirement for manual wall switches located within primary sidelit daylight areas.

3.7.1 Energy Savings for Proposed LPD Reduction

To calculate the savings from this measure, 2013 TDV (nonresidential 15 year) energy costs were used to calculate the cost effectiveness of occupancy sensors, controlling the lighting over workstations groups of various sizes.

The hourly PAF profiles developed in Section 3.5.5 were applied to the open office lighting baseline schedules from ADM (2002). The resulting hourly savings were applied to half of the presumed installed load (0.9 W/sf[2]). We applied the savings to half the installed load following discussions at the first two stakeholder meetings, which confirmed that designers and occupants would not want to have their entire lighting load controlled by occupant sensors, both for aesthetic reasons and to reduce annoyance to occupants. We also discounted 15% of the baseline lighting energy use, which is presumed to have been saved already by a concurrent proposal for Controllable Lighting under Section 131(b).

Assumed controlled LPD = 0.9*(1-0.15)*0.5 = 0.3825 W/sf

For all 8760 hours, for the four control group sizes, the savings in kWh/sf were multiplied by 2013 TDV $/kWh energy costs. This was done for the population-weighted average of all California Climate Zones, as well as (for information) three specific climate zones CZ3, CZ8, and CZ12. This analysis was conducted using the 2013 TDV methodology and the results are shown in Figure 21.

Figure 21 shows that the value of the savings varies only slightly between climate zones. Because the savings for zones of eight workgroups were so low, the PAF was set to zero, so no savings are predicted for this workgroup size.

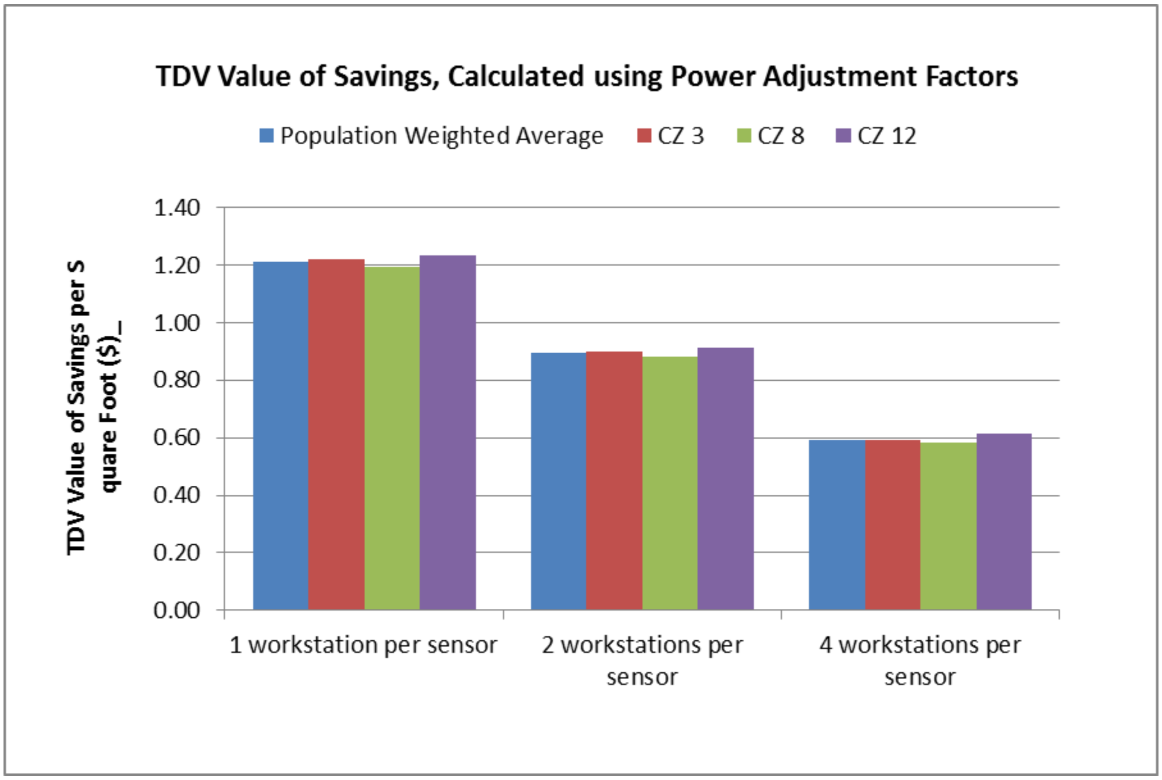


Figure 21. TDV Value of Savings from Occupancy Sensors, Calculated using Power Adjustment Factors

To provide a more useful metric of value of the measure, we summed the per-square-foot TDV value of the savings, over the area covered by each occupancy sensor, to obtain the total TDV savings per sensor. The saving in this format can then be used directly with the measure cost for each control group size, to determine cost-effectiveness.

3.7.2 Manual Control (Switch) in Primary Sidelit Daylight Areas

The analysis of the likelihood of manual switching by Hunt (1979, 1980) was used as the main resource in predicting the effectiveness of a manual light switch in the primary sidelit daylight area. This paper mainly deals with behavioral aspects of lighting use in spaces with different occupancy and lighting use patterns. Of main interest to this CASE proposal is its field research-based correlational chart between ‘minimum working plane illuminance’ and ‘probability of people switching on the lights (%)’. Hunt’s research concludes that an overall lighting level of 15 fc produced an 18% probability of requiring extra light, whereas at 50 fc this probability was negligible (less than 1%). Hunt conducted a field study and derived the relationship between illuminance and switching likelihood shown in Figure 22 (1 footcandle = 10.76 lux).

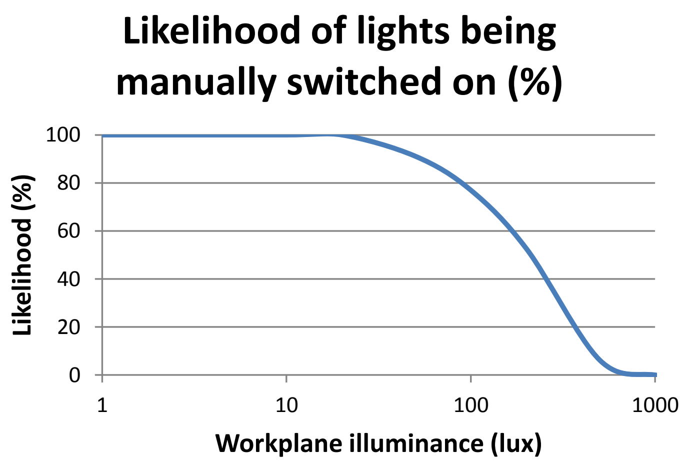


Figure 22. Likelihood of Lighting being Manually Switched on when an Occupant Enters a Space

To estimate the likely magnitude of energy savings from this measure, we created a daylighting model of a representative daylit space (a classroom) using DaySim. DaySim generates 8760 daylight illuminances at various depths in the primary sidelit daylight zone. The model was intended to model a typical 900sf classroom with a 30% window-to-wall ratio and glazing with 50% visible light transmittance. The other assumptions in the model that affected daylight penetration, such as reflectances and overhang depth were kept conservative to avoid over predicting the amount of daylight in the primary sidelit daylight zone.

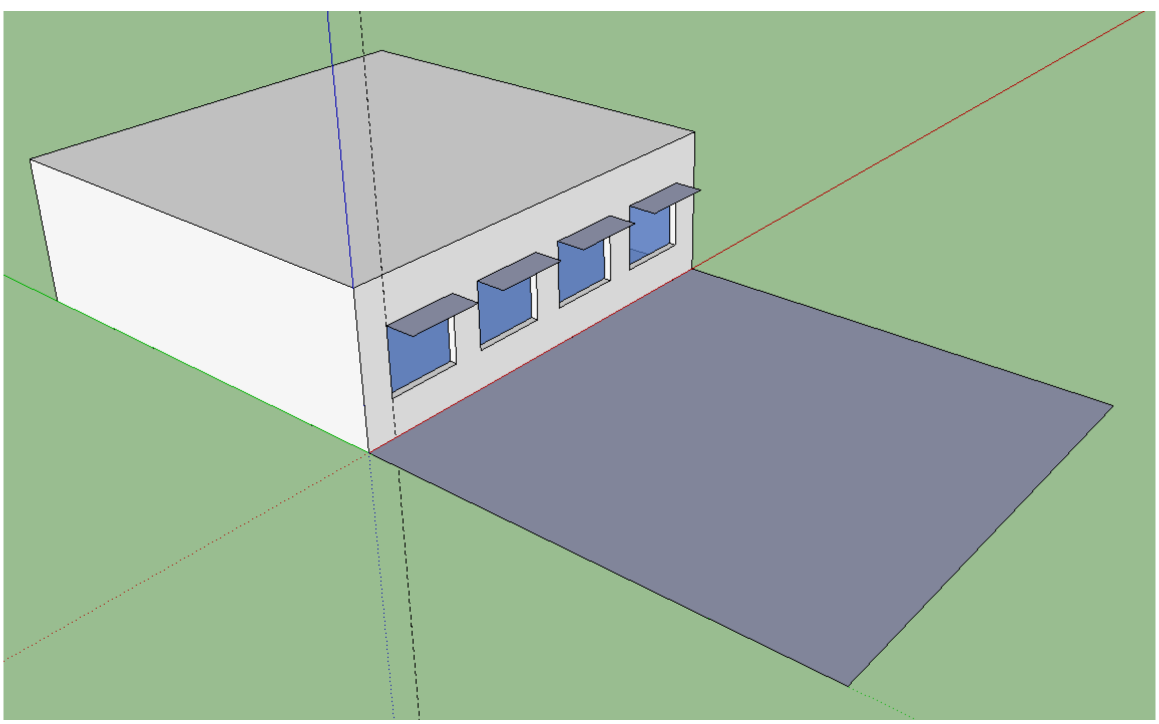


Figure 23. DaySim Classroom Model Used to Estimate Photocontrol Savings

Based on average hourly daylight illuminance values in the primary sidelit daylight zone and the correlational curve in Figure 22, each hour during the operating hours was assigned a likelihood of lights being switched on. Within each day, this cumulative percentage was added up through the hours from 8a.m. until midnight (we assumed that 8a.m. would be an average time at which a primary daylit space becomes occupied). To calculate savings, we took the average daily lighting energy use profile for "all commercial space" from CEUS (Itron 2005) and subtracted out two elements:

1. "Night lighting", which we conservatively assumed to be 25% of the installed load. This lighting is left on overnight and is therefore not available to be switched on by occupants when they enter the space.
2. The cumulative percentage of lighting that we calculated would be manually switched on (from the Hunt curve). Figure 24 shows that this cumulative percentage increases sharply in the morning (because the daylit area is dark at some times of year) then levels out before increasing sharply again toward the evening.

Figure 24 shows that the resulting savings occur primarily in the middle of the day, and peak at around 30% of the installed lighting load. The average savings is 17% of the installed load, or 0.71 kWh/sf/yr at 0.68W/sf (0.68W/sf is 0.8W/sf office LPD adjusted downward by 15% for Controllable Lighting savings).

The total savings over the entire day is equal to TDV$2.46/sf over the 15-year measure life used in the 2013 Title 24 cost effectiveness methodology. Therefore, for a primary daylit zone of 100sf with 100 controlled Watts of lighting, the measure would save approximately TDV$246 over its life.

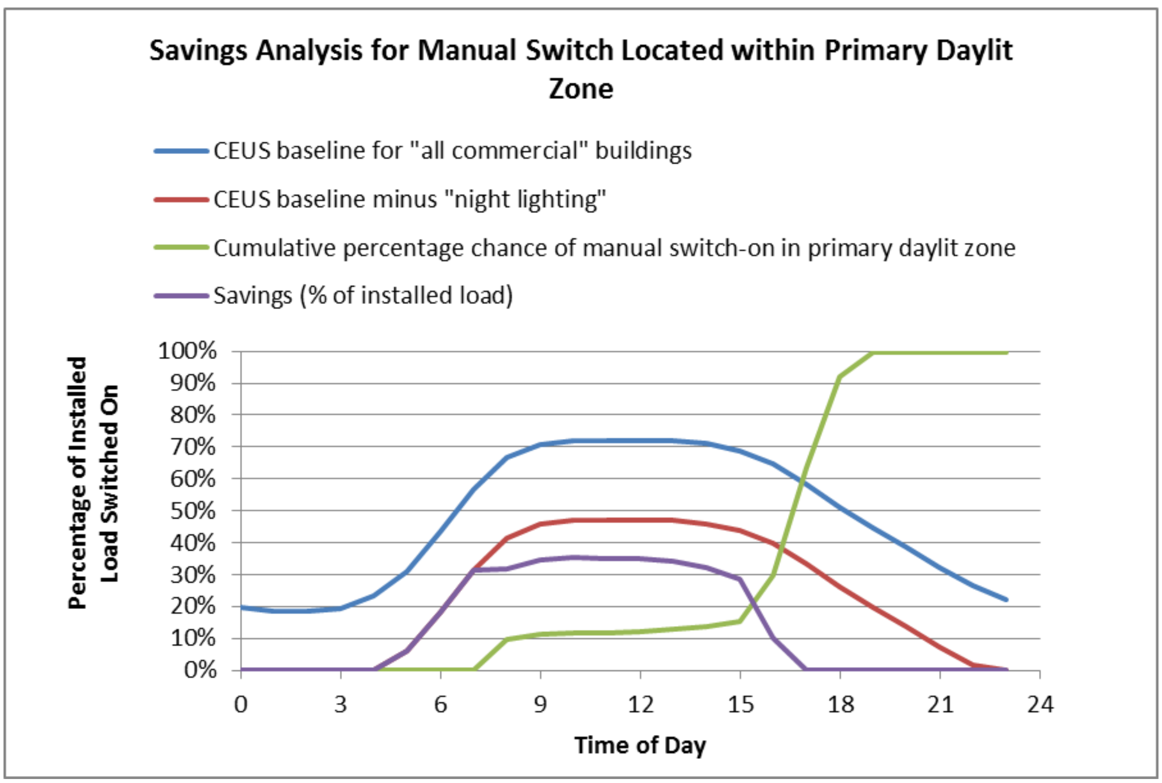


Figure 24. Savings Analysis for Manual Switch Located within Primary Daylit Zone

3.8 Cost effectiveness for Occupancy Sensor Controls in Open Offices.

Because the proposed measure is only a Power Adjustment Factor (PAF), it does not strictly require a cost-effectiveness calculation. However, because the PAF is in part intended to help achieve a reduction in open office lighting power density from 0.9W/sf to 0.75W/sf, we are presenting the cost-effectiveness calculations.

The costs of occupancy sensors used in this study were collected in a survey in 2009 for the SDG&E sponsored Hotel Bi-level Lighting CASE (San Diego Gas and Electric 2009).

There are two basic technologies commonly used in occupancy sensors: passive infrared, and ultrasonic. The two technologies are each most effective at detecting a different type of movement. Infrared sensors detect changes in the pattern of infrared light they can "see" through a Fresnel-type lens in the front of the unit. For this reason infrared sensors are particularly good at detecting people walking *across* the field of view of the sensor. Conversely, ultrasonic sensors emit a unidirectional ultrasonic signal that reflects back from the room surfaces into the sensor; any movement (primarily *toward or away from* the sensor is detected as a change in the reflected frequency (Doppler effect). "Dual technology" sensors incorporate both technologies to improve the chances of detection.

Assuming that the sensors are mounted on the ceiling (which is by far the cheapest mounting location), infra-red sensor are most suitable because they are line-of-sight sensors, i.e. they can be fitted with lenses or shrouds to prevent them from detecting movement outside a certain area of detection. Conversely, ultrasonic sensors are not line-of-sight and cannot be shielded in this way; they can only be "tuned" to reduce their sensitivity to the point where they are not triggered by nearby movements, but reducing their sensitivity in this way also makes them less likely to detect the movement of people directly underneath, i.e. in the *intended* zone of detection.

	Unit cost for equipment	
Occupancy Sensor Type	**Line Voltage**	**Low Voltage**
Infrared	$49.91	$62.20
Ultrasonic	$99.21	$137.19
Dual technology	$91.75	$108.89

Figure 25.Average Price of Ceiling Mounted Occupancy Sensors from a 2009 Pricing Survey

Figure 25 shows costs that were collected from California dealers for 82 occupancy sensors of infrared, ultrasonic and dual technology types. The average price of ultrasonic-only sensors was slightly higher than the cost of dual-technology sensors, which seems counterintuitive, but this is because ultrasonic-only sensors are a small, niche market, while dual-technology sensors are more common. Based on these prices, and on the CASE team's experience, we chose the infra-red sensors as the basis for our cost estimate.

The measure cost is a combination of the equipment cost and the labor cost to install the occupancy sensor. To calculate installation cost we used the RS Means (2010) value of 1.1 hours to install an occupancy sensor. We assumed a 30% reduction in the installation time because many identical occupancy sensors would be installed close to one another, resulting in a time savings for the electrician. We used RS Means' California average rate of $86/hr for electrician labor, to give a total labor cost of $66 per sensor (1.1 x 0.7 x $86).

We have assumed that the ballasts used in conjunction with occupancy sensor control are ballasts that allow for a "load shed" or other reduced wattage state below full output, or that ballasts are wired in tandem to allow one lamp per fixture to be switched off.

Figure 26 shows that for each control group size (1,2 and 4), the cost of the measure (column C) is less than the TDV savings (column F), and therefore the measure is cost-effective for all control group sizes. Larger control groups (2 and 4 workstations) have a higher cost-benefit ratios (2.6 and 1.9 respectively) than 1 workstation per group (1.3).

Control Group Size (# workstations)	Cost of Occupancy Sensor ($)	Cost of Labor ($)	Total Cost of Measure ($)	Area covered by occupancy sensor (sf)	TDV of Savings from PAF, per sf	TDV of Savings from PAF, per sensor
	A	B	C=A+B	D	E	F=D*E
1	$49.91	$66.22	$116.13	125	$1.21	$151.47
2	$49.91	$66.22	$116.13	250	$0.89	$223.65
4	$49.91	$66.22	$116.13	500	$0.59	$296.39

Figure 26. Cost-Effectiveness for Occupancy Sensor Controls

3.9 Statewide Savings from Office Lighting Power Density Reductions

Statewide savings were calculated by reducing the baseline energy use for offices in proportion to the reduction in allowed LPD. A 15% reduction in energy use due to the proposed Controllable Lighting requirements was taken into account before calculating the savings from this measure.

	Equation	Private offices	Open offices
Hours of use per year (from proposed ACM schedules)	A	1310	3907
2008 Title 24 LPD (W/sf)	B	1.1	0.9
2008 Energy Use (kWh/sf/yr)	C=A*B/1000	1.44	3.52
Energy use after 15% reduction for Controllable Lighting (kWh/sf/yr)	D=0.85*C	1.22	2.99
Proposed 2013 Title 24 LPD (W/sf)	E	1	0.75
Energy use under proposed LPD (kWh/sf/yr)	F=D*(E/B)	1.11	2.49
Savings (kWh/sf/yr)	G=D-F	0.11	0.50
Statewide new construction (Msf/yr)	H	9.25	16.7
Statewide savings (GWh/sf/yr)	I=G*H	**1.03**	**8.29**
Statewide peak load reduction (MW)	See footnote 1	**3.7**	**11.0**
Statewide TDV$ savings		**$ 983,000**	**$ 7,620,000**

1. From the ACM schedule, the peak for open offices averages 93% of installed load from 12:00-18:00, and for private offices averages 52%

Figure 27. Statewide Savings from Office LPD Reductions

The calculated savings assume that the DEER values for percentage of office floor space devoted to open and private offices (45% and 25% respectively) are applied equally to the 28Msf of large office buildings and the 9Msf of small office buildings predicted by the CEC's construction forecast.

3.10 Cost-Effectiveness of Requiring a Manual Control (Switch) in Primary Sidelit Daylight Areas < 250 sf

In a separate CASE study, we are proposing that spaces with primary sidelit daylight areas > 250sf should be required to have automatic daylighting controls. In spaces <250sf these automatic controls are not cost-effective, so to gather potential savings in these spaces, without incurring a large additional cost, we analyzed the cost-effectiveness of requiring a manual lighting control (switch) in the daylight zone to control the lighting within the daylight zone.

The rationale for this measure is that if the light switch is located with the primary daylit zone (instead of, for instance, by a door in a non-daylit part of the space), then occupants are less likely to switch the lighting on because a) they have to walk further to get to the switch, and b) the daylight illuminance in the area around the switch may be high enough that they do not feel a need to switch on the lights.

The savings calculated for this measure are shown in Section 3.7.2.

The cost of adding one more switch leg to a space, based on RS Means' costs for new construction, is $19.50 labor, $40 for a timer switch, and $23.35 to add 30' of wire to supply the switch. The total cost of the measure for a typical space is therefore $82.85. Because the cost of the measure is less than the TDV savings, the measure is cost-effective.

3.11 Statewide Savings from Manual Switch in Primary Sidelit Daylight Areas

Statewide savings were calculated by applying the calculated savings from the daylight switch to the lighting power densities for the affected spaces. Because there is no available data for the percentage of floorspace that would be affected by this requirement, we have assumed conservative numbers. The value of 4.5% for offices was generated by assuming that 10% of open office floorspace would be affected, and open offices account for 45% of office floorspace. For schools, we assumed that one third of the lighting in half of all classrooms would be affected, and that classrooms account for 60% of school floorspace. A 15% reduction in energy use due to the proposed Controllable Lighting requirements was taken into account before calculating the savings from this measure.

Building Type	2014 New Construction (million sf)	Energy savings per square foot in daylit zone (kWh/ft^2/yr)	Percentage of floorspace affected	Peak load reduction per square foot in daylit zone (W/sf)	Statewide energy savings (GWh/yr)	Statewide peak load reduction (MW)
Large office (>30,000 sf)	28	0.67	4.5%	0.22	0.8	0.27
Small office (<30,000 sf)	9	0.67	4.5%	0.22	0.3	0.09
Schools	10	1.07	10%	0.34	1.1	0.34
Others	61	0.89	1%	0.29	0.5	0.18
Total	**108**	**N/A**	**N/A**	**N/A**	**2.7**	**0.88**

Figure 1. Statewide Savings from the Daylight Switch Requirement

3.12 New Hourly Baseline for Open Office Lighting

Because the Power Adjustment Factors calculated for this proposal apply only to open offices, we need to create an hourly schedule for this space type in the Alternative Compliance Method (ACM) Manual. The ACM requires a "baseline" hourly schedule for offices, and adjusted hourly schedules that show the effect of the controls for which the PAF is being claimed.

Throughout the energy savings analysis for this measure, we have used the baseline hourly schedule for open offices from the bi-level lighting study that was the basis for the ACM schedules (ADM 2002). Therefore we propose that this same schedule be used as the baseline schedule for open offices in the ACM.

Figure 28 shows the weekday hourly schedule from the ADM study, which we propose to use in the new addition to Table N2-8 (Nonresidential Occupancy Schedules) of the ACM Manual. Because the weekday schedules from the ADM study rely on sparse and inconsistent data, we propose to retain the existing Saturday and Sunday values from the present 'Lights (%) Uncontrolled' part of Table N2-8.

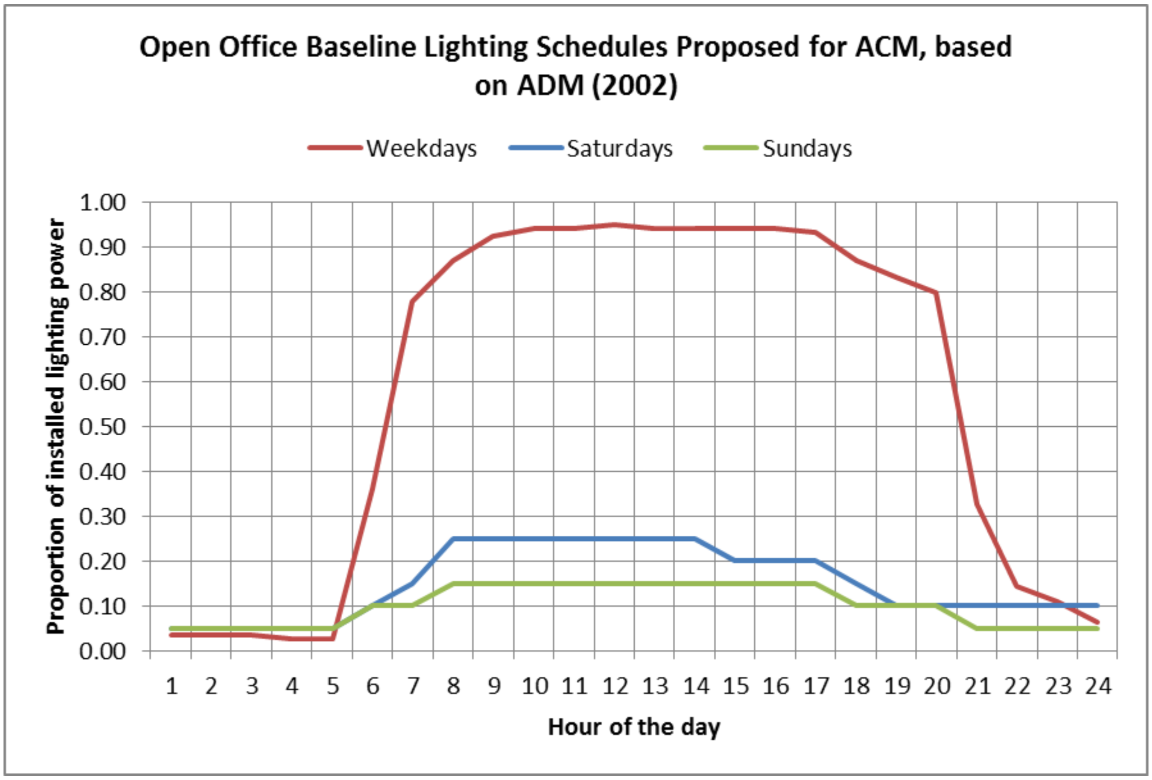


Figure 28. Open Office Baseline Lighting Schedules Proposed for ACM, based on ADM (2002)

Hour	Private offices			Open offices		
	Weekday	**Saturday**	**Sunday**	**Weekday**	**Saturday**	**Sunday**
0	0.00	0.00	0.00	0.04	0.05	0.05
1	0.00	0.00	0.00	0.04	0.05	0.05
2	0.00	0.00	0.00	0.04	0.05	0.05
3	0.00	0.00	0.00	0.03	0.05	0.05
4	0.00	0.00	0.00	0.03	0.05	0.05
5	0.03	0.01	0.00	0.36	0.10	0.10
6	0.08	0.02	0.01	0.78	0.15	0.10
7	0.19	0.05	0.03	0.87	0.25	0.15
8	0.41	0.11	0.07	0.92	0.25	0.15
9	0.56	0.15	0.10	0.94	0.25	0.15
10	0.63	0.17	0.11	0.94	0.25	0.15
11	0.61	0.16	0.11	0.95	0.25	0.15
12	0.58	0.15	0.10	0.94	0.25	0.15
13	0.59	0.15	0.10	0.94	0.25	0.15
14	0.59	0.15	0.11	0.94	0.20	0.15
15	0.58	0.15	0.10	0.94	0.20	0.15
16	0.45	0.12	0.08	0.93	0.20	0.15
17	0.28	0.07	0.05	0.87	0.15	0.10
18	0.17	0.04	0.03	0.83	0.10	0.10
19	0.15	0.04	0.03	0.80	0.10	0.10
20	0.11	0.03	0.02	0.33	0.10	0.05
21	0.08	0.02	0.01	0.14	0.10	0.05
22	0.04	0.01	0.01	0.11	0.10	0.05
23	0.03	0.01	0.00	0.06	0.10	0.05

Figure 29. Proposed Hourly Office Lighting Schedule

3.13 Materials Impacts

This measure reduces the allowed lighting power densities in offices, but this is unlikely to ersult in reduced consumption of materials because the total number of luminaires in any building is likely to be unchanged by this measure. This is because most luminaires are part of a regular grid that is determined by the illuminance and uniformity required for general illumination, not by the requirement for egress and emergency lighting.

This measure also encourages the use of occupancy sensors in open offices, but since this is a voluntary power adjustment factor we have no way to estimate what the penetration of the measure will be, and therefore no way to predict the likely materials impact. However, the impact would be small even if the measure were widely adopted, due to the low materials content of occupancy sensors.

Materials impacts per component are shown in Appendix III—Data for Materials Impacts. Note that the values for mercury and lead content of components (except for lamps) are calculated by using the maximum percent-by-weight values allowed under California law, and so represent a conservative overestimate of the mercury and lead content.

4. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

4.1 Changes to Lighting Power Density (LPD) Allowances

The proposed change affects the LPD for Open Offices

TABLE 146-F AREA CATEGORY METHOD - LIGHTING POWER DENSITY VALUES (WATTS/SF)

PRIMARY FUNCTION		ALLOWED LIGHTING POWER (W/ft²)	PRIMARY FUNCTION		ALLOWED LIGHTING POWER (W/ft²)
Auditorium		1.5 [1]	Laboratory, Scientific		1.4 [4]
Auto Repair		0.9 [2]	Laundry		0.9
Beauty Salon		1.7	Library	Reading areas	1.2
Civic Meeting Place		1.3 [1]		Stacks	1.5
Classrooms, lecture, training, vocational room		1.2	Lobbies	Hotel lobby	1.1 [1]
Commercial and industrial storage (conditioned. & unconditioned.)		0.6		Main entry lobby	1.5 [1]
Commercial and industrial storage (refrigerated)		0.7	Locker/dressing room		0.8
Convention, conference, multipurpose and meeting centers		1.4 [1]	Lounge/recreation		1.1
Corridors, restrooms, stairs, and support areas		0.6	Malls and atria		1.2 [1]
Dining		1.1 [1]	Medical and clinical care		1.2
Electrical, mechanical, telephone rooms		0.7 [2]	Offices	> 250 square feet	~~0.9~~ **0.8**
Exercise center, gymnasium		1.0		≤ 250 square feet	~~1.1~~ **1.0**
Exhibit, museum		2.0	Parking garage	Parking Area	0.2
Financial transactions		1.2 [1]		Ramps and Entries	0.6
General commercial and industrial work	Low bay	0.9 [2]	Religious worship		1.5 [1]
	High bay	1.0 [2]	Retail merchandise sales, wholesale showrooms		1.6
	Precision	1.2 [3]	Tenant lease space		1.0
Grocery sales		1.6	Theaters	Motion picture	0.9 [1]
Hotel function area		1.5 [1]		Performance	1.4 [1]
Housing, Public and Commons Areas	Multi-family, Dormitory	1.0	Transportation Function		1.2
	Senior Housing	1.5	Waiting area		1.1 [1]
Kitchen, food preparation		1.6	All other		0.6

4.2 Exception to Section 146 (a)

A building complies with this section if the actual lighting power density calculated under Subsection (a) is no greater than the allowed indoor lighting power calculated under Subsection (c).

(a) **Calculation of Actual Indoor Lighting Power Density.** The actual indoor lighting power of the proposed building area is the total watts of all planned permanent and portable lighting systems; subject to the following specific requirements and adjustments under Subsections 1 through 4.

EXCEPTION to Section 146(a) Up to ~~0.2~~ 0.3 watts per square foot of portable lighting for office areas shall not be required to be included in the calculation of actual indoor lighting power density.

4.3 Changes to Lighting Power Density (LPD) Allowances, Complete Building Method

TABLE 146-E COMPLETE BUILDING METHOD LIGHTING POWER DENSITY VALUES (WATTS/SF)

TYPE OF USE	ALLOWED LIGHTING POWER
Auditoriums	1.5
Classroom Building	1.1
Commercial and industrial storage buildings	0.6
Convention centers	1.2
Financial institutions	1.1
General commercial and industrial work buildings	
High bay	1.0
Low bay	1.0
Grocery stores	1.5
Library	1.3
Medical buildings and clinics	1.1
Office buildings	~~0.85~~ 0.8
Parking Garages	0.3
Religious facilities	1.6
Restaurants	1.2
Schools	1.0
Theaters	1.3
All others	0.6

4.4 Changes to Power Adjustment Factors (PAFs)

TABLE 146-C LIGHTING POWER ADJUSTMENT FACTORS

<table>
<tr><th colspan="2">TYPE OF CONTROL</th><th>TYPE OF SPACE</th><th>FACTOR</th></tr>
<tr><td colspan="2">Multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D</td><td>Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room.</td><td>0.20</td></tr>
<tr><td colspan="2" rowspan="3">Multi-level occupant sensor (see Note 2) that reduces lighting power at least 50% when no persons are present. May be a switching or dimming (see Note 3) system.</td><td>Hallways of hotels/motels , multi-family, dormitory, and senior housing</td><td>0.25</td></tr>
<tr><td>Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)</td><td>0.15</td></tr>
<tr><td>Library Stacks (maximum 2 aisles per sensor)</td><td>0.15</td></tr>
<tr><td rowspan="3">Occupancy Sensors</td><td>At least one occupancy sensor per 1 to 125 sf, ceiling mounted and shielded/tuned for coverage area</td><td>In open plan offices > 250 sf</td><td>0.4</td></tr>
<tr><td>At least one occupancy sensor per 126 to 250 sf, ceiling mounted and shielded/tuned for coverage area</td><td>In open plan offices > 250 sf</td><td>0.3</td></tr>
<tr><td>At least one occupancy sensor per 251 to 500 sf, ceiling mounted and shielded/tuned for coverage area</td><td>In open plan offices > 250 sf</td><td>0.2</td></tr>
<tr><td rowspan="2">Dimming system</td><td>Manual</td><td>Hotels/motels, restaurants, auditoriums, theaters</td><td>0.10</td></tr>
<tr><td>Multiscene programmable</td><td>Hotels/motels, restaurants, auditoriums, theaters</td><td>0.20</td></tr>
<tr><td colspan="2">Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal. (See Note 1)</td><td>All building types</td><td>0.05</td></tr>
<tr><td colspan="2">Manual dimming of dimmable electronic ballasts. (see Note 3)</td><td>All building types</td><td>0.10</td></tr>
<tr><td colspan="2"></td><td></td><td></td></tr>
<tr><td colspan="2">Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal when used in combination with manual dimming of dimmable electronic ballasts (see Note 1 and 3).</td><td>All building types</td><td>0.15</td></tr>
<tr><td rowspan="2">Combined controls</td><td>Multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D combined with automatic multi-level daylighting controls</td><td>Any space ≤ 250 square feet within a daylit area and enclosed by floor-to-ceiling partitions, any size classroom, corridor, conference or waiting room. The PAF may be added to the daylighting control credit</td><td>0.10</td></tr>
<tr><td>Manual dimming of dimmable electronic ballasts (see Note 3) when used in combination with a multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D.</td><td>Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room</td><td>0.25</td></tr>
</table>

<table>
<tr><td rowspan="10">Automatic multi-level daylighting controls (See Note 1)</td><td rowspan="3">Total primary sidelit daylight areas less than 2,500 sf in an enclosed space and all secondary sidelit areas. (see Note 4)</td><td></td><td colspan="4">Effective Aperture</td></tr>
<tr><td>General Lighting Power Density (W/sf)</td><td>>10% and ≤20%</td><td>>20% and ≤35%</td><td>>35% and ≤65%</td><td>> 65%</td></tr>
<tr><td>All</td><td>0.12</td><td>0.20</td><td>0.25</td><td>0.30</td></tr>
<tr><td rowspan="7">Total skylit daylight areas in an enclosed space less than 2,500 square feet, and where glazing material or diffuser has ASTM D1003 haze measurement greater than 90%</td><td></td><td colspan="4">Effective Aperture</td></tr>
<tr><td>General Lighting Power Density (W/sf)</td><td>0.6% ≤ EA < 1%</td><td>1% ≤ EA < 1.4%</td><td>1.4% ≤ EA < 1.8%</td><td>1.8% ≤ EA</td></tr>
<tr><td>LPD < 0.7</td><td>0.24</td><td>0.30</td><td>0.32</td><td>0.34</td></tr>
<tr><td>0.7 ≤ LPD< 1.0</td><td>0.18</td><td>0.26</td><td>0.30</td><td>0.32</td></tr>
<tr><td>1.0 ≤ LPD < 1.4</td><td>0.12</td><td>0.22</td><td>0.26</td><td>0.28</td></tr>
<tr><td>1.4 ≤ LPD</td><td>0.08</td><td>0.20</td><td>0.24</td><td>0.28</td></tr>
</table>

NOTES FOR TABLE 146-C:

1. PAFs shall not be available for lighting controls required by Title 24, Part 6.
2. To qualify for the PAF the multi-level occupant sensor shall comply with the applicable requirements of Section 119.
3. To qualify for the PAF all dimming ballasts for T5 and T8 linear fluorescent lamps shall be electronic and shall be certified to the Commission with a minimum RSE in accordance with Table 146-D.
4. If the primary sidelit daylight area and the secondary sidelit daylight area are controlled together, the PAF is determined based on the secondary sidelit effective aperture for both the primary sidelit daylight area and the secondary sidelit daylight area.

4.5 In Section 131 (c), a mandatory manual control (switch) in primary sidelit daylight area of spaces with daylight area < 250 sf to control lighting in the daylight area.

Addition to Section 131(c) 2

2. Luminaires providing general lighting that are in or are partially in the skylit daylight area and/or the primary sidelit daylight area shall be controlled as follows:

A. ~~*Primary sidelit and s*~~ **<u>S</u>**kylit daylight areas shall have at least one lighting control that:

i. Controls at least 50 percent of the general lighting power in the ~~*primary sidelit and*~~ skylit daylight areas separately from other lighting in the enclosed space.

ii. Controls luminaires in **<u>skylit</u>** ~~*primary sidelit*~~ areas separately from ~~*skylit*~~ **<u>primary sidelit</u>** areas.

~~*EXCEPTION to Section 131(c) 2A: Primary sidelit and skylit daylight areas that have a combined area totaling less than or equal to 250 square feet within any enclosed space.*~~

<u>B. Primary sidelit daylight areas less than 250 square feet in the following areas shall have an independent switching device that must be manually actuated to energize the lighting in the primary sidelit daylight area. The switching device must be reset by an automatic shut-off control system or a timer switch, or must be a vacancy sensor:</u>

<u>Classrooms, lecture, training, vocational rooms; laboratories; libraries; offices >250sf.</u>

<u>EXCEPTION to Section 131(c)2B: Primary sidelit daylight areas that contain less than 100W of lighting</u>

~~*B*~~**<u>C</u>**. For all skylit daylight areas:

i. The skylit daylight area shall be shown on the plans.

ii. All of the general lighting in the skylit area shall be controlled independently by an automatic daylighting control device that meets the applicable requirements of Section 119.

iii. The automatic daylighting control shall be installed in accordance with Section 131(c)2D.

EXCEPTION 1 to Section 131(c)2B: Where the total skylit daylight area in any enclosed space is less than or equal to 2,500 square feet.

4.6 Changes to ACM Schedules

Addition to Table N2-8 Nonresidential Occupancy Schedules (Other than Retail) of ACM Manual

The following lines are proposed to be added to the existing table.

Lights (%) Uncontrolled	WD	4	4	4	3	3	36	78	87	92	94	94	95	94	94	94	94	93	87	83	80	33	14	11	6
	Sat	5	5	5	5	5	10	15	25	25	25	25	25	25	25	20	20	20	15	10	10	10	10	10	10
Open Office	Sun	5	5	5	5	5	10	10	15	15	15	15	15	15	15	15	15	15	10	10	10	5	5	5	5

Lights (%) Open Office	WD	4	4	4	3	3	36	41	53	66	71	73	70	67	73	73	73	65	50	43	45	20	10	11	6
	Sat	5	5	5	5	5	10	8	15	18	19	19	18	18	19	16	15	14	9	5	6	6	7	10	10
1 Osensor per 1-125 sf	Sun	5	5	5	5	5	10	5	9	11	11	12	11	11	12	12	12	11	6	5	6	3	3	5	5

Lights (%) Open Office	WD	4	4	4	3	3	36	38	57	70	77	79	78	72	78	80	81	73	54	46	48	21	10	11	6
	Sat	5	5	5	5	5	10	7	16	19	20	21	20	19	21	17	17	16	9	6	6	6	7	10	10
1 Osensor per 126-250 sf	Sun	5	5	5	5	5	10	5	10	11	12	13	12	12	12	13	13	12	6	6	6	3	3	5	5

Lights (%) Open Office	WD	4	4	4	3	3	36	52	68	83	89	90	87	93	88	88	90	85	62	53	52	22	11	11	6
	Sat	5	5	5	5	5	10	10	20	22	24	24	23	22	23	19	19	18	11	6	7	7	7	10	10
1 Osensor per 256-500 sf	Sun	5	5	5	5	5	10	7	12	13	14	14	14	13	14	14	14	14	7	6	7	3	4	5	5

4.7 Code Language Proposed by the California Energy Commission

Below is the text of the code language proposed by the California Energy Commission for sections 131 and 146. This language was sent by the CEC to the California investor-owned utilities Codes and Standards Team on August 17, 2011.

4.7.1 Changes to Lighting Power Density (LPD) Allowances

TABLE ~~146-F~~ **146-C** AREA CATEGORY METHOD - LIGHTING POWER DENSITY VALUES (WATTS/SF)

PRIMARY FUNCTION		ALLOWED LIGHTING POWER (W/ft^2)
Auditorium		1.5 [1]
Auto Repair		0.9 [2]
Beauty Salon		1.7
Civic Meeting Place		1.3 [1]
Classrooms, lecture, training, vocational room		1.2
Commercial and industrial storage (conditioned. & unconditioned.)		0.6
Commercial and industrial storage (refrigerated)		0.7
Convention, conference, multipurpose and meeting centers		1.4 [1]
Corridors, restrooms, stairs, and support areas		0.6
Dining		1.1 [1]
Electrical, mechanical, telephone rooms		0.7 [2]
Exercise center, gymnasium		1.0
Exhibit, museum		2.0
Financial transactions		1.2 [1]
General commercial and industrial work	Low bay	0.9 [2]
	High bay	1.0 [2]
	Precision	1.2 [3]
Grocery sales		1.6
Hotel function area		1.5 [1]
Housing, Public and Commons Areas	Multi-family, Dormitory	1.0
	Senior Housing	1.5
Kitchen, food preparation		1.6

PRIMARY FUNCTION		ALLOWED LIGHTING POWER (W/ft^2)
Laboratory, Scientific		1.4 [4]
Laundry		0.9
Library	Reading areas	1.2
	Stacks	1.5
Lobbies	Hotel lobby	1.1 [1]
	Main entry lobby	1.5 [1]
Locker/dressing room		0.8
Lounge/recreation		1.1
Malls and atria		1.2 [1]
Medical and clinical care		1.2
Offices	> 250 square feet	~~0.9~~ **0.75**
	≤ 250 square feet	~~1.1~~ **1.0**
Parking garage	Parking Area	0.2
	Ramps and Entries	0.6
Religious worship		1.5 [1]
	Retail merchandise sales, wholesale showrooms	1.6
Tenant lease space		1.0
Theaters	Motion picture	0.9 [1]
	Performance	1.4 [1]
Transportation Function		1.2
Waiting area		1.1 [1]
All other		0.6

4.7.2 Exception to Section 146 (a)

(a) Calculation of Actual Indoor Lighting Power Density. The actual indoor lighting power of ~~the~~ **all** proposed building areas is the total watts of all planned permanent and portable lighting systems; subject to the following specific requirements and adjustments under Subsections 1 through 4.

EXCEPTION to Section 146(a): Up to ~~0.2~~ **0.3** watts per square foot of portable lighting for office areas shall not be required to be included in the calculation of actual indoor lighting power density.

4.7.3 Changes to Lighting Power Density (LPD) Allowances, Complete Building Method

TABLE ~~146-E~~ **146-B** COMPLETE BUILDING METHOD LIGHTING POWER DENSITY VALUES (WATTS/SF)

TYPE OF USE	ALLOWED LIGHTING POWER
Auditoriums	1.5
Classroom Building	1.1
Commercial and industrial storage buildings	0.6
Convention centers	1.2
Financial institutions	1.1
General commercial and industrial work buildings	
High bay	1.0
Low bay	1.0
Grocery stores	1.5
Library	1.3
Medical buildings and clinics	1.1
Office buildings	~~0.85~~ **0.8**
Parking Garages	0.3
Religious facilities	1.6
Restaurants	1.2
Schools	1.0
Theaters	1.3
All others	0.6

4.7.4 Changes to Power Adjustment Factors (PAFs)

TYPE OF CONTROL		TYPE OF SPACE	FACTOR
To qualify for any of the Power Adjustment Factors in this table, the installation shall comply with the applicable requirements in Section 146(a)2			
Multi-level occupant sensor (see Note 2) combined with multi-level circuitry and switching in accordance with Section 146(a)2D		Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room.	0.20
Occupancy Sensors	**At least one occupancy sensor per 1 to 125 sf, ceiling mounted and shielded/tuned for coverage area**	**In open plan offices > 250 sf**	**0.4**
	At least one occupancy sensor per 126 to 250 sf, ceiling mounted and shielded/tuned for coverage area	**In open plan offices > 250 sf**	**0.3**
	At least one occupancy sensor per 251 to 500 sf, ceiling mounted and shielded/tuned for coverage area	**In open plan offices > 250 sf**	**0.2**
Dimming system	Manual	Hotels/motels, restaurants, auditoriums, theaters	0.10
	Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters	0.20
With Tier 2 RSE ballast	Demand Responsive Control	All building types less than 10,000 square feet	0.05
	Manual Dimming		0.10
	Demand Responsive Control plus Manual Dimming		0.15
Combined Controls	Manual dimming of Tier 2 certified ballasts when used in combination with a multi-level occupantsensor	Any area ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, conference or waiting room	0.25

4.7.5 In Section 131 (c), a mandatory manual control (switch) in primary sidelit daylight area of spaces with daylight area < 250 sf to control lighting in the daylight area.

2. Luminaires providing general lighting that are in or partially in the Skylit Daylit Zones and the Primary Sidelit Daylit Zones shall be controlled independently by fully functional automatic daylighting controls that meet the applicable requirements of Section 119, and the applicable requirements below:

A. All Skylit Daylit Zones and Primary Sidelit Daylit Zones shall be shown on the plans.
B. Luminaires in the Skylit Daylit Zone shall be controlled separately from those in the Primary Sidelit Daylit Zones
C. Luminaires that fall in both a Skylit and Primary Sidelit Daylit Zone shall be controlled as part of the Skylit Daylit Zone

4.8 Differences between the Recommended and Proposed Language

This section highlights the key differences between the language recommended by the IOU team (Sections 4.1 through 4.6) and the language proposed by the CEC (Section 4.7).

CEC language reduces Allowed Lighting Power Density for Offices over 250 square feet

The proposed Lighting Power Density for offices over 250 square feet is 0.75 W/sf, instead of the 0.8 W/sf recommended by the IOU CASE team.

CEC language revises requirements for daylighting

The proposed daylighting requirements in the new section 131(d) will require automatic daylighting control in all primary sidelit and skylit daylit zones. This change makes the recommended requirement for a control switch located in the daylit zone obsolete.

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Appendix I—Literature Review

5.1 Mahone et al. 2004. Effectiveness of Bi-Level Switching in Offices, Retail Space and Classrooms.

This paper summarizes the results of work originally conducted in 2001, in support of a Title 24 code change, looking at the use of bi-level switching in several building types. Calculated energy savings were based on an assumption that, in comparison to single-level (simple all-on / all-off switching), bi-level circuits were saving energy whenever only one of the circuits (rather than both) was energized. The findings of this paper are relevant to proposal A2 in the introduction.

The paper presents measured data on bi-level circuit use in a total of 256 open and private offices, retail and classroom spaces in 79 buildings. All the spaces had three-lamp fixtures, resulting in the four possible conditions shown in the table below.

Type of Space	Open office	Private office	Classroom
Both Switches OFF	10.4%	30.3%	57.6%
Both Switches ON	65.8%	47.9%	34.4%
High-Wattage Switch Only ON	14.9%	14.5%	5.3%
Low-Wattage Switch Only ON	8.9%	7.3%	2.8%

Figure 30. Bi-level switching, calculated savings from Mahone et al.

The highest savings were in private offices (22%), with open offices showing 16% savings. Classrooms showed only 8% savings, presumably because teachers seldom chose to keep some of the lighting off when the classroom was occupied.

The difference between private offices and open-plan offices is consistent with the findings of Moore et al., that occupants do not feel confident to reduce the light level when others are present in the space, i.e. that controls that over smaller groups of people are likely to result in greater energy savings, as well as perhaps in greater subjective perception of control and comfort. The study did not analyze whether the savings were correlated with the size of the controlled lighting zone, for open offices.

The study found that savings from bi-level switching in open offices were reduced in spaces that had high levels of daylight. Perhaps surprisingly, private offices did not show this reduction in savings due to daylight. The paper does not discuss whether this result was statistically significant.

5.2 Pacific Gas and Electric Company. 2009. High Efficiency Office: Low Ambient/ Task Lighting Pilot Projects

This pair of pilot projects (in a large open plan office and a smaller mixed plan office) monitored the patterns of use and the energy consumption of two "low ambient / task" lighting systems. In both pilots, an existing suspended indirect lighting system was relamped with lower output lamps to a level of approximately 20 footcandles, and the light level was supplemented locally by adjustable LED task lights.

The monitored energy use showed a 37% reduction and 49% reduction in energy use compared to an estimated Title 24 baseline, in the large and small offices respectively. The lighting energy use intensities were 1.7 and 2.0 kWh/sf/yr respectively, compared to approximately 3 to 4 kWh/sf/yr for a typical lighting system compliant with Title 24 2008. The larger reduction in the small office was due in part to the replacement of some energy-intensive decorative lighting with dramatically more efficient LED fixtures.

In both pilots, user-controlled task lighting was switched on for 30 to 40 percent of the time during the working day, though the task lighting accounted for only 0.1 W/sf of the total lighting load of approximately 0.65 W/sf. Most of the lighting energy use reduction came from substitution overhead lighting for task lighting (and the consequent reduction in required lumens) rather than from people manually switching off their task lights.

Occupant satisfaction with the lighting was very high; in one of the two buildings *all* the occupants preferred the new lighting to the old lighting.

The large office pilot included a test of demand response functionality, which switched the ambient light level to 10 footcandles for two hours shortly after lunch, then back up again. Many occupants did not notice the change (probably due to high levels of daylight), and of those who did, all of them thought that the demand response event was acceptable as a way to reduce power in an emergency.

5.3 Rubinstein. 2009. Achieving 60-80% Lighting Energy Savings in Open Plan Offices With Intelligent Workstation Lighting (Unpublished study)

In this unpublished pilot project, Rubinstein installed suspended direct/indirect luminaires over each workstation in an open plan office. Luminaries were positioned carefully over each workstation, to cast most of their light on to the task area. The direct component of the luminaires was controlled by an occupancy sensor that covered only the single cubicle directly beneath the luminaire. The indirect component was left permanently switched on during working hours.

Similarly to PG&E 2009a and 2009b, this approach saved energy mostly by tailoring the light distribution of the luminaires closely to the task area, and achieved secondary Secondary savings by occupancy sensor control of the direct component.

The achieved lighting energy use was slightly lower than either of the two PG&E pilot studies, at 1.4 kWh/sf/yr (compred with 1.7 and 2.0 for the PG&E pilots). Occupant satisfaction with the lighting was high, despite the experimenter's subjective report of a patchy appearance to the ceiling.

5.4 Escuyer and Fontoynont, 2001. Lighting Controls - A Field Study of Office Workers' Reactions.

This paper reports a qualitative study of the acceptability of lighting control systems by 41 French office workers, in three real office buildings. The first building had direct/indirect lighting from freestanding luminaires, the second has recessed "basket"-type fixtures while the third had recessed fixtures with specular parabolic louvers. The first building had manual "scene" controls, set using a hand held infra-red controller. The second had scene controls but also a default light level set by a photocontroller (the scene controls functioned as an override to the automatically set light level). The third building had a fully automatic photocontrol system with no manual override. Thus, the three buildings span a range of control from fully automatic to full manual, with the second building having both manual and automatic controls.

The occupants reaction to controls was confounded by the fact that the occupants in the first and second buildings (with the direct/indirect luminaires) reacted positively to their lighting, whereas the occupants in the third building (with recessed fixtures) were less satisfied; one quarter of them said that they suffered glare from the fixtures.

In the first building, 21% of the occupants said that they dimmed or increased the light level during the day. 37% did not touch their lighting controls at all, and 42% said that they switched their lights off when daylight was sufficient (total is 100%). In building B 83% of occupants said that they dimmed or increased the light level during the day. People added, on average, "between [15 and 40 footcandles] of artificial light on average to the lighting at their desk"; no similar figure is given for building B. The monitored data showed that people did not adjust their lighting as frequently as they said they did.

The authors report that 69% of the occupants in the buildings with automatic dimming photocontrols "had not noticed any dimming or increasing of the light levels". Occupants were also not annoyed by the occupancy sensor controls. The paper does not describe exactly how the occupancy controls were set up.

Fontoynont found that "Some respondents, in both buildings, tended to feel that too much light [came] 'from above'", and wanted to reduce their ambient light levels. Note that the ambient light levels were 50-60 fc in two buildings, and 70-90 fc in the third.

There was a wide variety of preferences for the "ideal lighting system". 22% of occupants wanted fully automatic lighting, 29% wanted fully manual.

"The preferences of people as regards the illuminance level greatly varied", and "people for [whom] th essential activity was working on the computer tended to choose low illuminances (100-300lux)". Note that this study was conducted in 2000, before bright flat panel displays were available, and when computer screen luminances were typically 80-150 cd/m^2.

This study echoes the results of Tenner (1997) and Hunt (1980) regarding the high degree of variation between individual occupants' choice of light level, and the potential for energy savings as a result: "Many people added less than [28 fc] of artificial light on the desktop, even in workplaces where daylight illuminances were mostly low ([0-10 fc])."

The researchers also found that "Manual dimming was more likely to produce conscious satisfaction [than automatic dimming alone]", which echoes the finding of HMG (2006) that automatic photocontrol systems are likely to function better when combined with manual override controls.

5.5 Hunt, D. 1980. Predicting artificial Lighting use - a method based upon observed patterns of Behaviour.

In a previous paper (Hunt 1979), Hunt conducted a meta-analysis of six previous switching studies, and in this paper presents a probit-based switching probability function that predicts the likelihood that someone will switch on the lights when entering an office or classroom, based on the minimum daylight illuminance in the room when they enter. Hunt found that minimum working plane illuminance accounted for 67% of the variation (R^2) in the probability of switching. He included another variable (main windows orientation) in his model to account for some of the remaining variation.

The illuminance at which 50% of people switch on the lights is 50 lux (around 5 fc). 10% of people will not switch the lights on even if there is only 2 fc in the space, but a different 10% of people will still switch the lights on even if there is 200 lux (around 20 fc). Very few people switch the lights on at over 500 lux (50 fc). Hunt's probability distribution clearly shows the large variation in personal preference for ambient light levels, and this study was conducted in 1980, before most people were conscious of a need to reduce energy consumption, so it's possible that today's occupants may be more motivated to leave their lights off than Hunt's subjects.

Hunt did not study off-switching behavior, because "People tend to switch on the lights if needed only at times when entering a space, and they rarely switch off the lights until the space becomes completely empty...a very small amount was observed in the field studies."

Hunt gives "switch-on probability" contours for various average daylight factor values and times of day, which allow easy prediction of the approximate likelihood of lights being manually switched on.

Hunt's finding that lights are switched on almost exclusively by people entering a space, shows that the "granularity" of control, i.e. the size of controlled spaces, makes a big difference to the likelihood of lights being switched on, and therefore to the lighting energy use of the space.

Hunt's findings also provide the basis for a logical model of manual switching probability in multi-person offices. It would be straightforward in a future study to use statistical software such as "Crystal Ball" to predict the likelihood of *someone* in a multi-person office switching on the lights on entry, given a random sample of occupants in a multi-person office.

5.6 Jennings, Rubinstein, DiBartolomeo, Blanc. 2000.Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed

This paper deals only with perimeter private offices which are daylit, so is not relevant to this literature review.

5.7 Maniccia, Rutledge, Rea and Morrow. 1998. Occupant Use of Manual Lighting Controls in Private Offices.

This paper deals only with private offices, most of which were daylit. The daylit offices are not relevant to this literature review, but the paper gives statistics for the "interior" (non-daylit) offices which are relevant.

This study was intended to analyze the incremental effect of adding manual control to offices that had automatic lighting controls. The experimental design divided the occupants into three kinds of lighting controls—a "manual on" group in which dimmable office lighting had to be manually switched on; an "auto restore" group in which dimmable lighting was automatically restored to its previous level by occupancy sensor control when someone entered the space; and an experimental control group for whom no advanced controls were installed. The second experimental variable was the type of dimming control provided—either a dimmer by the office door, or a personal dimmer at each desk.

The manual-on group dimmed their lights for 20 percent of the time, whereas the auto-restore group dimmed their lights for between 29 and 49 percent of the time (presumably because the lights auto-restore at the previous dimmed level, rather than requiring the occupant to manually restore the lights to their preferred dimmed level).

The location and type of dimming control also affected energy use; occupants adjusted their lights significantly more frequently when a convenient desk-mounted dimming control was provided. Unfortunately the paper does not analyze the effect of the personal dimmer on lighting energy use, but more active use of lighting controls is likely to mean lower energy use.

For the interior offices, savings due to people overriding their lights off were negligible (1%) as expected, and the savings due to the addition of manual dimming controls was 6%, compared to having the lights on full during work hours. These savings were in addition to the 43% savings achieved by occupancy sensor controls in the private offices (not that this savings figure is much higher than the 25% reported as being typical in LRC (2003).

Over the course of the observation period, 74% of people manually dimmed their lights at least once. Although, among those people who did dim their lights, there was an average of only one adjustment every 3.9 days; this long period is due in part to the auto-restore system that "remembers" dimming settings,removing the need to occupants to dim their lights every time they return to their desk.

The study found that offices were occupied on average for 4 hours and 36 minutes per day, or 46 percent of a ten-hour work day (sample of 58). This is likely to be a good estimate of a statewide average occupancy for a workspace, because at this particular test building *all* the offices were private offices, so there was no bias toward managers or professionals having private offices, as there would be in most buildings, with the associated bias toward those workers being more mobile during the work day. Note that this occupancy period is *as measured by an occupancy sensor with a 20-minute time delay*, so the actual occupied period is slightly less than the period quoted. Also, note that offices that were used for less than 5 hours per week were removed from the data set, so vacant offices were not included in this average.

5.8 Moore et al. 2002. A field study of occupant controlled lighting in offices. Lighting Res. Technol. 34,3 (2002) pp. 191–205

This paper reports a study of 14 open-plan offices equipped with various kinds of occupant controls. Workstation lighting conditions were recorded at intervals throughout a year, to take account of the effects of daylight. The results, in keeping with other studies, showed that occupants chose a wide range of workstation illuminance levels, many significantly below engineering recommendations. On average, luminaire were consuming only 55% of thehri rated power.

The type of manual controls provided had a significant effect on energy consumption. The lowest luminaire outputs were in buildings where the lighting control system reset the lighting automatically to a low default level The size of luminaire control groups, and the location of control devices (close to or far away from occupants) were both statistically associated with lower luminaire output.

5.9 Moore et al. 2003a, A qualitative study of occupant controlled office lighting. Lighting Res. Technol. 35,4 (2003) pp. 297–317

This study is a qualitative addendum to Moore et al. (2002). It investigated whether the reduced illuminance levels found in the previous paper caused lower subjective assessments of lighting quality than were achieved at full luminaire output. It found that occupants "on the whole had positive perceptions of lighting quality, strongly suggesting that the significant energy savings previously shown to be attributable to systems were not achieved at the expense of occupant comfort.", i.e. that providing occupants with high levels of manual control does not lead to a degradation in subjective lighting quality for other occupants of the same space.

5.10 Moore et al. 2003b. Long-term patterns of use of occupant controlled office lighting. Lighting Res. Technol. 35,1 (2003) pp. 43–59

This study was a long-term extension to the short-term monitoring carried out in Moore et al. (2002). the long-term results confirmed the short-term results. On average over the course of the year, the 45 occupants who took part in the study chose a mean working plane illuminance of only 26fc, with individual averages ranging from 9fc to 70fc. The study also illustrated that occupants in very similar working conditions, carrying out very similar tasks exhibit very different preferences for levels of electric light, which supports the hypothesis that energy savings can be achieved by taking advantage of the inherent variation in people's preferred light levels.

Unlike Newsham et al. (2008) and Hunt (1979, 1980), Moore et al. (2003b) did not find a strong relationship between daylight availability and the manual switching of luminaires. They found, on the contrary, that switching on luminaires was a "habitual" activity, seemingly unaffected by time of day or season of the year.

5.11 Moore et al., 2004. Conflict and Control, the Use of Addressable Lighting in Open Plan Office Space.

This paper assesses occupants self-reported experiences with using locally addressable dimmable lighting systems in 14 open plan office buildings. Of 183 occupants interviewed, two-thirds reported having avoided using lighting controls due to "fear of conflict with others", and almost one quarter reporting that this was a "frequent" or "towards frequent" occurrence.

Size of control group ranged from 1 to 6 luminaires. Size of control group was found to be correlated with the experience of conflict (significant at the 95% level), but not however with the avoidance of using controls,

The authors concluded that people appreciate control of their lighting, but that control can be *too* fine-grained if the light from one person's controlled luminaire falls into another person's workspace--"disturbance caused by others switching was a significant contributor to conflict" in spaces where the control zones were small (3 or fewer luminaires). "Thus it would appear that systems would benefit from attention to luminous distribution, particularly trying to prevent overspill of light to areas outside the local control group. Current designs based upon unitary switching use overlapping distributions of light for modeling and uniformity purposes, this may not be the most appropriate approach to design for locally dimmable systems. It may in fact be necessary to divorce task lighting from peripheral lighting."

The authors found that experience of conflict was *not* related to control group size, i.e. people were not more likely to experience conflict when control groups were larger. However, the likelihood of conflict *was* significantly related to the location of the control device—people whose controllers were located in their workspace were less likely to report conflict than those whose controllers were located at a distance from their desk (wall or column mounted).

The authors did not directly analyze whether less or more energy was used with more these controls. Because the lighting conditions and other contextual factors were different at the 13 sites, the effect of control group size would probably have been overwhelmed by those other factors.

5.12 LRC (Lighting Research Center). 2002. **Reducing Barriers to the Use of High *Efficiency* Lighting Systems. Final Report: Year 2.**

The Lighting Research Center compiled 26 research papers, case studies and manufacturer claims of energy savings for the energy savings from occupancy sensors. In some cases the research studies presented data from several sites, so the LRC report actually covers more than 50 individual data points.

Their analysis divided the spaces into three categories:

- Private spaces (mostly private offices), savings averaged 25%, at least 17 data points;
- Shared spaces with scheduled use (e.g. classrooms), savings averaged 30%, at least 11 data points;
- Shared spaces with sporadic use (e.g. open-plan offices, corridors, bathrooms), savings averaged 40%, at least 23 data points.

The results show that shared spaces achieved higher savings than private spaces. This may be surprising because private spaces such as private offices are generally unoccupied for more hours per day, so the savings from occupancy sensors could be expected to be higher. The LRC paper does not However, it should be considered that the lights in private offices are frequently left off or switched off by the occupants on leaving, whereas the lights in shared spaces are much less likely to be manually switched off.

5.13 Newsham, G, Aries, M, Mancini, S, Faye, G. 2008. **Individual Control of Electric Lighting in a Daylit Space.** ***Lighting Research and Technology, Vol. 40, No. 1, 25-41 (2008)***

In this laboratory study, 40 participants were prompted every 30 min during an entire work day to use dimming control over electric lighting to choose their preferred light level in a private office. Illuminances and luminances were recorded just before and just after each prompt. There was a wide variation in chosen light levels between individuals, and there was a strong (inverse) relationship between daylight and manual dimming level. On average, manual dimming controls reduced energy use by 25% compared to a baseline of full light output; though unfortunately this is only given as a combined figure, for both daylit and non-daylit periods; the achieved reduction through dimming for *non*-daylit periods only is not provided. The lighting system delivered 50fc at the desktop.

6. Appendix II—Non-residential Construction Forecast Details

6.1 Summary

The Non-Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from Dodge construction database, the demand forecast office future generation facility planning data, and building permit office data.

All CASE reports should use the statewide construction forecast for 2014. The TDV savings analysis is calculated on a 15 or 30 year net present value, so it is correct to use the 2014 construction forecast as the basis for CASE savings.

6.2 Additional Details

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ) as well as building type (based on NAICS codes). The 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). HMG has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and additional construction. Total construction is the sum of all existing floor space in a given category (Small office, large office, restaurant, etc.). Additional construction is floor space area constructed in a given year (new construction); this data is derived from the sources mentioned above (Dodge, Demand forecast office, building permits).

Additional construction is an independent dataset from total construction. The difference between two consecutive years of total construction is not necessarily the additional construction for the year because this difference does not take into consideration floor space that was renovated, or repurposed.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has provided CASE authors with the ability to aggregate across multiple building types. This tool is useful for measures that apply to a portion of various building types' floor space (e.g. skylight requirements might apply to 20% of offices, 50% of warehouses and 25% of college floor space).

The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022 (or 10-12 years in the future), and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure). The CEC non-residential construction forecast is the best publicly available data to estimate statewide energy savings.

6.3 Citation

"NonRes Construction Forecast by BCZ v7"; Developed by Heschong Mahone Group with data sourced August, 2010 from Abrishami, Moshen at the California Energy Commission (CEC)

Appendix III—Data for Materials Impacts

This section sets out the raw data used to calculate the materials impacts of the proposed measure (see Overview: Section F), and the underlying data and assumptions.

Component	Weight per component (lbs)					
	Mercury	Lead	Copper	Steel	Plastic	Others (Identify)
3-lamp magnetic ballast for linear fluorescent, steel case	0.0035	0.0035	0.20	3.30	0	0
3-lamp electronic ballast for linear fluorescent, steel case	0.0025	0.0025	0.15	2.35	0	0
3-lamp electronic ballast linear fluorescent, plastic case	0.0005	0.0005	0.15	0.1	0.25	0
occupancy sensor	0.0005	0.0025	0.15	0.1	0.25	0
#12 power wiring, 100'	0	0	2	0	0	0
Cat 5 control wire, 100'	0	0	0.94	0	0	0
Linear fluorescent or compact fluorescent lamp	0.00001	0	0	0	0	0
35W PAR30 CMH lamp	0.0055	0	0	0	0	0
70W PAR30 CMH lamp	0.022	0	0	0	0	0
150W T6 CMH lamp	0.031	0	0	0	0	0

Figure 31. Materials Content of Typical Lighting Components, by Weight

Note that in Figure 31 the materials weights for an occupancy sensor are the same as those for an electronic ballast with a plastic case. We made this assumption because these two components are very close to the same size, and both contain electronics that control electrical power, within an insulated plastic case.

Mercury and Lead

The figures for mercury and lead were calculated in one of two ways. For electrical components (ballasts and occupancy sensors) they were calculated by using the maximum allowed percentages, by weight, under the European RoHS[3] requirements, which were incorporated into California state law effective January 1, 2010. The California Lighting Efficiency and Toxics Reduction Act applies RoHS to general purpose lights, i.e. "lamps, bulbs, tubes, or other electric devices that provide functional illumination for indoor residential, indoor commercial, and outdoor use." RoHS allows a maximum of 0.1% by total product weight for both mercury and lead. In practice the actual percentage of mercury and lead in these components may be very much *less* than these values, so the values in the table are conservative overestimates. Values for the total weight of these components (from which the lead and mercury values are calculated) were obtained from the online retailer

[3] http://ec.europa.eu/environment/waste/weee/index_en.htm

www.ballastshop.com, and corroborated by the Lighting Research Center's Specifier Report on electronic ballasts[4].

For lamps, the mercury content of the lamp is almost always given by the lamp manufacturer in product cut sheets. The figures in the table are all based on high-volume products from the online catalog for Philips lighting. The amount of lead in a lamp is assumed to be negligible; no information on the presence of these substances in lamps could be found either from product manufacturers or from online sources.

Copper, Steel and Plastics

For ballasts, the amount of copper and steel was estimated by comparing the weight of the electronic plastic-cased ballast with the electronic steel-cased ballast, and assuming that the difference in weight was due to the steel case (i.e., that the electronics inside the two ballasts were the same). For the plastic ballast, a little more than half the weight of the component was assumed to come from the case, with the remaining weight being made up by copper and steel. For the magnetic ballast, the weights for copper and steel were scaled up from the electronic ballast, in proportion to the increase in total component weight (from 2.5lbs up to 8lbs).

For wiring, the weight of copper was calculated using the cross-sectional area of the conductor wires, and multiplying this by the nominal length (100') and by the density of copper (8.94 g/cm^3). The area of the conductor wires was obtained from online sources[5].

For lamps, the amount of copper, steel and plastic in a lamp is assumed to be negligible; no information on the presence of these substances in lamps could be found either from product manufacturers or from online sources.

[4] http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SREB2.pdf

[5] http://en.wikipedia.org/wiki/American_wire_gauge, and http://en.wikipedia.org/wiki/Cat_5