CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Automated Lighting Controls and Switching Requirements in Warehouses and Libraries

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team September 2011

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1. Overview

Description	The proposed measure is to require the installation of occupancy sensors in warehouse aisle ways and open spaces, and library stack aisles throughout California. The occupancy sensors are to be configured to switch off at least one-half of the installed lighting wattage, and to be in accordance with Section 119 the occupancy sensor time delay should be no longer than 30 minutes. In addition to the warehouse study, we conducted an additional study into the use of automatic occupancy controls in library stack aisles. This analysis was conducted in response to stakeholder requests at the May 4th 2011 (third) stakeholder group meeting. For clarity, the methodology and analysis for library stacks are presented in an addendum (Section 5).
Type of Change	**Mandatory Measure** The change would add and modify mandatory requirements for automatic lighting controls and switching. This change would not significantly change the scope or direction of the current Standards. This change would not require implementation of systems or equipment that are not already readily available on the market and for use in the proposed applications. These systems are already regulated and included in the current Standards for different occupancy types, and are an option in the Power Adjustment Factor table for warehouses. The Standards and Manuals language would be modified in order to include the new requirements. The change would require an addition to Section 131.

Energy Benefits	The energy savings benefits of this measure are reduced power loads used in lighting end use. Because warehouses and libraries are operated during the afternoon, peak demand will also be reduced. Savings estimates are based on measured lighting and occupancy patterns. The table below shows annual savings in each occupancy type, in kWh/ft^2/yr, cumulative statewide savings in GWh/yr, and cumulative statewide peak load reduction in MW/yr. The measure is expected to save 83.1 GWh/yr, and to reduce peak load by 8.55 MW. Energy benefits broken down by individual spaces are as follows:

Space Type	Energy savings per square foot (kWh/ft^2/yr)	Statewide energy savings (GWh/yr)	Statewide peak load reduction (MW)	Statewide TDV Savings (TDV$)
Aisle Freezer	1.17	1.0	0.16	$ 2,600,000
Aisle Non-refrigerated	1.50	69.5	8.02	$ 153,900,000
Aisle Refrigerated	1.82	3.1	0.49	$ 7,600,000
Open Non-refrigerated	1.96	30.2	1.23	$ 66,200,000
Open Refrigerated	1.75	1.0	0.10	$ 2,500,000
Open Freezer	1.96	0.6	0.02	$ 1,200,000
Warehouse Total	**1.62**	**105.4**	**10.03**	**$ 234,000,000**
Library Stack	**1.08**	**0.07**	**0.04**	**$ 2,600,000**
Measure Total	**NA**	**105.5**	**10.1**	**$ 236,600,000**

The total statewide TDV energy reduction is 2,105,000,000 kBTU.

Non-Energy Benefits	This measure does not provide non-energy benefits, except for the intangible benefit of making building occupants more aware of energy use.

Environmental Impact

The only significant environmental impacts of the measure are those related to the energy savings.

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

	Mercury	Lead	Copper	Steel	Plastic	Others (Identify)
Statewide impact	93(I)	93(I)	166328(I)	18530(I)	46325(I)	NC(I)

Water Quantity and Quality Increase, (Decrease), or No Change (NC):

	Water Savings (or Increase) (Gallons/Year)	**Mercury Content**	**Other Contaminants, Specify**
Per Unit Measure[1]	NC	NC	NC
Per Prototype Building[2]	NC	NC	NC

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

	NOX	**SOX**	**CO**	**PM10**	**CO2**	**VOC**
Per Unit Measure[1]	0.00026	0.0015	0.00037	0.00012	0.94	NC
Per Prototype Building[2]	0.58	3.5	0.84	0.27	2110	NC

Technology Measures

Measure Availability and Cost:

Technology to satisfy the proposed measure is readily and widely available from multiple manufacturers. Occupancy controls have been on the market for a substantial period of time. Acceptance and success of this technology is widely acknowledged. The principal manufacturers are: 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. The market is available to supply adequate equipment to meet the requirements of this measure; of the nearly three (3) dozen distributors contacted, all were prepared to fill orders next day. A thorough market survey effort discovered that 92 distinct models are available to serve this measure's purpose, and the two most commonly suggested models were CMR-9 made by SensorSwitch and W-*A (where * is 500, 1000 or 2000 ft^2 coverage area) made by Wattstopper.

Useful Life, Persistence and Maintenance:

Life of ceiling mounted occupancy sensors is identified by Title 24 as 15 years (AEC & CEC, 2005). We have assumed that the energy savings associated with this technology will be sustained for the life of the product. Stakeholders confirmed that, when properly installed, there are no maintenance costs related to this technology except for initial commissioning.

Performance Verification	The proposed measure would require commissioning during initial installation of the system by an electrician. According to a 2007 survey of contractors conducted by Lighting Controls Association and referenced in this report, commissioning of occupancy sensors is already standard practice and is well understood by contractors. Therefore we do not believe that an acceptance test should be required. Furthermore, the CA utilities, the California Energy Commission, and others have implemented an extensive program of contractor training in lighting controls installations, known as California Advanced Lighting Controls Training Program (www.calctp.org); this is expected to improve the level of practice in lighting controls installation.
Cost Effectiveness	The measure is cost effective with a payback period of approximately one to three years. See section 3.7.2 for details.
Analysis Tools	The benefits from this measure can be quantified using the current reference methods. The installation and operation of this measure, along with impacts on energy consumption can be modeled in the current reference methods and analysis tools. However since this measure is proposed as mandatory, analysis tools are not relevant since the measure is not subject to whole building performance trade-offs.
Relationship to Other Measures	The proposed measure would eliminate the current (2008) Power Adjustment Factor of 0.2 for occupancy sensors in spaces >250sf: PAF of 0.2 for "Multi-level occupant sensor combined with multi-level circuitry and switching in accordance with Section 146(a)(2)(D)", in "Any space >250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room." The proposed measure would also eliminate the PAF of 0.15 for occupancy sensors in library stacks.

2. Methodology

This section summarizes the methods we used to collect data for this CASE report. We gathered data from a wide variety of sources and conducted several different kinds of analyses, so this section sets out our broad methodology and describes how those methods contributed to the overall recommendations.

Note that, during the California Energy Commission's pre-rulemaking proceedings, we were asked to include a technical and cost-effectiveness analysis for requiring bi-level occupancy sensors in library stacks as well as for warehouse aisles. The methodology for the analysis of library stacks is presented in an addendum, in Section 5.

2.1 Data on Lighting Energy Use

In order to assess the savings potential from this measure, HMG asked occupancy sensor manufacturers for any recorded data on occupancy and lighting use. Watt Stopper and Sensor Switch were specifically contacted because HMG knew that both of these control manufacturers have a practice of providing loggers to interested parties for the use of logging occupancy and light status within their own buildings. Sensor Switch was able to provide HMG with a data logger set that included over 1,300 loggers which were installed in 51 different warehouses. This data was gathered by customers of Sensor Switch in order to monitor energy use and quantify savings that Sensor Switch's occupancy sensors could potentially offer. Watt Stopper was not able to provide any data for warehouses.

Sensor Switch loggers record both occupancy and light status (on/off) in a particular space. The logger built by Sensor Switch is designed to check the status of a room every two minutes; this interval is acceptable statistically because over the course of the logging duration (sometimes many months) the recorded data provides an accurate log of the status of a particular area.

By identifying periods when the logger recorded the space as both "unoccupied" and "lights on", we were able to determine the overall savings potential for the space both as a percentage of total lighting energy use and as a percentage of absolute time. Having data at short intervals meant that we could calculate the effect of various occupancy sensor time delays on the resulting savings.

2.2 Effect of Daylighting on Savings

Title 24 requires that non-refrigerated warehouses have skylights installed, and that automatic daylighting control devices (photocontrols) be installed to switch off or dim the electric lighting when daylight levels are adequate. Therefore, in non-refrigerated warehouses, the savings theoretically achievable by occupancy sensors are reduced because some of those savings have already been achieved by daylighting.

We modeled the effect of daylight in the sample warehouses by using an Excel tool –Skycalc™– developed by HMG for Energy Design Resources (EDR) with funding provided by Southern California Edison (SCE). Skycalc uses DOE2 to calculate the daylight illuminances available in a space with skylights installed. We calculated electric lighting savings based on the foot-candle (fc) estimates from Skycalc, in conjunction with a switching scheme as described below:

- Daylight < 10 fc   100% electric lights are on (no savings)

- 10 fc < Daylight > 20 fc 69% electric lights are on (31% savings)
- 20 fc < Daylight > 30 fc 39% electric lights are on (61% savings)
- 30 fc < Daylight 8% electric lights are on (92% savings)

Using data from a study conducted in 2005 by HMG for PG&E[1], we have reduced the savings from daylighting by a factor of 8%, to take account of the fact that photocontrol systems, while effective, do not function perfectly in practice. The 2005 study found an overall 92% realization rate for photocontrol systems in warehouses.

We used this switching scheme because it represents the most savings that can cost-effectively be achieved in warehouses by using multi-level controls, and therefore produces a lower bound (conservative) estimate of the remaining savings that can be achieved by the occupancy sensors. In practice, most warehouses use only one or two levels of switching, rather than three, and are required by Title 24 to switch off only two-thirds of the electric lighting (not the 92% we have modeled).

2.3 Data on Space Geometry

Though the data set contains only warehouse spaces, we sub-categorized several types of space to achieve better granularity. Following guidance given during the first stakeholder meeting, we categorized spaces as being *freezer*, *refrigerated* or *non-refrigerated* spaces, and as: *mezzanine*, *aisles* or *open spaces*. HMG consulted with the Stakeholder Group to confirm that the distinction between these three space types is something that is understood by people in the industry. Mezzanines are nonstructural floors that are added to increase the available square footage of a warehouse. They are usually constructed from steel and come with access stairs and their own integrated electrical power and lighting. They can be used as office space, storage for small items, changing rooms, lockers, etc. In grocery warehouses they are sometimes used as an interface between the warehouse and the retail space, for the transfer of goods.

Using a 3x3 matrix, each logged space was therefore categorized as being one of nine types (see Figure 1).

Warehouse Space Type	Aisle	Open	Mezzanine
Freezer			
Non-refrigerated			
Refrigerated			

Figure 1. The nine space types used in the analysis

To assign the correct space type to each set of logged data, we used the descriptions that were written by the warehouse managers of each facility at the time the loggers were installed. Many of the locations were poorly described (e.g. "1st Floor Warehouse") thus, HMG decided to omit any sensor that was not clearly defined as one of the space types.

Note that Title 24 2008 defines the following types of warehouse buildings/spaces:

[1] McHugh, Pande, Ander, Melnyk. 2004. Effectiveness of Photocontrols with Skylighting. Published in the 2004 IESNA Annual Conference Proceedings Paper #13 pp. 1-18 IESNA, New York. Available online at http://www.h-m-g.com/downloads/Papers/Photocontrol_effectiveness_Paper13wcover.pdf

- REFRIGERATED WAREHOUSE is a building or a space constructed for storage of products, where mechanical refrigeration is used to maintain the space temperature at 55 F or less.
- REFRIGERATED SPACE is a building or a space that is a refrigerated warehouse, walk-in cooler, or a freezer.
- STORAGE, COLD, is a storage area within a refrigerated warehouse where space temperatures are maintained at or above 32 F.
- STORAGE, FROZEN is a storage area within a refrigerated warehouse where the space temperatures are maintained below 32 F.

For the purposes of this analysis, freezer and Storage, Frozen are synonymous. Title 24 does not currently contain definitions of aisles or open areas in warehouses, so we have added proposed definitions, in Section 0.

2.4 Stakeholder Meetings

The purpose of the stakeholder meetings was to help create the lighting model of warehouse spaces, to confirm whether the lighting layouts, lighting controls, and warehouse operating assumptions were correct, and most importantly to confirm that the proposed measure(s) would not have a significant adverse effect on warehouse operations.

We convened a Stakeholder Group comprised of representatives from the industries affected by this proposal. These included:

- Lighting controls manufacturers
- Luminaire manufacturers
- Lighting designers
- Warehouse owners
- Grocery Store owners

See section Appendix A – Stakeholder Group Participants for a list of Stakeholder Group participants. We attempted to ensure that all these groups were well represented in the final stakeholder group. In addition to the final participant list, we contacted the following people who were unable to join the group: one (1) lighting designer, one (1) controls manufacturer, one (1) researcher.

We conducted three meetings with stakeholders in Oakland to discuss the study's progress. Meetings were held on Tuesday, December 2nd, 2008, Tuesday, March 3rd, 2009, and Tuesday, April 28th, 2009. The following items were discussed in the meetings:

- Current standard practice and best practice for warehouse lighting.
- Current code requirements and potential future changes.
- Current design problems and technology limitations/opportunities.
- Initial analysis of potential energy savings from warehouses, based on logged data.
- Proposed lighting layouts for warehouse open spaces and aisles

- Results of a survey of designers and end-users, asking about typical lighting configurations and controls options
- Proposed code language and discussion of how people will comply in practice
- Cost/Benefit analysis for proposed measures

Stakeholders provided a great deal of support and feedback on the proposals, as well as providing insight into the potential industry/technology barriers surrounding the proposals. Additionally, stakeholders were able to clarify common practice, design, and methods within these particular spaces types. For instance stakeholders gave us most of the information required for the lighting models—typical dimensions for warehouse aisles, luminaire spacings, lamp types, and information about how warehouses are typically broken down into different functional areas. Most importantly, they confirmed that the use of controls in warehouses was a suitable way to save energy, and would not interfere with warehouse operations.

HMG also contacted individuals beyond those included in the Stakeholder Group in order to make use of knowledge of a particular topic. For instance we contacted other lighting controls companies that were not on the stakeholder group to confirm the functions, price and availability of suitable occupancy sensors.

2.5 Designer/User Survey

To find out whether designers, installers or users have *already* used occupancy controls successfully in these spaces, we wanted to gather information from people who had designed, installed or maintained occupancy sensor controlled lighting. We therefore developed a web-based survey intended for architects, lighting designers, and facility managers (the survey questions varied between the three professions). Survey participants were asked a variety of questions about projects on which they had used occupancy controls, including what lighting equipment and controls were installed, the dimensions of the space, whether savings were achieved, and any maintenance or user response issues.

2.6 Review of Current Standards

To understand the existing context in which this proposal may be established, and how it may affect other code measures, we conducted a detailed review of sections 119, 131, and 146 of the current (2008) Title 24 Standards. When we had developed draft language we reviewed this with Gary Flamm[2] at the California Energy Commission to check compatibility with Title 24's overall structure and specific provisions, and to work out which of several language options would be most appropriate.

Since this proposal suggests turning lights off within aisles, which are often paths of egress, it was very important to be cognizant of the capacity for affecting lighting regulations in these areas. We therefore reviewed Section 7.9.2.1 of the Life Safety Code within the NFPA standards and the California Building Code Section 1003.2.9.1 in order to fully understand the current standards regarding emergency lighting for the means of egress.

[2] These discussions took place between September 2008 and March 2009

2.7 Lighting Models

We used industry-standard radiosity software (Lumen Designer) to model light distributions in typical spaces under both a base case and proposed scenario. We calculated light levels (footcandles) and lighting power densities (Watts/sf) for the modeled spaces. We confirmed with the stakeholder group that the lighting layouts we had used were common lighting design practice for these spaces. The lighting models were extremely helpful as a basis for discussing the proposed measures, because they focused the thoughts of the Stakeholder Group on the specific challenges that might occur in real installations.

2.8 Emergency Lighting Models

We ran additional simulations, in order to ensure that the necessary emergency light levels (1 fc along the centerline of egress (NFPA and CA Fire Codes, see bibliography) could be maintained by the lighting equipment and layouts we had used in the lighting models.

2.9 Market and Pricing Survey

To find out typical market prices and availability of occupancy sensors, we contacted lighting controls distributors to ask for prices. Because many different models of occupancy sensor were available from each distributor, we asked them which model(s) they would recommend for various typical applications, and asked them to price those models. We stratified the sample by region to obtain a range of prices from different cities in California, and we attempted to obtain prices for all the common types of occupancy sensor. Details of this analysis are provided in section 3.7.1.

2.10 Library Stacks

Physical data on library stack dimensions were collected from a survey of eight libraries of various types in California and Washington. The data were collected from a photocontrols field study performed by HMG for Southern California Edison, Pacific Gas and Electric Company and Northwest Energy Efficiency Alliance in 2005. The libraries surveyed ranged from large university libraries to small public branch libraries. Operating hours for each surveyed library were also collected from each library's website. However, because monitored data for occupancy controls in library stacks were not available, lighting data from warehouse uses (outlined in section 3.3.1) were used as a proxy, due to the similarities in expected use patterns between warehouse aisles and library stack aisles.

2.11 Cost-Effectiveness Calculation

Occupancy sensors are considered to have a useful life of 15 years[3] (AEC & CEC, 2005). Therefore we calculated estimates for annual energy savings and the resulting value of savings over 15 years, expressed as a net present value. Although the savings returned due to occupancy sensors are realized over 15 year life, costs are fixed and must be paid at the time of installation.

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[3] Due to an absence of data about the useful life of sensors in specific environments, the standard value of 15 years is assumed to apply in all environments, e.g., high temperatures in warehouse ceilings, low temperatures in refrigerated warehouses, etc.

By subtracting the costs from the net present value of the cumulative savings, we calculated the net financial benefit of the measure.

We conducted the life cycle cost calculation using the California Energy Commission Time Dependent Valuation (TDV) methodology for the 2008 standards[4]. Each hour is assigned an estimated price for energy, and the sum of these prices over the life of the measure yields the present dollar value of savings. Life cycle cost is the difference between the TDV $ value for 15 year energy savings and the initial occupancy sensor costs. Cost effectiveness is proved when this difference is positive; in addition, we have reported the benefit:cost ratio as an additional measure of cost effectiveness.

2.12 Statewide Savings Estimates

The statewide energy savings associated with the proposed measures will be calculated by multiplying the energy savings per square foot with the statewide estimate of new construction in 2014. Details on the method and data source of the nonresidential construction forecast are in Appendix E—Non-Residential Construction Forecast details.

[4] See the California Energy Commission's guidance on Time Dependent Valuation: http://www.energy.ca.gov/title24/2005standards/archive/rulemaking/documents/tdv/index.html

3. Analysis and Results

This section summarizes the results of the data collection and analysis described above. It includes an analysis of the amount of statewide floorspace, occupancy sensor energy savings, designer survey results, equipment prices, and measure cost-effectiveness.

Note that, during the California Energy Commission's pre-rulemaking proceedings, we were asked to include a technical and cost-effectiveness analysis for requiring bi-level occupancy sensors in library stacks as well as for warehouse aisles. This analysis is described in Section 5: Addendum – Library Stack Lighting Controls.

3.1 Percentage of Floorspace Devoted to Warehouse Space Types

To estimate the percentage of warehouse floorspace that is aisles versus open areas, we used the proportion of each type from the sample of logged data, which was 75%/25% (aisle space vs. open space respectively). We asked the Stakeholder Group whether this was a fair estimate of the proportions of those two space types, and they agreed that it was.

Within these two space types, we further divided the sample by the storage temperature of the space. Again, we used the proportions of each temperature type from the sample of logged data. The number of loggers and the resulting percentages of total warehouse space are shown in Figure 2. Based on stakeholder interactions, HMG defined space breakdowns as reported in Section 2.3.

Warehouse Space Type	Aisle	Open	Mezzanine[1]
Freezer	10 (2%)	0	0
Non-refrigerated	223 (65%)	73 (21%)	1
Refrigerated	28 (8%)	12 (3.5%)	15
Totals	*251 (75%)*	*85 (25%)*	*Omitted*

1. Please see section 2.3 for a definition of the Mezzanine space type

Figure 2 Number of data loggers installed by space type (% of total warehouse space)

Of the spaces that were categorized as mezzanine, there were no freezer spaces, only one refrigerated space, and 15 non-refrigerated spaces. Due to this small sample for Mezzanine floor space, this data was omitted from further analysis.

3.2 Review of Current Code Language Content and Context Review

We reviewed the current Title 24 requirements for warehouses to understand how the new requirements could most easily be incorporated into the existing code. We also reviewed other relevant standards including the fire codes and IESNA illuminance recommendations, because these standards ensure that people are able to see adequately and to find their way out of buildings during an emergency. Each of these standards influenced our proposed code language to some degree, as described below.

3.2.1 Current Title 24 Standards

In discussion with Gary Flamm at the California Energy Commission we developed the following understanding of how lighting controls requirements are structured within Title 24. We conducted this review of the current standards to ensure that our proposed language does not upset the existing structure and create contradictions or unnecessary complexity.

Structure of the Lighting Controls Requirements

Title 24 has a hierarchy of lighting controls, divided into three tiers. The first, simplest tier is “area controls” (section 131(a)); this requires that each space divided by ceiling-height partitions have a control capable of switching off all the lighting in the space. A simple wall switch is sufficient to meet this requirement. The second tier is “multi-level controls” (section 131(b)), which requires circuitry or dimming capability to allow some of the lighting to be switched off while the rest is left on (or vice-versa). The third is “shut-off controls” that shut off some or all of the lighting in response to a signal such as occupancy or daylighting.

Current (2008) Lighting Power Density Requirements

The 2008 Title 24 standards require that Commercial/Industrial Storage applications use the *Area Category* or *Tailored* methods for determining area Lighting Power Density (LPD). Area Category Method (Table 146F) allows an LPD of 0.6 W/sf for non-refrigerated storage and 0.7 W/sf for refrigerated storage. To ensure a conservative estimate of savings, in all of our calculations we have assumed that warehouses are lit with 0.6 W/sf of lighting (for the buildings we studied, we did not have actual LPD values).

Current (2008) Title 24 Lighting Controls Requirements

Warehouse open areas should be designated as egress routes under Section 10-103(a)(2) of Title 24, Part 1[5], when they serve as egress routes for the aisle ways that lead off from them. Egress lighting of 0.3 W/sf is exempt from the requirement for area controls (wall switches occupancy sensors) in Section 131(a). Therefore, in theory, under Title 24 2008, warehouses should have at least one “readily-accessible” wall switch that controls the lighting in the space (except for the 0.3 W/sf that is exempted). Note that because warehouse racks are not “floor to ceiling partitions”, each aisle is *not* currently required to have separate lighting controls.

Section 131(b) requires multi-level controls in spaces that have a connected load greater than 0.8 W/sf. Because warehouses are limited to either 0.6 or 0.7 W/sf (non-refrigerated and refrigerated respectively), they are exempt from the requirement for multi-level controls. Note, however, that in practice there may already be two levels of control for open areas because 0.3 W/sf of the lighting may be on a separate circuit for egress lighting.

Section 131(d) Shut-Off Controls requires automatic shut-off controls in addition to the area controls required by Section 131(a). Section 131(d) is subject to the same exemption for egress lighting as Section 131(a). The requirement of Section 131(d) can be met with an automatic time clock control, by occupancy sensor control, or by an automatic daylighting control device. In daylit warehouses (i.e. all new-construction non-refrigerated warehouses) this requirement is met in practice by the prescriptively-required automatic daylighting control device. Each automatic

[5] Note that Title 24 Part 1 is not part of the Energy Efficiency Code—the Energy Efficiency Code is Part 6, although it is often referred to simply as “Title 24” for convenience.

shut-off control device must be equipped with a manual off-override that serves an area no larger than 5,000 sf.

As a result of these requirements, the current least-cost configuration for warehouse lighting is to have photocontrols with an off-override wall switch in non-refrigerated warehouses, and to have a timeclock control in conjunction with an off-override in refrigerated warehouses. In both cases there will be one circuit for egress lighting that is either uncontrolled (on 24/7), or controlled by a time clock or a manual switch. In both cases there is no need for the aisles to have separate controls.

Power Adjustment Factors (PAFs)

If designers choose to install bi-level controls in warehouses they can earn a Power Adjustment Factor (PAF)[6]. Warehouses can claim PAF of 0.15 when the following condition is met: "Occupant sensor controlled multi-level switching or dimming system that reduces lighting power at least 50% when no persons are present (maximum of 2 aisles per sensor in warehouses)."

Skylights

Skylights are required in spaces greater than 8,000 sf with ceiling heights of 15 ft or higher[7]. At least one half of the floor area shall be in the daylight area served by skylights (refrigerated warehouses are exempt, see Exception 1 to 143c). Photo controls are mandatory in daylit areas greater than 2,500 sf; whereas spaces smaller than 2,500 sf can receive a compliance credit for installing controls.

3.2.2 Code Requirements for Emergency Lighting

The California Building Code Section 1003.2.9.1 states that, "The means of egress serving occupied portions shall be illuminated at an intensity of not less than 1 fc at the floor level."

The National Fire Protection Association (NFPA) Section 7.9.2.1 code states:

"Automatic motion sensor-type lighting switches shall be permitted within the means of egress, provided that the switch controllers are equipped for fail-safe operation, the illumination timers are set for minimum 15-minutes duration, and the motion sensor is activated by any occupant movement in the area served by the lighting units." And,

"*Emergency lighting facilities shall be arranged to provide initial illumination that is not less than an average of 1 ft-candle (10.8 lux) and, at any point, not less than 0.1 ft-candle (1.1 lux), measured along the path of egress at floor level….A maximum-to-minimum illumination uniformity ratio of 40 to 1 shall not be exceeded*."[8]

3.2.3 IESNA Recommended Illuminance Levels

The IESNA Handbook (9th edition) recommends a minimum of 5-10 fc for simple orientation, short visits, and bulk storage. It recommends 15-20 fc for basic visual acuity and fine item storage (Section 10), and IESNA recommends 20-50 fc for detailed visual tasks. Stakeholders

[6] California Code of Regulations, Title 24 Part 6 Table 146C

[7] California Code of Regulations, Title 24 Part 6 Section 143 c

[8] NFPA section 7.9.2.1

identified areas where higher light levels may be needed, such as where workers are performing detailed eye to hand type tasks (quality control, attaching small parts, etc). IESNA recommends 20-50 fc for detailed visual tasks/performance. Therefore, HMG recommends not including these spaces in this proposed code change.

3.3 Energy and Peak Load Savings

Each logger was in place for two to four weeks, with occupancy and light level data recorded at two minute intervals, so the granularity of the logged data was sufficient for us to generate accurate estimates of savings due to different occupancy sensor time delays. A brief analysis of the effect of time delay showed that reducing the delay to less than 30 minutes resulted in almost no additional savings, unless the delay was reduced close to zero (which is not acceptable to occupants). This suggests that most of the savings accrue during long unoccupied periods, either overnight or at times when a specific aisle is not being accessed.

The occupancy patterns of each of the defined warehouse spaces were analyzed to reveal savings potential by hour of the day, and by weekday/weekend. Savings potential is defined as the amount of time for which the space is lit and unoccupied, multiplied by the lighting power density (LPD) of the space. Because we are calculating savings from a new construction measure, we set all the spaces to have a LPD of 0.6W/sf, the prescriptive limit set by Title 24 2008 (Tables 146-E and 146-F).

The data set shows a distinction in pattern of use between weekend and weekdays. Figure 3 shows the distinction between baseline energy consumption (the percentage of time for which lights were on in the sample buildings) and the energy consumption with occupancy sensors installed (lights on *and unoccupied*). The technical potential for energy savings is therefore the difference between the two lines.

This calculation is based on a 30-minute occupancy sensor time delay, i.e. we used a database algorithm to search through the data for continuous periods of 30 or more minutes during which the lights were on and the space was unoccupied.

The savings potential (difference between the two lines) is roughly constant throughout the day, fluctuating between 15% and 30% (note that this difference cannot be seen during the daylit periods in Figure 3). This suggests that savings from occupancy sensors are available at all times of day, and therefore that many of the warehouses in the dataset had 24-hour operation.

Figure 3 shows that the savings that can be obtained by occupancy sensors in a daylit (non-refrigerated) warehouse drop close to zero during the middle of the day because the electric lighting has already been switched off by the photocontrol system which is prescriptively required by Title 24. Similar plots for all warehouse space types are presented in Appendix D – Energy Use Graphs.

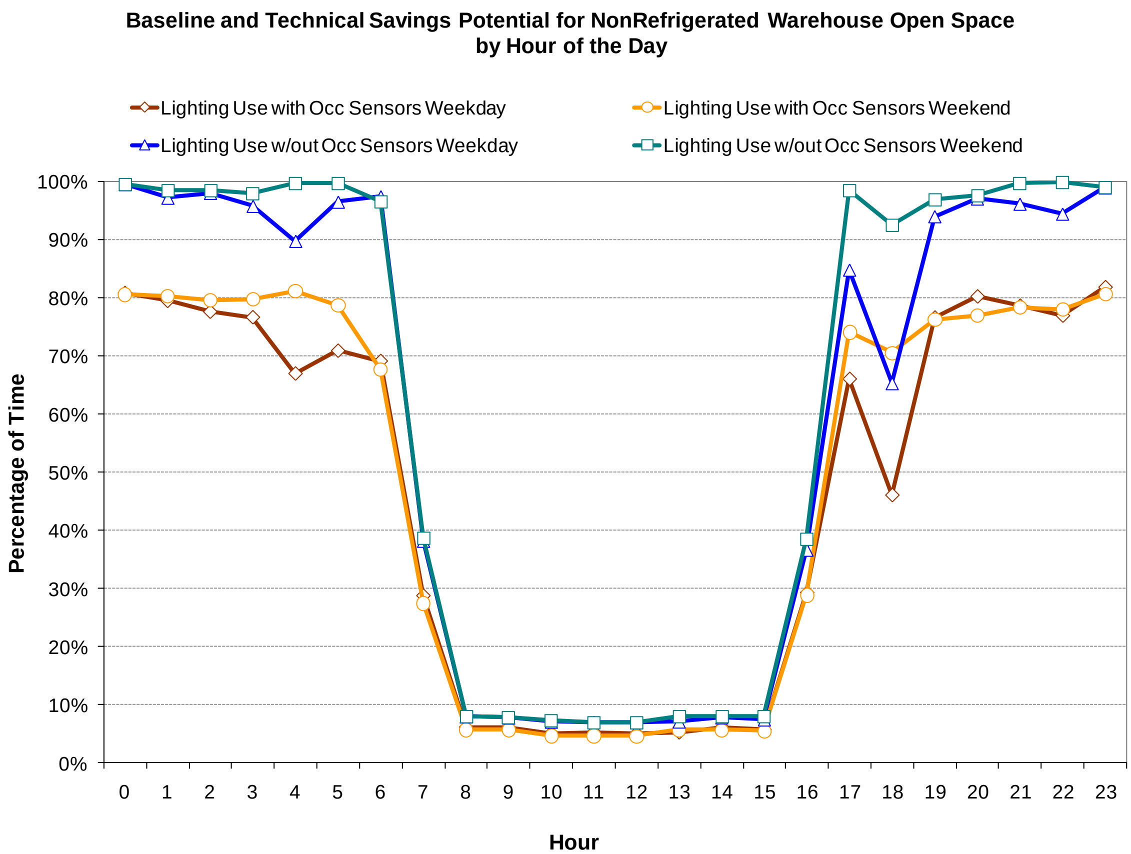

Figure 3: Baseline and Technical Savings Potential for Non-refrigerated Warehouse Open Spaces, by Hour of the Day and by Weekday/Weekend

3.3.1 Savings per Square Foot

In both aisles and open areas, the lighting was on for the majority of the time during the baseline condition (93% of the day), but the lights could be switched off (because spaces were unoccupied) for 20% of the day on average, meaning that this measure would reduce lighting load to zero for 13% of the time during the year (20%-7%). These values are a weighted average by the statewide floor area of each space type.

Assuming an installed load of 0.6W/sf, reducing this load to zero 13% of the time (8760 hours times 0.13) equals 0.08 W/sf savings on average, or 0.7 kWh/sf/yr (see Figure 4 for a breakdown of hourly savings by space type).

Note that the W/sf savings figures in Figure 4 are for weekdays only, and have been reduced somewhat, due to the savings already achieved by daylighting, in the nonrefrigerated warehouse types. The reduction in lighting use between 8 am and 3 pm is due to the daylight adjustment based on Skycalc values as explained in Section 2.2.

Note that these savings are calculated from the occupancy patterns of real buildings in the data set, so are not based on notional assumptions about operating hours as is sometimes the case with savings estimates.

For each of the space type classifications in Figure 2, we calculated savings per square foot (W/sf) in Figure 4 based on operating hours as measured by the logging occupancy sensor data, in conjunction with an assumption that the installed load in a Title 24-compliant warehouse would be the maximum allowed 0.6 W/sf.

The savings by hour in Figure 4 due to occupancy sensors indicates that the different types of warehouse space have distinctly different daily patterns of use, reflecting the different times at which goods are loaded, unloaded and distributed around the warehouse. However, all types show significant savings from occupancy sensors, which leads us to believe that the measure should apply equally to all five of the space types shown in Figure 4.

Figure 4 shows that aisles have higher savings than open spaces, which is to be expected because the open areas are generally thoroughfares that people use to access the aisles, so open areas have higher levels of traffic and fewer unoccupied periods. Refrigerated and freezer spaces have the highest potential savings, primarily because daylighting controls don’t deduct from the savings.

Hour	Aisle Freezer	Aisle Non-refrigerated	Aisle Refrigerated	Open Non-refrigerated	Open Refrigerated
0	0.40	0.29	0.24	0.11	0.37
1	0.37	0.25	0.24	0.11	0.33
2	0.41	0.23	0.24	0.12	0.31
3	0.40	0.21	0.29	0.11	0.33
4	0.46	0.22	0.41	0.14	0.37
5	0.46	0.22	0.42	0.15	0.31
6	0.42	0.30	0.30	0.17	0.32
7	0.40	0.13	0.27	0.06	0.29
8	0.43	0.03	0.33	0.01	0.29
9	0.38	0.02	0.27	0.01	0.24
10	0.34	0.02	0.27	0.01	0.20
11	0.29	0.02	0.35	0.01	0.15
12	0.25	0.02	0.31	0.01	0.20
13	0.27	0.02	0.31	0.01	0.17
14	0.21	0.02	0.43	0.01	0.20
15	0.28	0.02	0.34	0.01	0.22
16	0.27	0.10	0.26	0.04	0.25
17	0.26	0.26	0.26	0.11	0.26
18	0.27	0.26	0.26	0.12	0.26
19	0.30	0.28	0.25	0.10	0.28
20	0.42	0.30	0.24	0.10	0.36
21	0.42	0.31	0.23	0.10	0.36
22	0.39	0.30	0.25	0.10	0.36
23	0.40	0.30	0.26	0.10	0.36
Average	*0.35*	*0.17*	*0.29*	*0.08*	*0.28*
Peak Savings[9]	*0.28*	*0.26*	*0.43*	*0.12*	*0.26*

Figure 4. Weekday Lighting Energy Savings from the Use Of Auto-On Auto-Off Occupancy Sensors with a 30 Minute Time Delay(W/sf)

3.3.2 Statewide Savings

To assess statewide savings potential, we also needed to know how much floorspace within the state of California is taken up by each of the space types. We used three data sources for this estimation: the CEC 2014 Construction forecast, NRNC and CEUS (see bibliography) We were able to obtain estimates for warehouse floor space from the NRNC. A description is provided in Section 6.3.

The CEC construction forecast estimates that there will be 32 million square feet of nonrefrigerated warehouses, and 1.8 million square feet of refrigerated warehouses built in 2014.

[9] Peak savings is the greatest reduction in load during any single hour between 12:00 and 18:00 on weekdays, for each space type.

In the same year, the total existing construction will be 1060 million and 59 million square feet respectively. These estimates are closely in accord with other sources.

According to the California Nonresidential New Construction (NRNC) database , new warehouse floorspace totaled 233 million ft^2 from 1999 – 2005. Therefore annual warehouse new construction was 38.8 million ft^2 per year during this period. The NRNC survey details not only the building type (warehouses belong to the CEC defined “C&I Storage” space) but also the specific occupancy area types within each building. It shows that 84% of the 38.8 million ft^2 of new warehouse construction is used for stocking and storing goods, the remaining 16% is used for various other purposes including electronic equipment, dining, lockers and changing rooms, offices, etc. Therefore we estimate that the annual square footage of warehouse new construction affected by this measure will be 32.6 million ft^2 (38.8 million * .84).

To calculate the square footage of lighting retrofits within *existing* buildings, we used the measure life for lighting systems assumed within Title 24 (15 years) and the approximate life of a warehouse building (30 years). Typically, therefore, each warehouse building has one lighting retrofit within its 30 year life. This means that lighting retrofits occur in 3.3% of warehouse floorspace per year.

Using the NRNC data that 84% of the floorspace would be subject to this new code requirement, and using the data from the CEC construction forecast, we expect that retrofits account for another 1060*0.84*(1/30) = 29.7 million square feet in nonrefigerated and 1.7 million square feet in refrigerated warehouses of lighting eligible for this new requirement.

We calculate that this measure will affect a total of 65.2 million square feet of lighting, as summarized in Figure 5. In this table, the square footage for each space type is back calculated from the grand statewide total square footage, using the proportion of space types shown in Figure 2.

	Non-refrigerated	Refrigerated	Freezer
Aisle	46.3	1.7	0.9
Open	15.4	0.6	0.3
Total	61.7	2.3	1.2
Grand Total		**65.2**	
New Construction Subtotal		33.8	
Lighting Retrofit Subtotal		31.4	

Figure 5. Square Footage of Lighting Affected by this Measure - Million sf per Year

Figure 6 shows the projected technical savings potential from the measure. The values are calculated by multiplying the affected square footage from Figure 5 by the energy savings per square foot shown in Figure 4.

	Non-refrigerated	Refrigerated	Freezer
Aisle	69.5	3.1	1.0
Open	30.2	1.0	0.5
Total	99.6	4.2	1.5
Grand Total		105.3	

Figure 6. Energy Savings Potential from this Measure – GWh per year

3.4 Results of Designer/User Survey

The main purpose of the survey was to find people who had used occupancy sensors in warehouses, and to ask about their experiences with those installations. We sent out a web survey during January and February 2009. To reach as many qualified people as possible, we sent the survey to the IESNA Controls Committee to publicize the survey via their email list, and to the IESNA Motherlode Chapter (Sacramento) to publicize the survey via their newsletter. We also sent it to all members of the Stakeholder Group with a request to forward to their professional contacts, and to architects and developers.

We found that only one survey participant had experience using occupancy sensors in warehouse spaces. According to his answers, typical dimensions of aisle ways are 70’0” x 4’0”, with fixtures 10’0” on center. Typical design illuminance for aisle ways is 15 – 20 fc. Each aisle was controlled by an occupancy sensor with one controlled circuit covering two aisles (there were 10 aisles so five circuits in total). There were seven (7) fixtures per aisle, so 14 fixtures were controlled by each sensor. Time delay was set to 10 minutes. The respondent stated that common practice is for each sensor to control two switch legs.

Additionally, he stated that lighting in the open spaces of a warehouse typically provides 15 – 20 fc. He used occupancy sensors with a 10 minute delay in the open spaces. The survey participant reported no negative feedback from occupants and that none of the occupancy sensors had ever failed for either space type.

3.5 Lighting Model and Simulations

Industry-standard radiosity-based lighting design software (Lumen Designer 2.0) was used to check illuminance levels from typical light fixtures and layouts, to verify that the required levels of illuminance could be met using the proposed LPDs, and that emergency lighting would have sufficient brightness and uniformity.

3.5.1 Warehouse Simulation

Using Lumen Designer radiosity software, we developed a warehouse model with dimensions of 276’0” x 30’0” for an aisle way (10 ft wide aisle with 10 ft wide shelving on either side) and 45’0” x 136’0” for an open space (area without permanent partitions higher than 5 ft). Illuminance plots from the software are shown in Appendix B—Illuminance Plots for Warehouses.

The aisle way and open area were modeled side by side with no obstructing partition, therefore allowing light within each space to affect the adjacent light levels, as is typical in warehouses. Fixtures were modeled consistently throughout the entire space as 3 x 32W 4' T8 direct fixtures. Lamps had a lumen output of 2900, and fixtures were spaced at 20' on center. HMG ran simulations on the model for two scenarios:

- All lights on (simulating normal lighting state)
- 2/3 of installed lighting off (simulating unoccupied periods)

Lumen Designer results are detailed in Figure 7, and the graphical output from the software is shown in Figure 8 and Figure 9. HMG presented these results to stakeholders and they agreed that the lighting technologies, layouts, light levels and power densities in the simulation were typical of standard practice in warehouses. HMG consulted the IESNA Handbook and confirmed recommendations of 5-10 fc for simple orientation/short visits and 15-20 fc for basic visual acuity, which this proposal would allow. Stakeholders did identify areas where higher light levels may be needed. These would be areas were workers are performing detailed eye to hand type tasks (quality control, attaching small parts, etc). IESNA recommends 20-50 fc for detailed visual tasks/performance. Illuminance requirements for these tasks are almost always provided by localized task lighting, rather than by a high level of lighting throughout the space. Therefore we have not included detailed visual tasks in this study.

By modeling the aisle and open space in "emergency lighting" mode, assuming a typical number of fixtures equipped with emergency ballasts, HMG found that 1 fc could be easily maintained with an LPD as low as 0.046 W/sf.

Figure 7 shows that even if the occupancy sensors were to fail in the off mode, there would still be sufficient lighting available from the uncontrolled lamps to provide more than the 1 fc average illuminance required for egress lighting (see shaded cells).

Space Type	Lighting Conditions	Minimum illuminance (fc)	Average illuminance (fc)	Maximum illuminance (fc)	LPD (W/sf)
Aisle	All lights on (occupied state)	11	14	15	0.49
	2/3 of lights off (unoccupied state)	3.7	4.7	5	0.16
Open Area	All lights on (occupied state)	14	19	21	0.44
	2/3 of lights off (unoccupied state)	4.7	6.3	7	0.15

Figure 7. Table of Summary Data from Lumen Designer

Figure 8. Radiosity Rendering of a Warehouse Open Space in the Occupied (left) and Unoccupied (right) States

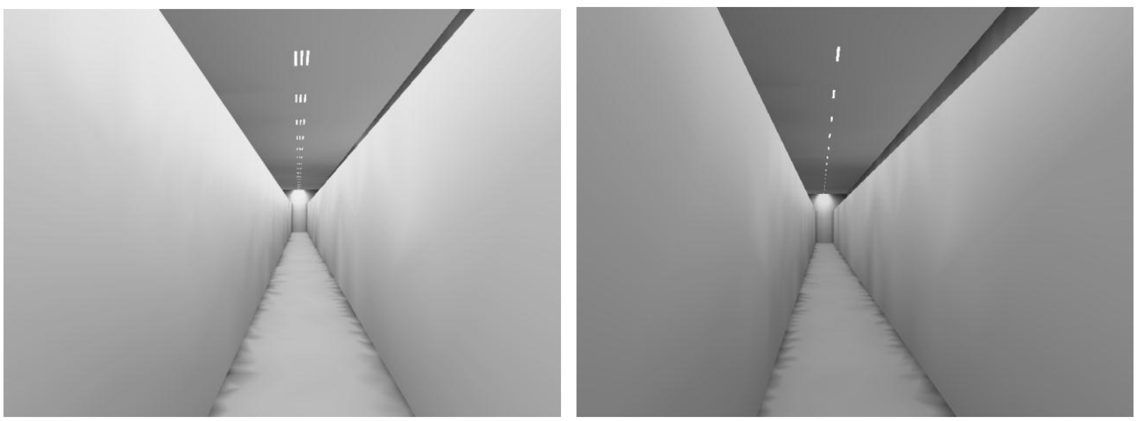

Figure 9. Radiosity Rendering of a Warehouse Aisle in the Occupied (left) and Unoccupied (right) States

3.6 Market and Pricing Survey

The market and pricing survey provides the equipment costs that form part of the basis for the life-cycle costing in section 3.7, and serves to demonstrate that the equipment proposed for this code measure is available from several different suppliers.

To contact lighting distributors for the survey, we started by using the lists of sales reps on the websites of the following major occupancy sensor manufacturers. Between them, we believe that these manufacturers account for the overwhelming majority of occupancy sensor sales in the state. Manufacturers are listed in alphabetical order:

- Cooper Controls
- Greengate
- Hubbell
- Leviton
- Lightolier
- Lutron
- SensorSwitch
- Square D
- Wattstopper

From the websites of these manufacturers we generated a list of sales reps that includes 156 businesses throughout California and is geographically segmented as shown in Figure 10. Because the first four manufacturers we surveyed provided such a large number of sales rep contacts, we did not pursue sales rep contacts for the remaining five manufacturers. However, because there is so much overlap (i.e. each of the sales reps carries multiple manufacturers' sensors), all eight manufacturers are well represented by the sales reps we surveyed. Figure 10 gives an indication of the relative market saturation based on the larger manufacturer's sales rep locations. The table shows that occupancy sensors are available throughout the state, and that in each area of the state there are several manufacturers represented. This provides evidence that the market for occupancy sensors is well established and competitive, and able to handle the increase in orders that would result from this code change.

Region	Leviton	Lutron	SensorSwitch	WattStopper
SF Bay Area[10]	17	88	65	132
Inland Empire[11]		77	30	
Los Angeles	17	264	85	99
Sacramento	17	231	20	33
San Diego	17	110	75	33
Other	17		50	33

Figure 10. Number of Sales Reps Listed on each Manufacturers' Web Site, by Region

Seven sales reps from each region were randomly selected and called. We asked them for occupancy sensor prices, but not all reps responded with prices, the main reason being that in order to generate a bid query, the rep required project information (location, size, contractor name) which we did not have. Of those willing to assist in the survey, we asked each sales rep:

Which manufacturer's products do you most commonly sell?

What model(s) would you recommend?

What would be the labor cost for a certified electrician to complete the installation?

Can you please provide your thoughts on the relative quality of the sensors you carry and any additional insights you have about occupancy sensors?

This survey was intended to be relatively informal and open-ended, and focused on gleaning as much information as possible from the anecdotal responses given by lighting equipment reps throughout the state.

As shown in Figure 11, we obtained prices on 41 ceiling-mounted occupancy sensors. We also collected technical data on these sensors. This data was necessary to ensure that the full cost of the sensor accessories was included, and that diversity in the market was adequately captured. The technical data we collected included:

[10] Alameda, Contra Costa, Marin, Napa, San Benito, San Francisco, San Mateo, Santa Clara , Santa Cruz, Solano, Sonoma counties

[11] Riverside and San Bernardino counties.

- Area served
- Time delay programming
- Power pack requirement
- Sensor technology (dual, ultrasonic or infrared)
- Voltage input (line or low)

Field of view.

	Line voltage	Low Voltage	Total
Infrared	6	3	9
Ultrasonic	19	1	20
Dual technology	2	10	12
Total	27	14	41

Figure 11. Number of Occupancy Sensors for which Prices were Obtained, by Type

Figure 12 shows the mean price for the six major types of occupancy sensor in the survey. We have not shown the range of prices obtained from different sales rep for each sensor type, but the range of prices was low compared to the difference between the sensor types.

As expected, line voltage sensors are cheaper than low voltage sensors. This is because low voltage sensors are designed to allow manual-on operation, and therefore must include circuitry for input from a low voltage switch, along with a transformer. Both these accessories add cost.

	Line Voltage	Low Voltage
Infrared	$49.91	$62.20
Ultrasonic	$99.21	$137.19
Dual technology	$91.75	$108.89

Note that price includes the price of all associated power packs, lenses etc.

Figure 12. Average Price of Ceiling-Mounted Occupancy Sensors in Pricing Survey, by Type

3.7 Cost Effectiveness

The hourly (8760) estimates for energy use were multiplied by the hourly values for Time Dependent Valuation (TDV $/kBTU) to obtain hourly estimates for the value of the energy saved. TDV$ and kWh values were summed over 8760 hours to quantify annual savings. TDV$ are in present value dollars. Additionally, we compared the cumulative annual savings with the costs of installing and purchasing occupancy sensors to quantify Life Cycle Cost (ΔLCC).

3.7.1 Sensor Costs per Square Foot

Cost-effectiveness is determined by the price of the sensors (see 3.6) and the amount of floorspace that can be controlled by a sensor. The Stakeholder Group told us that line voltage infrared sensors are typical for warehouse applications, because user override is usually not desirable (therefore low voltage switches are not required), and because ultrasonic sensors do not work well in open areas. Based on this information we have used line voltage sensors as the basis for the cost effectiveness calculations. From the pricing survey, the mean price of these sensors was $49.91 (Figure 13) .

For the floorspace served by each sensor, we used the 40’ on-center spacing suggested by the stakeholder group (and typically quoted in manufacturers’ literature), along with a conservative (low) estimate of the width of aisles, at 8’ (also from the stakeholder group). This gives an average of 320 square feet served by each sensor—much less than the 1000 square foot maximum quoted by manufacturers, and therefore well within the technical capability of commonly-available sensors. For open areas we have assumed a slightly greater coverage of 500 square feet, which is the lowest value typically quoted by manufacturers.

We used a survey conducted by Craig DiLouie for the Lighting Controls Association[1] (LCA) to estimate how often contractors are called back to fix problems with occupancy sensors (we did not use this survey to calculate other costs). The survey found that contractors are called back to 20% of jobs to change occupancy sensor sensitivity or time delay. In our cost calculations we have included the cost for a one-hour contractor call-back in 20% of cases.

The LCA survey also found that contractors are generally familiar with the installation and calibration of occupancy sensors, which leads us to believe that they would be competent to install them in warehouses for this code measure: *“electrical contractors routinely calibrate motion sensitivity and time delay settings in occupancy sensor installations; recommend occupancy sensors in a majority of lighting retrofit projects; select time delay settings that on average support optimal energy savings and lamp life; and are satisfied with occupancy sensor performance, ease of installation and commissioning, and customer/occupant acceptance.”*

[1] DiLouie, Craig. Study Finds Occupancy Sensors Routinely Commissioned by Satisfied Contractors, but Suffer High Callback Rate . July 2007. Accessed at http://www.aboutlightingcontrols.org/education/papers/2007_occ_sensor_study.shtml

Installed Cost (per sensor)		**Notes**
Dual technology line voltage sensor	$49.91	From pricing survey
Installation and commissioning	$100.00	1 hour (per RS Means) at $100/hr
Callbacks	$20.00	20% callbacks per LCA survey
Total	**$169.91**	
Area Served by each sensor		
Length	40'	From manufacturers' literature,
Width	8'	Conservative estimate of typical aisle width
Area	**320 ft^2**	(500 $ft^2$for open spaces)
Total Cost per Square Foot		
Total	**$0.53 /$ft^2$**	($0.34 / ft^2 for open spaces)

Figure 13. Installed Costs for Occupancy Sensors

3.7.2 Life Cycle Cost and Benefit:Cost Ratio

The present value of the total savings over the 15 year measure life is shown in Figure 14, in the "savings" column. The second column (ΔLCC) is the difference between the savings estimate and the installed cost for occupancy sensors, shown in Figure 13. Because the ΔLCC value is positive, the measure is cost-effective over its 15 year life. Figure 14 also shows the benefit:cost ratio for each space, i.e. the number of times the cost savings outweigh the installation costs over the life of the measure.

The TDV calculation of the value of energy savings over the life of the measure is too complicated to reproduce in this report, because it requires the summing of hourly values over the course of several years, adjusted for net present value. Instead we have provided the final values for savings and cost, shown in Figure 14.

Space Type	Savings (TDV $/ft^2)	ΔLCC (TDV $/ft^2)	Benefit:Cost Ratio
Aisle Freezer	$3.02	$2.48	5.68
Aisle Non-refrigerated	$3.33	$2.74	6.26
Aisle Refrigerated	$4.39	$3.80	8.26
Open Non-refrigerated	$4.29	$3.92	12.64
Open Refrigerated	$4.42	$4.04	13.00
Open Freezer	$4.29	$3.92	12.64
Average	$3.64	$3.11	7.99

Figure 14. Table of Life Cycle Cost

3.8 Materials Impacts

This proposed measure will result in the use of more occupancy sensors in warehouse aisles, and this section quantifies the impact of those sensors in terms of the materials used in their manufacture.

The materials impact calculations below use the same assumptions as are shown in the calculations of cost-effectiveness and statewide savings in the preceding sections.

The materials impacts *per component* are shown in Appendix 7.6. 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.

		Number of square feet per component		
Component	**Basis for calculation**	Warehouse aisle ways	Warehouse open areas	Library stacks
Occupancy sensors	One occupancy sensor per 40’ length of corridor, which is 5.7’ wide (see Section **Error! eference source not found.**)	40’ length of aisle way multiplied by 8’ width = 320 sf	500sf, which is half the 1000sf coverage typically stated by manufacturers	Two occ sensors per 22’ length of aisle multiplied by 2x6’ width of aisles plus 4’ stack between = 352 sf
Additional power wiring for luminaires	#12 power wiring equal in length to the total length of corridor affected by the measure (i.e., tandem wiring of fixtures)	100’ of #12 wire serves 100x8 = 800 sf of corridor	Luminaires on 20’x10’ centers, so 10’ of wire per 200 sf = 2000 sf per 100’ of wire	100’ of #12 wire serves 100x6 = 600 sf of aisle

Figure 15. Basis for Calculation of Materials Impacts

Component	square feet per component	Materials impact (lbs/year)					
		Mercury	**Lead**	**Copper**	**Steel**	**Plastic**	**Others (Identify)**
Warehouse aisles			48.8	Million square feet of aisle per year			
Occupancy sensors	320	76	76	22875	15250	38125	0
Additional power wiring for luminaires	800	0	0	122000	0	0	0
Warehouse open areas			16.3	Million square feet of open area per year			
Occupancy sensors	500	16	16	4890	3260	8150	0
Additional power wiring for luminaires	2000	0	0	16300	0	0	0
Library stacks			0.07	Million square feet of stacks per year			
Occupancy sensors	352	0	0	30	20	50	0
Additional power wiring for luminaires	600	0	0	233	0	0	0
Statewide total		**93**	**93**	**166328**	**18530**	**46325**	**0**

Figure 16. Statewide Materials Impact

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

This section describes the specific recommended code language. It contains two sets of proposed language:

- Code Language Recommended by the Investor-Owned Utilities Codes and Standards Team
  - This is the language that was proposed in the Draft CASE Report submitted by the IOU team to the CEC in the spring of 2011.
- Code Language Proposed by the California Energy Commission
  - This is the language that was sent from the CEC to the IOU team and other stakeholders in August 2011.

After the two sets of proposed language, we have included a discussion of how the language developed from its initial form to its final form.

We have used the language from the 2008 standard, and have used underlining to indicate new language and strikethroughs to show deleted language.

This section presents the proposed language both for warehouses and for library stacks.

4.1 Summary of Initial Code Change Proposals

This section summarizes the code language initially recommended by the IOU team.

We propose to change the standards to require that at least half of the lighting in warehouse aisles and open spaces, and library stack aisles be controlled by an occupancy sensor that switches the lighting off at unoccupied times. The occupancy sensor would have to meet the requirements for occupancy sensors in section 119(d), with the caveat that it need not switch off *all* the lighting in the space.

We propose to add a new section 131(h), to set out those spaces in which occupancy sensors are required.

This proposal allows an opportunity to simplify the code. We propose to remove the Power Adjustment Factor of 0.15 for "Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)", allowed when the lighting is controlled by a "Multi-level occupant sensor (see Note 21) that reduces lighting power at least 50% when no persons are present. May be a switching or dimming system." (see Note 32) in table 146-C.

We also propose to revise section 131(b) by lowering the threshold for multi-level controls from 0.8 W/sf to 0.5 W/sf. We were advised by the Energy Commission that we should recommend a reduction in this threshold, but not until the stakeholder process had already concluded, so we did not have an opportunity to discuss this change with stakeholders. The threshold for multi-level controls has not been lowered for several code cycles, during which LPDs have been reduced significantly in many space types, so this change is required to maintain the "hierarchy" of controls (basic switch/multi-level switching/automatic controls). Lowering this requirement for bi-level controls would affect the following spaces:

- Electrical, mechanical, telephone rooms 0.7 W/sf

- Locker/dressing room 0.8 W/sf
- Commercial and industrial storage (refrigerated) 0.7 W/sf

All other spaces are not affected by the drop from 0.8 W/sf to 0.5 W/sf. They are either higher than 0.8 W/sf and therefore already required to install bi-level or they are below 0.5 W/sf. Therefore, a change in this threshold would not negatively affect many spaces, but would allow us to keep the hierarchy of the code intact.

Finally, we propose to lower the exemption for emergency lighting from 0.3 W/sf to 0.2 W/sf, because the requirement to switch off at least two thirds of the lighting conflicts with the 0.3 W/sf threshold whenever the installed LPD is less than 0.6 W/sf (which it must be in warehouses). The lighting calculations we carried out for the warehouse space (Section 3.3) showed that sufficient emergency illuminance could be achieved in the corridor using 0.05 W/sf.

4.2 Code Language Recommended by the Investor-Owned Utilities Codes and Standards Team

This is the language that was originally proposed to the CEC by the IOU Codes and Standards team as a result of the stakeholder meetings and analysis described in this report, and as a result of initial discussions with the CEC. This language was presented in the Draft CASE report.

SECTION 101(b)

NONRESIDENTIAL FUNCTION AREA OR TYPE OF USE

Commercial and industrial storage is a room, area, or building used for storing items.

> <u>**Aisle way** is a warehouse facility term describing a long, usually narrow space between storage racks. Aisles are usually lit using a single row of ceiling fixtures along the centerline of the aisle.</u>
>
> <u>**Open area** is a warehouse facility term describing a large unobstructed area that is typically used for the handling and temporary storage of goods.</u>

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

<u>**(d) Shut-off Controls**</u>

<u>**6. Areas where Occupant Sensors are Required in Addition to Section 131(c)1.**</u>

> <u>**A. In aisle ways and open spaces in warehouses, in addition to meeting the shutoff requirements in Section 131(c)1, lighting shall be controlled with occupant sensors that automatically reduce lighting power by at least 50%. The occupant sensors shall independently control lighting in each aisle way. Occupant sensor range shall not extent beyond the aisle being controlled by the sensor.**</u>
>
> <u>**EXCEPTION 1 to Section 131(c)6A: In aisle ways and open spaces in warehouses in which the installed lighting power is 80% or less of the value allowed under the Area Category Method, occupant sensors may reduce lighting power by 40%.**</u>
>
> <u>**EXCEPTION 2 to Section 131(c)6A: When metal halide lighting is installed in warehouses, occupant sensors may reduce lighting power by 40%.**</u>

B. In single-ended library bookstack aisles 10’ or longer, or double-ended bookstacks 20’ or longer, in addition to meeting the shutoff requirements in Section 131(c)1, lighting shall be controlled with occupant sensors that automatically reduce lighting power by at least 50%. The occupant sensors shall independently control lighting in each aisle way. Occupant sensor range shall not extent beyond the aisle being controlled by the sensor.

C. In parking garages, parking areas and loading and unloading areas, in addition to meeting the shutoff requirements in Section 131(c)1, general lighting shall be controlled by occupant sensors, and shall have at least one control step between 20 percent and 50 percent of design lighting power. A reasonably uniform level of illuminance shall be achieved in accordance with the applicable requirements in Table 131-A

EXCEPTION to Section 131(c): In no greater than 20 percent of the total parking garage floor area, lighting specifically designated for parking garage emergency egress lighting provided that the path of egress is designated on the plans and specifications submitted to the enforcement agency in accordance with Section 10-103(a)2 of Title 24, Part 1

SECTION 146(c)—CALCULATION OF ALLOWED INDOOR LIGHTING POWER DENSITY

TABLE 146-C LIGHTING POWER ADJUSTMENT FACTORS

TYPE OF CONTROL		TYPE OF SPACE	FACTOR
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
~~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.~~		~~Hallways of hotels/motels , multi-family, dormitory, and senior housing~~	~~0.25~~
		~~Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)~~	~~0.15~~
		~~Library Stacks (maximum 2 aisles per sensor)~~	~~0.15~~
Dimming system	Manual	Hotels/motels, restaurants, auditoriums, theaters	0.10
	Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters	0.20
Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal. (See Note 1)		All building types	0.05
Manual dimming of dimmable electronic ballasts. (see Note 3)		All building types	0.10
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).		All building types	0.15
Combined controls	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	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	0.10
	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.	Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, ~~corridor~~, conference or waiting room	0.25

			Effective Aperture			
Automatic multi-level daylighting controls (See Note 1)	Total primary sidelit daylight areas less than 2,500 ft² in an enclosed space and all secondary sidelit areas. (see Note 4)	General Lighting Power Density (W/ft²)	>10% and ≤20%	>20% and ≤35%	>35% and ≤65%	> 65%
		All	0.12	0.20	0.25	0.30
			Effective Aperture			
	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%	General Lighting Power Density (W/ft²)	0.6% ≤ EA < 1%	1% ≤ EA < 1.4%	1.4% ≤ EA < 1.8%	1.8% ≤ EA
		LPD < 0.7	0.24	0.30	0.32	0.34
		0.7 ≤ LPD< 1.0	0.18	0.26	0.30	0.32
		1.0 ≤ LPD < 1.4	0.12	0.22	0.26	0.28
		1.4 ≤ LPD	0.08	0.20	0.24	0.28

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.

NOTES FOR TABLE 146-C:

5. PAFs shall not be available for lighting controls required by Title 24, Part 6.

To qualify for the PAF the multi-level occupant sensor shall comply with the applicable requirements of Section 119

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.

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.

4.3 Code Language Proposed by the California Energy Commission

Below is the text of the code language proposed by the California Energy Commission for section 150(k). This language was sent by the CEC to the California investor-owned utilities Codes and Standards Team on August 17, 2011.

SECTION 101

Aisle Way is a warehouse facility term describing a long, usually narrow space between storage racks. ~~Aisles are usually lit using a single row of ceiling fixtures along the centerline of the aisle.~~

Commercial and Industrial Storage Area is a room, or area~~, or building~~ used for storing items.

Open Area is a warehouse facility term describing a large unobstructed area that is typically used for the handling and temporary storage of goods.

SECTION 131(c)

6. Areas where partial ON/OFF occupant sensors are required in addition to complying with Section 131(c)1.

A. In aisle ways and open areas in warehouses, lighting shall be controlled with occupant sensors that automatically reduce lighting power by at least 50 percent. The occupant sensors shall independently control lighting in each aisle way, and shall not control lighting beyond the aisle way being controlled by the sensor.
EXCEPTION 1 to Section 131(c)6A: In aisle ways and open areas in warehouses in which the installed lighting power is 80 percent or less of the value allowed under the Area Category Method, occupant sensors shall reduce lighting power by at least 40 percent.
EXCEPTION 2 to Section 131(c)6A: When metal halide lighting is installed in warehouses, occupant sensors shall reduce lighting power by at least 40 percent.

B. In library book stack aisles 10 feet or longer that are accessible from only one end, and library book stack aisles 20 feet or longer that are accessible from both ends, lighting shall be controlled with occupant sensors that automatically reduce lighting power by at least 50 percent. The occupant sensors shall independently control lighting in each aisle way, and shall not control lighting beyond the aisle way being controlled by the sensor.

7. Areas where partial ON/OFF occupant sensors are required instead of complying with Section 131(c)1.

- **A. [Subject not addressed in this CASE report]**
- **B. In parking garages, parking areas and loading and unloading areas, general lighting shall be controlled by occupant sensors having at least one control step between 20 percent and 50 percent of design lighting power. No more than 500 watts of rated lighting power shall be controlled by a single occupant sensor. A reasonably uniform level of illuminance shall be achieved in accordance with the applicable requirements in Table 131-A**

  Note: Interior areas of parking garages are classified as indoor lighting for compliance with Section 131(c)5C. Parking areas on the roof of a parking structure are classified as outdoor hardscape and shall comply with the applicable provision in Section 132.

SECTION 146(c)

Note that the table shown below reflects only the changes relevant to this CASE report, and does not reflect other proposed changes to this table.

TABLE 146-A LIGHTING POWER ADJUSTMENT FACTORS

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
~~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.~~		~~Hallways of hotels/motels , multi-family, dormitory, and senior housing~~	~~0.25~~
		~~Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)~~	~~0.15~~
		~~Library Stacks (maximum 2 aisles per sensor)~~	~~0.15~~
Dimming system	Manual	Hotels/motels, restaurants, auditoriums, theaters	0.10
	Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters	0.20
Demand responsive lighting control that reduces lighting power consumption in response to a demand response signal. (See Note 1)		All building types	0.05
Manual dimming of dimmable electronic ballasts. (see Note 3)		All building types	0.10
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).		All building types	0.15
Combined controls	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	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	0.10
	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.	Any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, ~~corridor~~, conference or waiting room	0.25

			Effective Aperture			
Automatic multi-level daylighting controls (See Note 1)	Total primary sidelit daylight areas less than 2,500 ft^2 in an enclosed space and all secondary sidelit areas. (see Note 4)	General Lighting Power Density (W/ft^2)	>10% and ≤20%	>20% and ≤35%	>35% and ≤65%	> 65%
		All	0.12	0.20	0.25	0.30
			Effective Aperture			
	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%	General Lighting Power Density (W/ft^2)	0.6% ≤ EA < 1%	1% ≤ EA < 1.4%	1.4% ≤ EA < 1.8%	1.8% ≤ EA
		LPD < 0.7	0.24	0.30	0.32	0.34
		0.7 ≤ LPD< 1.0	0.18	0.26	0.30	0.32
		1.0 ≤ LPD < 1.4	0.12	0.22	0.26	0.28
		1.4 ≤ LPD	0.08	0.20	0.24	0.28

~~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.~~

4.4 Explanation of Language Changes

Differences between the recommended language in section 4.2 and the language proposed by the California Energy Commission in section 4.4 are as follows:

- The CEC language rearranges the definitions of "Aisle way" and "Open area" to place them independently instead of as part of the definition for "Commercial and Industrial Storage."
- The CEC language removes the typical lighting description from the "Aisle way" definition and removes the phrase "or building" from the Commercial and Industrial Storage" definition.
- The CEC language changes the text of section 131(c)6 to read, "Areas where <u>partial</u> ON/OFF occupant sensors are required in addition to complying with Section 131(c)1," to clarify that only partial shutoff is required. Note that the term "partial on/off occupant sensor" does not yet have a definition in Section 101, but this is probably not needed, because it is not a "term of art" and the equipment used to achieve partial switching can be the same as the equipment used for full switching.
- The CEC language consolidates the notes in the Power Adjustment Factor table into a single note at the top of the table reading, "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."
- The CEC language includes a requirement for occupancy sensor control of at least half the lighting load in library book stacks, as recommended by the IOU team in response to stakeholder requests.

Differences between the recommended language in section 0 and the language proposed by the CEC as shown in section 4.3 represent clarifications, rewordings or rearrangements of the original recommended language. The intent of the language proposed by the California Energy Commission is consistent with the intent of the language recommended by this CASE report, and the modifications to the initial language do not affect the energy savings achieved by the measure

4.5 Material for Compliance Manuals

We will develop material for the compliance manuals in the final CASE report once the proposed code language has been approved by the California Energy Commission.

In this section, we will provide information that will be needed to develop the Residential and/or Nonresidential Compliance Manuals, including:

- Possible new compliance forms or changes to existing compliance forms.

- Examples of how the proposed Standards change applies to both common and outlying situations. Use the question and answer format used in the 2005 Residential and Nonresidential Compliance Manuals.
- Any explanatory text that should be included in the Manual.
- Any data tables needed to implement the measure.

5. Addendum – Library Stack Lighting Controls

5.1 Analysis and Results

This section summarizes the results of the energy savings and cost analysis conducted for library stacks. It includes an analysis of the amount of statewide floorspace, occupancy sensor energy savings, equipment prices, and measure cost-effectiveness. Energy Savings

Because we were not able to locate data on occupancy patterns specifically for library stack aisles, we assumed that library savings patterns would be most similar to the results for refrigerated aisles (see Figure 4). Aisleway occupancy data were available for nonrefrigerated, refrigeration, and freezer aisles; we chose to use the refrigerated aisle data as a proxy for library stacks. Nonrefrigerated aisles are an unsuitable comparison because they are daylit and therefore have less savings available during the day than library stacks (which are unlikely to be daylit); freezer aisles are an unsuitable comparison because they have infrequent occupancy.

Savings estimates for libraries were modified to account for the higher allowable lighting power density of 1.5 W/sf for library stacks, and to reflect the difference in operating hours. As discussed above, library operating hours were collected from the websites of each of the eight surveyed libraries, and compiled to create the schedule shown below in Figure 17. The schedule in Figure 17 shows the percentage of libraries open for each hour of each day of the week.

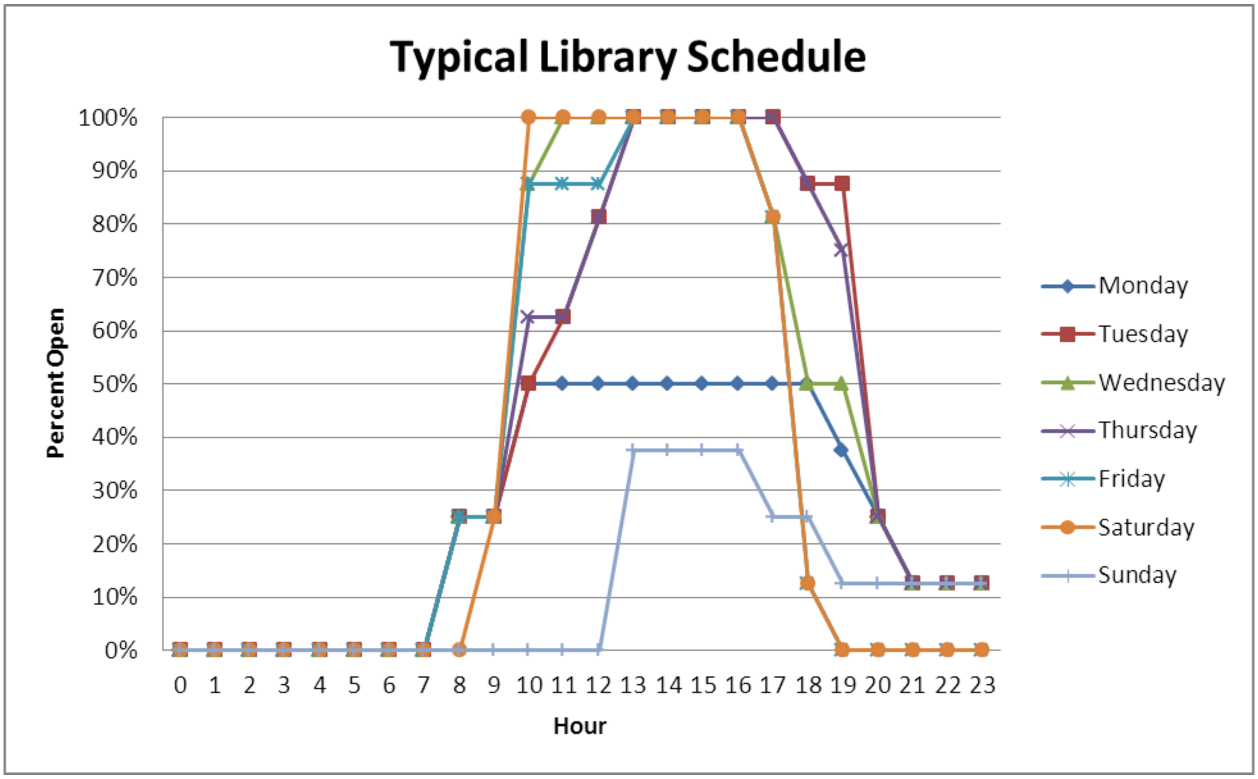

Figure 17: Schedule of Typical Library Hours (by percent of libraries open)

The schedule data shown in Figure 17 was combined with the savings estimates for refrigerated warehouse aisles (shown in Figure 4), and a multiplier was applied to transform the savings estimates from 0.6 W/sf LPD for warehouses to the 1.5 W/sf LPD allowed for library stacks.

Figure 18, below, shows the resulting estimated savings for library stacks (in W/sf) from the use of occupancy sensors, broken down by hour of the day and day of the week. Savings figures shown in the table below assume auto-on/auto-off occupancy sensors with a 30 minute delay time, consistent with the assumptions used in the warehouse analysis.

Based on the savings estimates shown below, the average energy savings from the proposed requirement to control 50% of library stack aisle lighting with on/off occupancy sensor would be 1.08 kWh/ft^2/year. The 50% requirement was chosen to be consistent with the proposed warehouse aisle requirements.

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.21	0.21	0.21	0.21	0.21	0.00	0.00
9	0.17	0.17	0.17	0.17	0.17	0.17	0.00
10	0.34	0.34	0.59	0.42	0.59	0.68	0.00
11	0.44	0.55	0.88	0.55	0.77	0.88	0.00
12	0.39	0.63	0.78	0.63	0.68	0.78	0.00
13	0.39	0.78	0.78	0.78	0.78	0.78	0.29
14	0.54	1.08	1.08	1.08	1.08	1.08	0.40
15	0.43	0.85	0.85	0.85	0.85	0.85	0.32
16	0.33	0.65	0.65	0.65	0.65	0.65	0.24
17	0.33	0.65	0.53	0.65	0.53	0.53	0.16
18	0.33	0.57	0.33	0.57	0.08	0.08	0.16
19	0.23	0.55	0.31	0.47	0.00	0.00	0.08
20	0.15	0.15	0.15	0.15	0.00	0.00	0.08
21	0.07	0.07	0.07	0.07	0.00	0.00	0.07
22	0.08	0.08	0.08	0.08	0.00	0.00	0.08
23	0.08	0.08	0.08	0.08	0.00	0.00	0.08

Figure 18: Library Stacks Lighting Energy Savings from use of Occupancy Sensors (W/sf)

5.1.1 Statewide and Peak Load Savings

For the purpose of estimating statewide construction, libraries fall under three building type categories in the CEC Construction Forecast. School and university libraries fall under the *school* and *college* categories respectively, and public libraries fall under the *miscellaneous* category. Based on US Department of Energy Reference Building models[1], we estimated that

[1] National Renewable Energy Laboratory, 2011.

5% of school and college square footage is library. In addition, based on data collected by the California State Library[1], and commercial building stock data in the California Commercial End-Use Survey (CEUS)[2], we estimated that 1.5% of miscellaneous commercial square footage is library. Finally, based on plans and photographs of the surveyed libraries, we estimated that, on average, approximately 50% of a library's floor area is taken up by bookstacks. Based on these estimates and the Non-Residential New Construction Forecast[3], we expect library stacks to make up 655,000 square feet of new construction per year. Of that 655,000 square feet, we expect 10%, or 65,500 square feet to have aisles long enough to require occupancy sensors.

Using the energy savings results discussed in the previous section and the construction estimates, we expect statewide energy savings from occupancy controls in library stack aisles to be 0.07 GWh/year, with a statewide peak load reduction of 0.04 MW.

5.1.2 Technical Feasibility

The technical feasibility of this measure depends on the ability of occupant sensors to reliably detect movement of people along a library stack aisle, while not being triggered by the movement of people across the end of the aisle (i.e. in adjacent areas). Library stacks are a challenging environment for occupant sensors because they are usually not sufficiently enclosed for ultrasonic sensors to work effectively, and infra-red sensors are much better at detecting movement across their field of view than they are of detecting movement toward or away from the sensor. Therefore, the most reliable solution in most cases is to use *two* sensors, one at each end of the aisle and oriented toward the center of the aisle.

Sensors that are suitable for this application are available from multiple manufacturers. For instance, sensors with 180 degree coverage include the Wattstopper WPIR series and Leviton OSC- series. Sensors that are designed for low mounting height and can be adjusted for small area detection (fixture-mounted sensors) include the Wattstopper FS- series and Leviton OSF10. Sensors with narrower fields of view than these are available by using special shields and lenses, but these incur additional design costs and additional risk of failure due to incorrect specification or design, so we have not used these special sensors as the basis for this measure.

Based on the coverage patterns from manufacturers' cut sheets for the sensors cited above, the minimum length of the library stack aisle that can reliably be covered by two of these sensors is 20-24' for a 10' ceiling. For ceilings above 10', special narrow field sensors can be used, or the sensors can be mounted on brackets attached to the bookstacks, from pendant rods from the ceiling, or to the underside of suspended fixtures.

5.1.3 Cost Effectiveness

Cost effectiveness for occupancy sensors in library stack aisles was determined using the same methodology as described above in Section 3.7. Initial installed costs per sensor are assumed to be $169.91, consistent with the findings described in Section 3.7.1. However, cost per square foot varies with the length of the stack aisle since each aisle would be controlled by a separate occupant sensor.

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[1] California State Library, 2011.

[2] California Energy Commission, 2005.

[3] California Investor-Owned Utilities, 2007.

Savings estimates were calculated using the Time Dependent Valuation (TDV) method as described in Section 2.10. Using the savings estimate schedule shown in Figure 18, and assuming that half the lighting in each aisle is controlled by an occupant sensor, the resulting TDV savings is estimated to be $2.61 per square foot of library stack. Stacks are assumed to be double-sided so that the sensor can be positioned over the centerline of the stack and “see” people on both sides of the stack.

Figure 19, below, illustrates the life cycle cost savings from the use of occupancy sensors in library stack aisles. Positive ΔLCC values, and Benefit:Cost Ratios greater than 1 indicate scenarios where the proposed measure is cost effective.

Stack Length (ft)	Cost ($/ft^2)	Savings (TDV $/ft^2)	ΔLCC (TDV $/ft^2)	Benefit:Cost Ratio
8	$7.08	$2.61	-$4.47	0.37
12	$4.72	$2.61	-$2.11	0.55
16	$3.54	$2.61	-$0.93	0.74
20	$2.83	$2.61	-$0.22	0.92
22	$2.57	$2.61	$0.04	1.02
24	$2.36	$2.61	$0.25	1.11
26	$2.18	$2.61	$0.43	1.20

Figure 19: Life Cycle Cost Savings

Figure 19 indicates that occupancy sensors in library stack aisles will be cost effective for all aisles at least 22 feet long.

6. Bibliography and Other Research

6.1 Codes and Standards

California Code of Regulations (CCR), Title 24. 2007. Known as the California Building Standards Code. Regarding standards for emergency egress lighting. http://www.bsc.ca.gov/title_24/default.htm

Life Safety Code of the National Fire Protection Association (NFPA). 2003. Regarding standards for emergency egress lighting. http://www.nfpa.org/categoryList.asp?categoryID=124&URL=Codes%20&%20Standards

Illuminating Engineering Society of North America. 2000. Lighting Handbook, 9th Edition. Regarding recommended light levels for space. www.iesna.org.

California Energy Commission (CEC).2005. Life Cycle Cost Methodology – 2008 California Building Energy Efficiency Standards. Prepared by Architectural Energy Corporation (AEC).

6.2 Personal Communications

Linda Murphy and Keith Sage. 2009. Program staff for California Multifamily New Homes Program. Regarding plans for multifamily buildings. February 2009.

Mara Blitzer. 2008. Senior Project Manager with Tenderloin Neighborhood Development Corp. Regarding use of occupancy sensors in multifamily corridors. October 2008.

Jay Wratten. 2008. Designer with Flack & Kurtz. Regarding use of occupancy sensors in multifamily corridors. November 2008.

Gary Flamm. 2009. Lighting Lead at California Energy Commission. Regarding hierarchy of code and appropriate code language for proposed measure. September 2008-March 2009.

Miguel Castellanos. 2008. Engineer with ECOM Engineering. Regarding installation and reliability of occupancy sensors. September 2008.

Teresa Clarke. 2008. Developer with Affordable Housing Alliance. Regarding her experience with controls in AHA's multifamily buildings. September 2008.

6.3 Other

SensorSwitch, Inc. 2008. Logged data from occupancy sensors. Not published.

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7. Appendices

7.1 Appendix A – Stakeholder Group Participants

The Stakeholders Group includes those who attended one of the three meetings, and a few people who we contacted separately to make use of specific expertise. Note that the Stakeholder Group for this proposed measure was combined with the Stakeholder Group for a measure on occupancy sensors in hotel and multifamily buildings.

- George Loisos, Architect/Lighting Designer, Loisos + Ubbelohde Architects
- Lisa Bornemann, Lighting Designer, H. E. Banks + Associates
- Christ Surunis, Sr. Account Supervisor - Hospitality, Lutron Electronics Company, Inc.
- Teresa Clarke, Senior Project Manager, Affordable Housing Associates
- Jeff Fox, Director of Projects and Product Development, Hilton Garden Inn Brand Management
- Ben Hahn, Marketing Manager, SensorSwitch
- Jim Abrams, President (Now Retired), California Hotel and Lodging Association
- Bobbie Singh-Allen, VP of Government Relations, California Hotel and Lodging Association
- Charles Knuffke, Panel Manager, The Watt Stopper
- Gregor Stewart, Associated Lighting Representatives, Inc.
- Nick Bleeker, Director of Business Development, Day-Brite Capri Omega
- Gary Flamm – California Energy Commission
- Jeff Fox - Hilton Hotels, Hilton Garden Brand
- Rick Lawton – Safeway
- Eric Richman – PNNL
- Lynn Mohrfield – California Hotel and Lodging Association
- Mike Crockett - Safeway

7.2 Appendix B—Illuminance Plots for Warehouses

This sections shows floor-level illuminance plots for a warehouse aisle (top of image) and open space (bottom of image) generated by Lumen Designer using standard radiosity calculations on a regular grid.

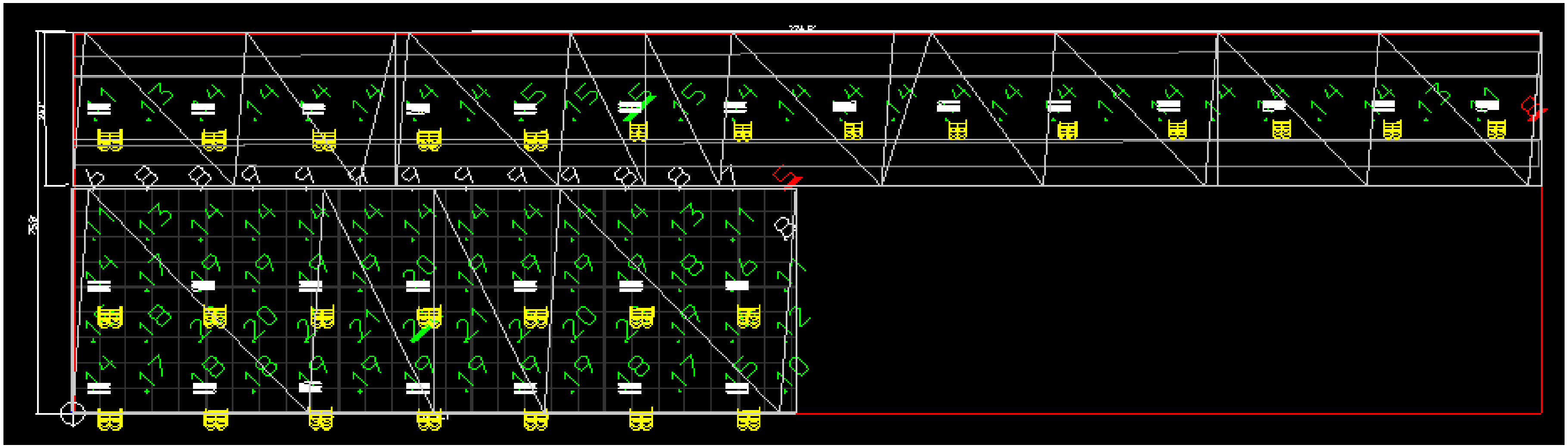


Figure 20. Illuminance Plot for Occupied State (all lighting on)

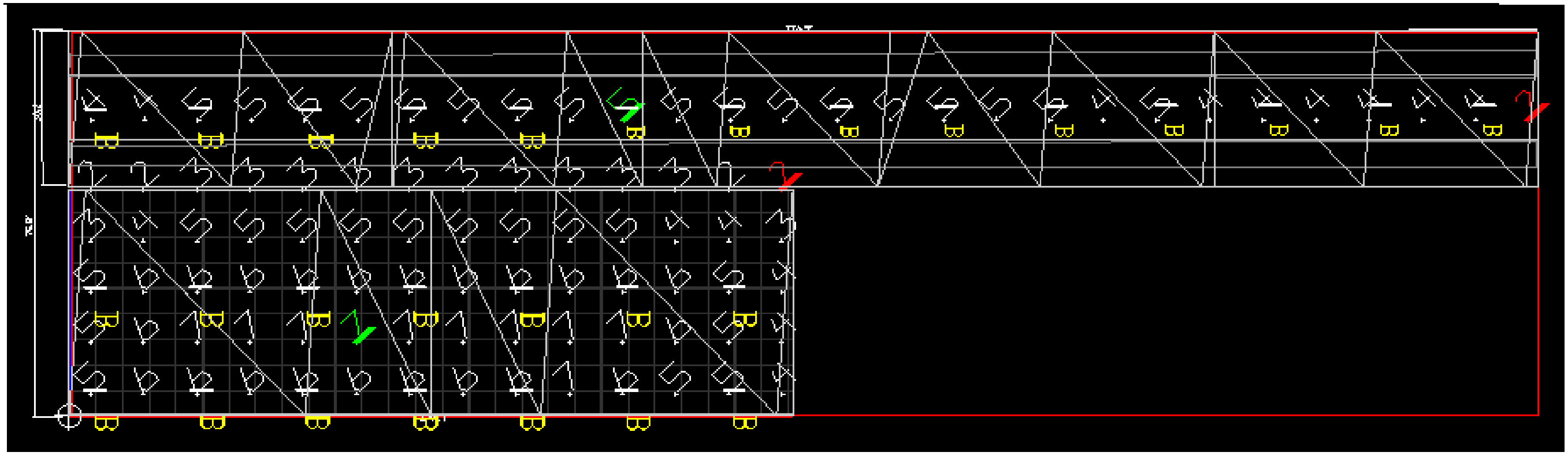


Figure 21. Illuminance Plot for Unoccupied State (2/3 of lamps off)

7.3 Appendix C—Results of Market and Pricing Survey

This appendix shows the results of the market and pricing survey. The survey was conducted in November and December 2008. The column showing “Required auxiliary equipment price” refers to power supplies and lenses that had to be included to make the equipment functional.

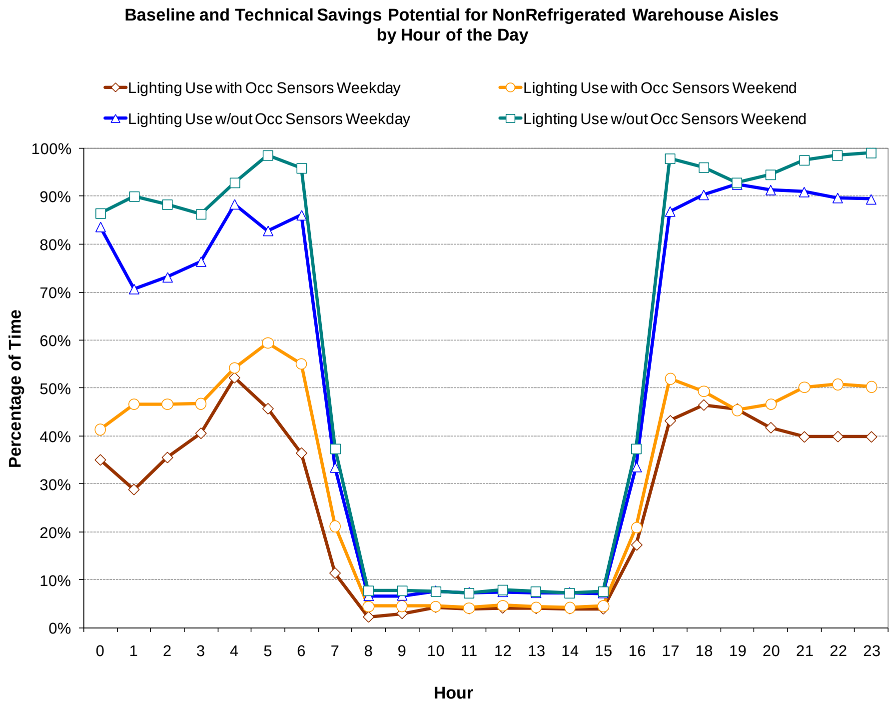
Region	Manufacturer Name	Unit Price	Req Aux Equipment Price	Low voltage model?	Line Voltage Model?	Infrared Model?	Ultrasonic Model?	Dual Tech Model?
BA	Leviton	$129.00	$31.00	TRUE	FALSE	FALSE	FALSE	TRUE
IE	Leviton	$125.00	$35.70	TRUE	FALSE	FALSE	FALSE	TRUE
IE	Leviton	$107.60	$35.70	TRUE	FALSE	FALSE	FALSE	TRUE
IE	WattStopper	$90.44	$23.41	TRUE	FALSE	FALSE	TRUE	FALSE
IE	WattStopper	$74.81	$23.41	TRUE	FALSE	FALSE	TRUE	FALSE
IE	WattStopper	$86.00	$35.00	TRUE	FALSE	TRUE	FALSE	FALSE
IE	WattStopper	$100.00	$35.00	TRUE	FALSE	FALSE	TRUE	FALSE
IE	WattStopper	$162.00	$35.00	TRUE	FALSE	FALSE	FALSE	TRUE
IE	WattStopper	$43.00		FALSE	TRUE	TRUE	FALSE	FALSE
LA	Leviton	$137.19		TRUE	FALSE	FALSE	TRUE	FALSE
LA	Leviton	$91.46		TRUE	FALSE	FALSE	FALSE	TRUE
LA	Leviton	$157.13		TRUE	FALSE	FALSE	FALSE	TRUE
SD	SensorSwitch	$67.50		FALSE	TRUE	FALSE	FALSE	FALSE
SD	SensorSwitch	$43.50		FALSE	TRUE	FALSE	FALSE	TRUE
SD	WattStopper	$90.00	$30.00	TRUE	FALSE	FALSE	TRUE	FALSE
SD	WattStopper	$110.00	$30.00	TRUE	FALSE	FALSE	TRUE	FALSE
Sac	SensorSwitch	$49.95		FALSE	TRUE	FALSE	FALSE	FALSE
Sac	SensorSwitch	$93.75		TRUE	FALSE	FALSE	FALSE	TRUE
Sac	SensorSwitch	$95.00		TRUE	FALSE	FALSE	FALSE	TRUE
Sac	WattStopper	$105.63	$25.02	TRUE	FALSE	FALSE	TRUE	FALSE
Sac	WattStopper	$123.38	$25.02	TRUE	FALSE	FALSE	TRUE	FALSE
LA	WattStopper	$92.67	$20.67	TRUE	FALSE	FALSE	TRUE	FALSE
LA	WattStopper	$40.00		FALSE	TRUE	TRUE	FALSE	FALSE
LA	Leviton	$140.00	$34.00	FALSE	FALSE	FALSE	FALSE	TRUE

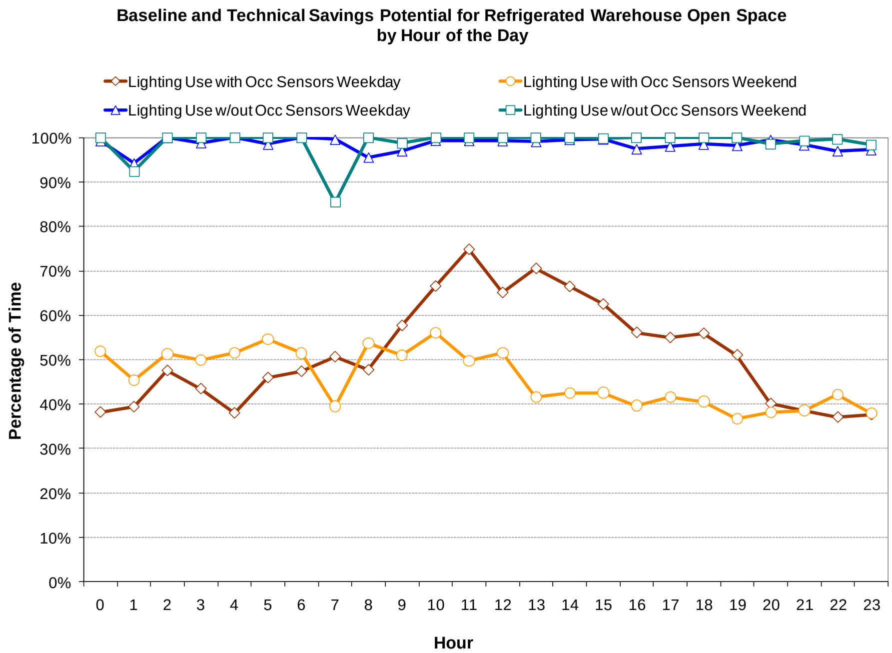
Region	Manufacturer Name	Unit Price	Req Aux Equipment Price	Low voltage model?	Line Voltage Model?	Infrared Model?	Ultrasonic Model?	Dual Tech Model?
BA	SensorSwitch	$49.00		FALSE	TRUE	FALSE	FALSE	FALSE
BA	SensorSwitch	$75.60	$37.32	TRUE	FALSE	FALSE	FALSE	FALSE
BA	SensorSwitch	$63.00		TRUE	FALSE	FALSE	FALSE	TRUE
BA	WattStopper	$109.00		TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$95.00		TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$120.00	$30.00	TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$100.00	$30.00	TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$80.00	$30.00	TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$88.20	$24.80	TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$107.10	$24.80	TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$125.10	$24.80	TRUE	FALSE	FALSE	TRUE	FALSE
BA	SensorSwitch	$50.00		FALSE	TRUE	FALSE	FALSE	FALSE
BA	SensorSwitch	$65.00		TRUE	FALSE	FALSE	FALSE	TRUE
BA	WattStopper	$107.00	$27.30	TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$91.63	$27.30	TRUE	FALSE	FALSE	TRUE	FALSE
BA	WattStopper	$75.00	$27.30	TRUE	FALSE	FALSE	TRUE	FALSE
BA	Leviton	$25.00	$31.00	TRUE	FALSE	TRUE	FALSE	FALSE

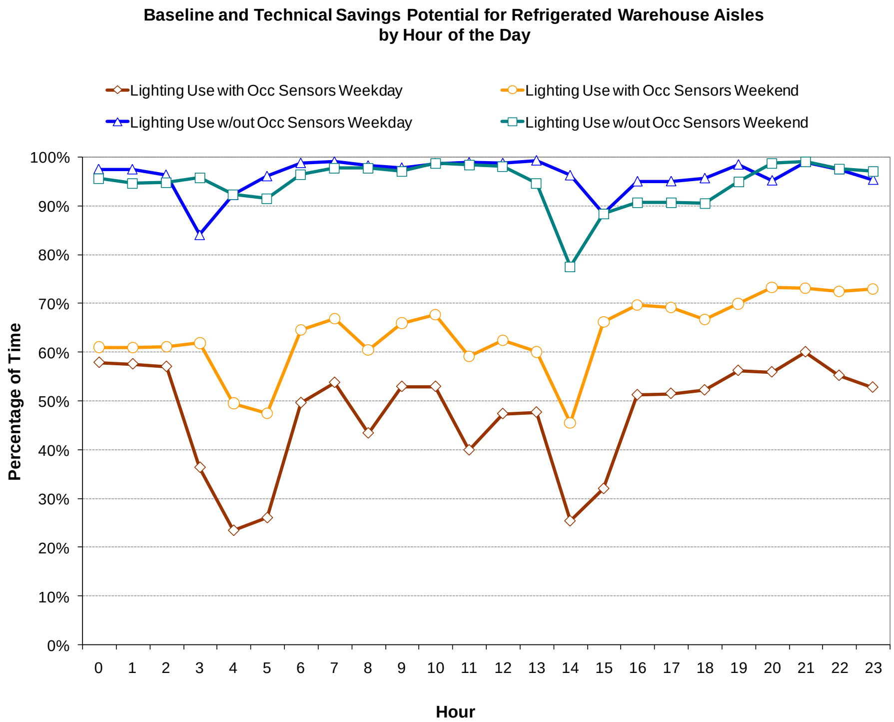
Figure 22. Results of Market and Pricing Survey

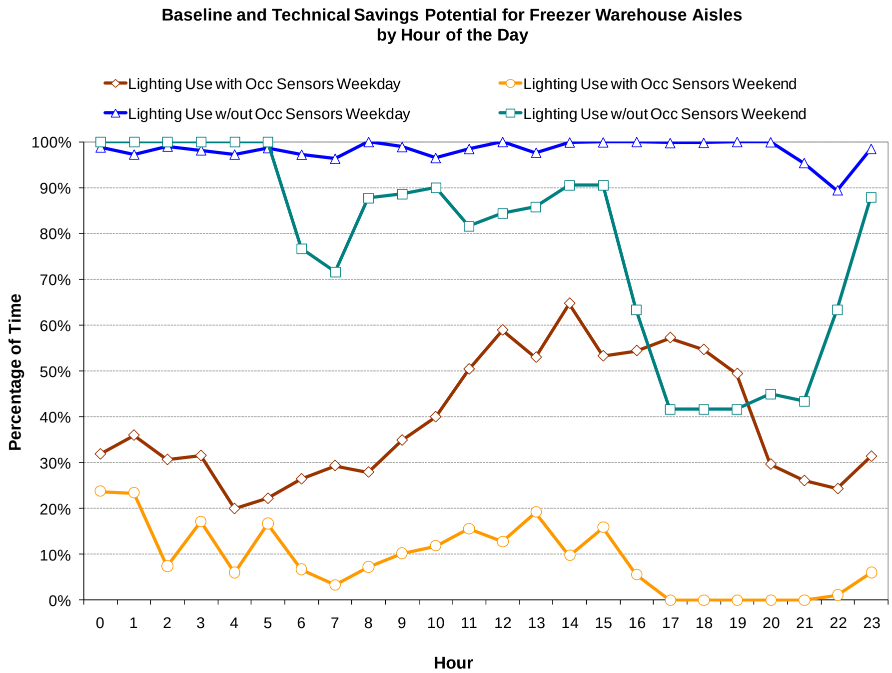
7.4 Appendix D –Energy Use Graphs

The following graphs show the energy use before occupancy sensors are installed (blue and gray lines) and the energy use after installation (yellow and red lines). The difference between the lines is the amount of savings realized for each space type. Each data point is the percentage of time that lights are on for a given hour of the day. This data is first presented in section 3.3.


Baseline and Technical Savings Potential for NonRefrigerated Warehouse Aisles
by Hour of the Day
Lighting Use with Occ Sensors Weekday
Lighting Use with Occ Sensors Weekend
Lighting Use w/out Occ Sensors Weekday
Lighting Use w/out Occ Sensors Weekend
Percentage of Time
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour


Baseline and Technical Savings Potential for Refrigerated Warehouse Open Space
by Hour of the Day
Lighting Use with Occ Sensors Weekday
Lighting Use with Occ Sensors Weekend
Lighting Use w/out Occ Sensors Weekday
Lighting Use w/out Occ Sensors Weekend
Percentage of Time
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour


Baseline and Technical Savings Potential for Refrigerated Warehouse Aisles
by Hour of the Day
Lighting Use with Occ Sensors Weekday
Lighting Use with Occ Sensors Weekend
Lighting Use w/out Occ Sensors Weekday
Lighting Use w/out Occ Sensors Weekend
Percentage of Time
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour



7.5 *Appendix E—Non-Residential Construction Forecast details*

7.5.1 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.

7.5.2 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.

7.5.3 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)

7.6 Appendix F—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	0.0005	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 23. Materials Content of Typical Lighting Components, by Weight

Note that in Figure 23 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[1] 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 www.ballastshop.com, and corroborated by the Lighting Research Center's Specifier Report on electronic ballasts[2].

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[3].

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

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

[3] http://en.wikipedia.org/wiki/American_wire_gauge, and http://en.wikipedia.org/wiki/Cat_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.