Lighting Controls

Codes and Standards Enhancement (CASE) Study

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Introduction

CASE Initiatives are Codes and Standards Enhancement (CASE) Studies that present arguments for including specific energy efficiency technologies or practices into existing energy codes, thereby providing a platform for consensus making among stakeholders. This CASE study, which addresses lighting controls, includes descriptions of the:

- technology,
- current practice,
- economics,
- key stakeholders, and
- implementation options and recommendations for inclusion in codes.

Lighting Controls in Current Title 24

Title 24, California's Energy Efficiency Standards for Nonresidential Buildings (Standards), generally applies to all nonresidential buildings, and also to the common areas of hotels/motels and high-rise residential (over three stories) buildings. Section 119 specifies control capabilities that manufacturers must certify to the California Energy Commission (Commission). Sections 130–139 specify the general lighting system and equipment requirements. High-rise residential and hotel/motel guest rooms are exempted from most of the requirements in this portion of the Standards and are subject instead to the residential lighting requirements; these space types will not be discussed in the remainder of this study.

Mandatory Lighting Control Requirements

The mandatory lighting control requirements apply to all lighting systems governed by the Standards. They establish minimum standards of practice for the types of lighting controls that must be installed, and for the capabilities of those controls. These mandatory measures quickly become "standard" practice in California construction. As a result, these requirements play a very powerful role in establishing basic lighting efficiency practices throughout the state.

Bi-level control

The Standards require that most spaces in buildings be switched or dimmed so that the lighting can be reduced by approximately one-half. The Standards refer to this strategy as "controls to reduce lighting"; less formally, it is called bi-level control. Techniques to accomplish bi-level control include:

- Switching that turns off half the lights in a space,
- Dimmers that reduce the entire space's light level by half,
- Individual switches for two or more groups of luminaires in a space, or
- Switching of the middle lamp of three-lamp luminaires.

There are a number of exceptions where bi-level control is not required. The first is for areas where it is generally impractical: spaces smaller than 100 square feet, spaces with only one luminaire, or spaces with less than 1.0 W/ft_ of installed lighting power.

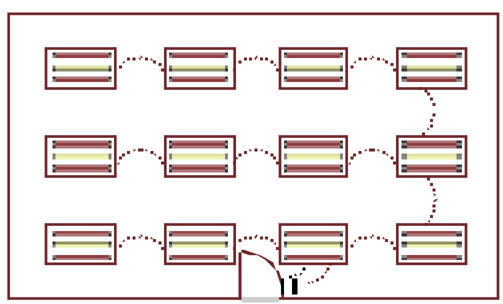

Figure 1. Bi-level Control Example

Figure 1 shows an example of a series of three-lamp luminaires with bi-level control. The outboard lamps are switched separately from the inboard lamps. This provides the occupant with four manually adjustable lighting levels: all on, two-thirds on, one-third on, and all off.

The Standards allow an exception when occupancy sensors control all the lights in a space.

The Standards also allow a bi-level control exception when there is an automatic time switch control device with a timed local override integrated into each manual switch.

Finally, bi-level control is not required in corridors.

Daylit area control

Another mandatory lighting control requirement of the Standards is that daylit areas in any space of over 250 square feet must have controls capable of switching 50% of the lamps in the daylit area separately from lamps in the non-daylit areas. The daylit area requirement may be met with manual switches or dimmers. This switching requirement is separate, and in addition to, the bi-level control requirement. As a consequence, a room with both daylit and non-daylit areas might have three or more switches to accommodate both requirements (or two separate dimmers).

Automatic shut-off control

A third lighting requirement of the Standards is that every building (or floor in a multistory building) over 5000 square feet in area must have controls that automatically turn off the lights during normally unoccupied time periods. This may be accomplished by using occupancy sensors or automatic timer controls.

If an automatic time switch is used to meet this requirement, it must, with limited exceptions, have an automatic holiday shut-off feature. In essence, this requires a 365-day programmable time switch. Also, there must be a manual override at each switch location for people working after hours. When the override is activated, it must automatically revert to the programmed schedule after no more than two hours. Figure 2 provides an example of how automatic shut-off controls might be installed in a building with both office and retail space.

If occupancy sensors are used to meet this requirement, then they must be installed throughout the building.

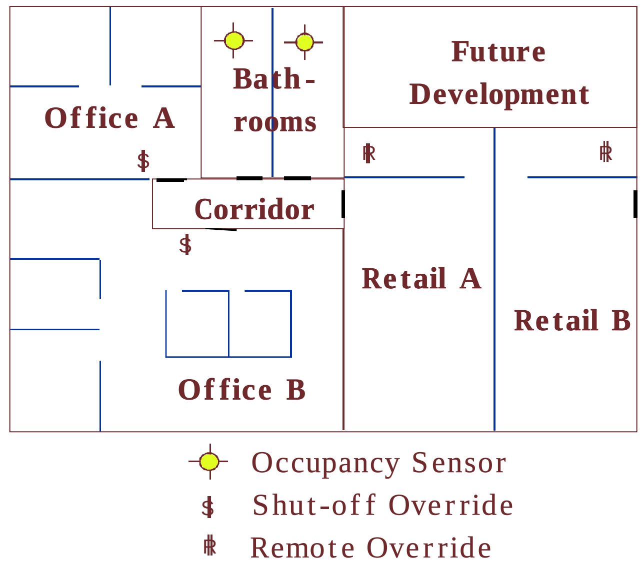

Figure 2. Automatic Shut-off Control Example

Mandatory Control Features

Devices used to meet the lighting control requirements must, according to the Standards, be supplied with instructions for installation calibration, have status signals, and be installed in accordance with the manufacturer's instructions. There are also specific requirements governing the details of operation for occupancy sensors, daylighting controls and other types of controls, which the manufacturer must meet.

Additions and Alterations

The Standards apply to all new work, and to alterations to existing lighting systems. The switching requirements are triggered whenever partitions are rearranged, because they apply room-by-room. The lighting control requirements, unlike the lighting power requirements, are not invoked simply by the replacement of lighting fixtures or changes in the installed lighting power. For example, if a room had only one switch, and all of the luminaires were replaced, then the lighting power density would be limited as if it were a new building. No additional lighting controls would be required.

LPD and Control Credits

The Standards limit the installed lighting power, expressed in watts per square foot or lighting power density (LPD). The allowed LPD is, in some cases, dependent on the application of lighting controls. When a lighting control is installed, it operates a specific block of lights. The lighting control credit is used to adjust the installed lighting power calculated for that block of lights.

For example, if a control operates 10,000 watts of installed lighting, and it qualifies for a lighting control credit of 0.20, then 20% of the 10,000 watts (2000 watts) are subtracted from the installed lighting power. This adjusted lighting power of 8000 watts makes it easier to meet the limitation on LPD. In effect, there is a tradeoff between the lighting control and a larger lighting power budget.

In theory, the energy use is equivalent between an LPD that meets the Standard, and a higher LPD combined with a lighting control device (where the adjusted LPD also meets the Standard). In actuality, there may be more or less energy use, depending on the occupancy pattern and the operation of the automatic lighting control.

Considerations for Standards Revisions

The Commission is required to show that the Standards are cost effective. Historically, lighting controls have been difficult to mandate because of the uncertainty regarding their use. The current requirements were based on cost-effectiveness analysis that was consensus based. Future requirements may require a more rigorous approach.

Technologies Considered

This CASE Study organizes the rather complex subject of lighting controls into a series of comparisons between competing alternatives. The comparisons are introduced here, and are then used throughout this study to discuss the implications and effectiveness of their use.

Bi-level Lighting Control vs. Single-Level Control

Bi-level lighting control is an extension of single-level control, offering the ability to reduce lighting power by 50% or more. It is a manual control strategy, which depends for its savings on the action of occupants.

Occupancy Sensor vs. Bi-level Control

The Standards allow the installation of occupancy sensors in lieu of bi-level control. A control credit may also be earned for the occupancy sensor. This replaces a more flexible manual control with an automatic control, and is assumed to save greater energy.

Automatic Shut-off vs. Manual Switch

The Standards require larger buildings to have automatic shut-off controls with accessible manual override controls. In some cases a lighting control credit is earned. This only applies to systems that have room-by-room override capabilities.

Daylight Area vs. General Switching

The Standard require daylit area switching in all areas over 250 square feet. This requirement is intended to give occupants the option of turning off lights when there is adequate daylight. This strategy has the same characteristics as bi-level control, in that it depends on occupant behavior to save energy.

Automatic Daylighting Control vs. Manual Daylighting Control

The Standards allow the option of using automatic daylighting controls to automatically reduce electric lighting when there is adequate daylight. The magnitude of the credit depends on the availability of daylight and on the type of daylighting control that is installed.

Technology Description

This section describes each of the lighting control strategies that are addressed in this report, and the technologies that may be used to implement them. We distinguish the term "control strategy," which describes the operation of controls to achieve energy savings, from the term "control technology", vzwhich refers to the particular hardware that is used. For example, the bi-level control is a strategy for reducing lighting levels in a room, and it may be implemented with different control technologies including simple light switches or dimming controls.

Throughout this section the technologies are first introduced, then information is provided based on interviews with electrical contractors. The interviews were extensive in-depth conversations that generally took just under an hour. Partly because of the time investment required for each interview, a low volume of interviews (nine) was conducted. The important effect of this is that for certain occupancy/control strategy combinations, the sample was quite small and the information presented should be characterized as anecdotal.

Besides alternative control strategies, two control technology issues emerged in our interviews with contractors: tandem-wired fixtures and dimmable ballasts.

Tandem-wired fixtures

Tandem-wired fixtures are not uncommon in large office installations but apparently aren't the rule either. Most contractors noted that there can be problems handling them. Problems include having to reeducate the installing staff (or simply making sure they are more careful in layout of the wiring runs) and occasional problems with the fixed length of the master/slave cabling not reaching where it has to go, given specific office lighting layouts. These "problems" did not seem to be of great concern to any of the contractors.

Dimmable ballasts

Dimmable ballasts are installed when asked for by the client—in other words, not often. They add about $40–50 per fixture and are typically on "line only" type controls. The contractors report that additional switching costs are about $150 each.

Bi-level Lighting Control

The following sections discuss the application of bi-level control to various space types.

Large Offices

It was virtually unanimous among electrical contractors that bi-level switching is avoided in large offices by the use of other strategies that the code allows as exceptions. These other strategies might not be cost effective if the only benefit was the avoidance of bi-level switching, but they offer other advantages in terms of code compliance, economics and utility. These issues are discussed further in the sections on occupancy sensors and automatic shut-off controls.

Small Offices

The typical small office has 3 to 4 three-lamp fixtures. Bi-level control, when present, is usually done with inboard-outboard switching.

Schools

Contractors report that there are generally 16–20 fixtures per classroom on 2–4 switches, with switching by row. Another common scenario they described is 12 fixtures per classroom with 2 switches and an occupancy sensor. This is the one occupancy where bi-level switching does appear to be common.

Retail

Bi-level control is very rarely used during open hours, when customers are in the store. It is relatively common, however, to use some form of bi-level control during closed hours, for restocking or cleaning.

Occupancy Sensor Controls

The most common type of automatic lighting controls in use in California is the occupancy sensor. Occupancy sensors can sense motion through infrared technology, through ultrasonic technology, or by a combination of the two. A newer technology senses sound that the occupant makes. Occupancy sensors typically have an adjustable time delay, so the lights go off after some time period during which they no longer sense human presence. Occupancy sensors save energy by ensuring that lights are turned off when they are not needed. Of course, a diligent occupant can actually save more energy by turning off lights when the room is vacated, because there is no time delay in that case. These controls are most appropriate in spaces with intermittent, irregular occupancy, such as bathrooms and conference rooms.

The Standards treat occupancy sensors two different ways. First, they may be used in lieu of the mandatory bi-level control requirement or used to meet the automatic shut-off requirement. This is often a less expensive way to meet these requirements. Second, occupancy sensors may earn a lighting control credit, provided the bi-level control and automatic shut-off control requirements are also met.

RLW's Non-residential New Construction Baseline Study (1999) found that 22%–38% of the buildings in the study had occupancy sensors. In the "Market Transformation Barriers and Strategies Study," (Heschong Mahone Group 2000b) designers, which included electrical contractors, said that if the Standards and the utility programs were to "go away," certain lighting advances (for example, T-8 lamps) would remain but lighting controls "would disappear." The same study found that many building owners at one time had a negative experience with lighting controls that did not work properly, and saw lighting controls (among other energy efficiency options) as sometimes being in conflict with comfort and productivity.

Title 24 occupancy sensor control credit

Only two of the contractors interviewed mentioned that they use the LPD credit for occupancy sensors, but most do use occupancy sensors as a way of avoiding installing bi-level switching. (Note however that in school classrooms, the desirable design includes both bi-level switching and occupancy sensors.) One lighting controls distributor indicated that he uses the LPD credit as a selling point for the control types they sell.

Large Office

Contractors generally did not distinguish between infrared, ultrasonic and dual technology occupancy sensors, but they made clear distinctions between ceiling-mounted and wall-mounted units. Their answers give the clear message that ceiling-mounted sensors are for high traffic and large spaces, while the less expensive wall-mounted sensors are used for individual offices, bathrooms, closets and storerooms.

One contractor said that he'd like to see motion sensors built right into the lamp fixture. Another said that the only occupancy sensors they install are the ones with adaptive technology (onboard logic circuits that adjust the time delays based on occupant behavior). They use these exclusively because their experience is that 75% of the calls back they got for occupancy sensors had to do with customer dissatisfaction with the on/off action/timing in the sensors that don't "learn."

Small Offices

About 80% of occupancy sensors in small offices are the wall-mounted type.

Corridors

According to about half the contractors, hallways don't often have switches (the contractor with the highest estimate, among this half only, said "20% of the time"). These same contractors said hallways generally do have occupancy sensors at a cost of about $1.50–$4.00 per linear foot of hallway. The other half of the contractors said that manual switches are installed in 40%–75% of hallways. This group said occupancy sensors cost about $5 per linear foot of hallway.

Schools

Occupancy sensors are commonly installed in most areas of schools (break rooms, offices, storerooms, gym, etc.) except bathrooms (due to vandalism concerns). Other than classrooms, that generally means 2 wallbox sensors and 8–12 ceiling-mounted sensors per school. When asked for other comments, one contractor offered, "People today would still buy occupancy sensors even if the code did not require it." Roughly three quarters of classrooms have occupancy sensors, but, according to some contractors, this percentage is declining.

Warehouses

Occupancy sensors are rarely installed for controlling lighting in warehouses. We were told that this is due to the long restrike time for HID lamps, which are commonly used in warehouses. It is ineffective to have to wait so long for the lights to come back up when the warehouse employees need to get work done. One contractor claims that occupancy sensors (as the night shut-off strategy) generally are used for the office spaces in warehouses but rarely for the warehouse spaces. This same contractor felt that most warehouse lighting control system installations are a waste because "they don't get used."

Automatic Shut-off Controls

The automatic shut-off control strategy can be implemented with a variety of control technologies, including twist or interval timers, simple time clocks, programmable lighting panel controls, and energy management systems (EMS) or building automation systems (BAS) with lighting control features. These controls may be used as schedulers to shut down lighting equipment, depending upon preset schedules for workdays and holidays, so that lighting is not left on during unoccupied periods.

They may also be used as load shedding controls to reduce the building's peak demand by dimming or shutting off lights during periods of unusually high building energy usage (such as summer heat waves). Rather than responding to a predefined timetable for lighting control, they respond to load signals. They primarily save on peak demand, as the time periods for load shedding are short and energy savings are small.

Energy management or building automation systems are designed primarily to operate complex mechanical systems, but they can be extended to control security, fire and lighting systems as well. They have great flexibility and can be customized to minimize energy use in all of these energy-using systems. Centralized controls are most likely to occur in larger, more complex building situations, such as large buildings, campuses or multi-site corporations.

Large Offices

Overwhelmingly, electrical contractors say that occupancy sensors are the most common method of automatically turning off the lights at night in large offices. They feel that time clock setup is a hassle. Of the two contractors who were exceptions, one said that occupancy sensors and central lighting control systems were used about equally, and the other said that the most common means was a time clock/photocell combination strategy.

Wall (twist) timers are not commonly used except in storage rooms and utility (janitor, electrical and mechanical) closets. One contractor said that he only puts them in as the local bypass control for building sweeps.

Small Offices

Facility managers reported that, for nighttime shut-off, occupants prefer occupancy sensors to night sweeps or time clocks, especially in small office spaces. One manager theorized that occupants can see when occupancy sensors turn off the lights and so they believe that there are energy savings; but since they don't see the effect of time clocks or night sweeps, they are less convinced that there are savings from these technologies.

Another facility manager said, "Automatic time sweeps frustrate the occupants, especially when working late and being alone on an office floor." He said that at least one control was disabled because a frightened worker called 911 to get them out of the building. Another facility manager indicated that problems like those with time sweeps can be solved simply by informing the occupants of the schedule, what to expect, and exactly where the override switches are.

Corridors

According to the majority of the facility managers interviewed, hallways and corridors were manually switched. One facility manager mentioned that the corridors and hallways in his facility are kept on the emergency light circuit and are half switched during night and weekend hours.

Schools

It is now becoming common for schools to have districtwide building automation systems that are capable of controlling the lighting on a predetermined schedule.

Retail

Most retail and grocery stores use time sweeps or sophisticated EMS to meet the automatic shut-off requirement. These systems often serve other energy and cost saving functions, and control heating, air conditioning and ventilation.

Warehouses

Many warehouses, even unconditioned ones, have automatic shut-off controls (as well as other lighting controls), and it may be appropriate for the Commission to consider extending the lighting requirements to them.

The most common ways of shutting off all the lights at night in a warehouse are automatic time switches devoted to that purpose and more sophisticated lighting systems that also control daylight switching. These systems are among the most sophisticated lighting control systems being installed in any of the occupancies we researched, and are chosen on the basis of the energy costs savings.

Occupancy sensors are rarely used except for some small storage spaces. One contractor claimed that occupancy sensors (as the night shut-off strategy) generally are used for the office spaces in warehouses but rarely for the warehouse spaces.

In larger warehouses, lighting management systems, installed primarily as daylighting controls, served as the automatic shut-off too. These were installed to reap energy cost savings, not because of code requirements.

Daylit Area Switching

Daylit area switching is a mandatory control strategy under the Standards. The technology for achieving daylit area switching offers the same range of choices, and the same implications for users, as does bi-level control.

Automatic Daylighting Controls

Photosensor controls use a light-sensing device as input to a switching or dimming control device. The broadest application of these is as daylighting controls[1] that dim or shut off portions of lighting systems, depending upon the amount of daylight the sensor sees. When properly designed, the occupants are always provided with at least the design illuminance levels through a mixture of daylight and electric light. The energy savings are due to reduced electric light usage and, to a lesser extent, to reduced cooling loads.

The two general types of daylighting control technology: step switching controls and dimming controls. The step switching controls typically turn off one lamp per fixture at a time, using a simple on/off control (for example, the first lamp goes off at 25 footcandles of daylighting, the second lamp goes off at 50 footcandles, etc.). Dimming controls reduce the electric light levels proportionally to the available daylight. Dimming controls are more costly than step switching controls, but the changes in electric lighting are more gradual and less noticeable to occupants.

There are two strategies for making the control decision to reduce lighting, regardless of the control technology used:

1. Open loop daylighting controls have sensors mounted where they cannot see the electric lighting being controlled, and instead measure the daylight quantities entering the space.
2. Closed loop daylighting controls sense the light level in the space where the electric lights are being controlled, and reduce the electric lighting component as the daylighting component increases.

There are advantages and disadvantages to each strategy, and the lighting control designer must decide which is most appropriate for a given application.

Daylighting controls can be used with skylights, windows, or a combination of both. Daylighting control makes sense as an energy-saving strategy in any space designed with sufficient daylight that is typically used during daytime hours. Daylighting controls can qualify for a lighting control credit under the Standards, provided the control system meets certain minimum functional requirements.

The contractors surveyed did not have a lot of experience with automatic daylighting controls.

Large Offices

One contractor indicated they typically install a photocell mounted on the southwest exterior of the building, a lighting control panel, programmable logic controller and relays.

Warehouses

The most common automatic daylighting system used in warehouses has photocells in the skylight well, at the ceiling or at the roof level. They can be installed with sensors pointing up, with sensors pointing down at specific spots on the floor, or with some

[1] "Daylighting control" here refers to the lighting controls that respond to availability of daylight, rather than to devices that control the distribution or intensity of the daylight itself as it enters the building.

pointing down and others pointing up. Lights are generally step switched rather than dimmed. Systems include a daylighting controller with a dead band and time delay adjustments.

The system often also controls exhaust fans so the cost of the lighting controls are split between the daylighting and exhaust systems. The cost usually includes tuning/commissioning. Functional testing is generally done by the control system manufacturer's factory representative. Maintenance has reportedly been fairly easy but adjustments are required as the layout of the warehouse changes.

Smaller warehouses seem to have simpler systems that are often built up from "available" components rather than sold as turnkey systems.

Control Strategies Dropped from Further Study

There are a number of topics that have been dropped from further study under this project because they are not widely utilized. They include:

- Multiscene programmable controls,
- Lumen maintenance controls, and
- Tuning control

Current Practice

This subsection discusses each of the lighting control types in terms of their position in the market and their application in nonresidential buildings. The available

Auto. Ltg. Controls	Distr./ Manf.		Designer		Bldg. Off.		Owner/ Devlpr.	
	#	%	#	%	#	%	#	%
Always	3	11%	1	4%	1	14%	-	-
Usually	5	19%	2	9%	-	-	2	25%
Frequently	8	30%	10	43%	3	43%	-	-
Occasionally	10	37%	7	30%	3	43%	3	38%
Never	-	-	2	9%	-	-	-	-
Don't Know	1	4%	1	4%	-	-	3	38%
Total	27	100%	23	100%	7	100%	8	100%

Figure 3. Use of Automatic Lighting Controls and Control Credits

Space Type	Occupancy Sensors	Continuous Dimming Daylight	Stepped Dimming Daylight	Lumen Maintenance	Combined Occ.Sensor and Daylight	Combined Occ.Sensor and Lumen Maint	Overall	Sample Size
Office	17.1%	0.6%	0.1%	0.0%	0.4%	0.4%	18.6%	662
Retail sales, showrooms	0.4%	0.3%	19.1%	0.0%	0.0%	0.0%	19.9%	187
Classrooms	38.9%	0.0%	0.0%	0.0%	0.0%	3.6%	42.6%	387
Storage, warehouse	10.8%	0.0%	0.5%	0.0%	0.9%	0.0%	12.3%	134
Gymnasiums	4.6%	0.0%	0.0%	0.0%	0.0%	0.0%	4.6%	75
Library	8.1%	0.5%	1.0%	0.0%	0.1%	1.6%	11.3%	75
Motion picture theater	0.5%	0.0%	0.0%	0.7%	0.0%	0.0%	1.2%	49
Churches/chapels	5.4%	0.0%	0.0%	0.0%	0.0%	0.0%	5.4%	35
Cnvntns, conf., meetings	12.7%	0.0%	0.0%	0.0%	5.4%	0.0%	18.1%	73
Auditorium	2.3%	0.0%	0.0%	3.6%	0.0%	0.0%	5.8%	34
Main entry lobby	3.5%	0.3%	0.9%	0.2%	0.0%	0.0%	4.9%	103
Bank/financial institution	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	20
Computer center	0.3%	0.1%	0.0%	0.0%	0.3%	4.4%	5.1%	44
Malls, arcades, atria	34.1%	0.0%	0.3%	0.0%	0.0%	0.0%	34.4%	9
Gnrl comm, industrial	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	15
Overall	**11.6%**	**0.4%**	**5.8%**	**0.1%**	**0.3%**	**0.6%**	**18.7%**	**2,329**

Figure 4. Percentage of Lighting Connected Load with Lighting Control Type by Space Type

data on lighting controls and their use in all but a few building types in California is rather limited. Perhaps the best current source, discussed below, is the onsite survey data collected over the past six years under the statewide utility new construction market assessment and evaluation program.

We also offer information from the literature and from our surveys about the use of the different control types in different spaces. Only two of the contractors we interviewed install lighting systems in retail. Only one of the facility managers is involved with retail space, although he manages nearly 150 retail facilities (52,000-ft_ average size). Therefore, our information on retail lighting controls is the least comprehensive.

The breakdown of lighting control types by space type in recent California new construction is shown in Figure 4. This is taken from the RLW baseline sample of buildings (RLW 2000), which includes 667 buildings built in California between 1994 and 1998. It is representative of the four major building types: office, retail, schools and public assembly, which account for 70% of all new construction square footage. Unfortunately, this study did not include warehouses, nor did it survey manual switching, bi-level control or automatic shut-off controls. It does, however, show that occupancy sensors are by far the most commonly used form of automatic load reduction controls, and that the other types are very seldom used. A notable exception is the use of stepped dimming daylighting controls, which control 19.1% of retail lighting. Also of note in Figure 4 is the high percentage of classroom lighting power (42.6%) that is automatically controlled. These findings are similar to what was recently learned in a survey of teachers (Heschong 2000).

In a recently completed lighting market characterization study (Heschong Mahone Group 2000a) distributors and manufacturers, designers, building officials and owner/developers in the Sacramento region were asked about their use of lighting controls. The interviewees were asked how often they used automatic lighting controls and control credits in meeting the Standards' lighting power density (LPD) requirements. Their responses, by group, are shown in Figure 3.

The percent columns indicate what portion of the respondents in the group gave the specific response. The number (#) columns indicate how many respondents gave the specific response. The general conclusion is that lighting control credits are used "frequently" or "occasionally" by most of these groups.

Interviewees were also asked about specific types of lighting controls, and the primary reasons for using each type. The results, by group, are shown in Figure 5. Everybody but the owner/developers felt that the Standards were the major reason for using lighting controls.

Life and failure rate of technology

Lighting controls divide into two broad categories with regard to life and failure rate. Manual switching controls are long lived and generally free from failure (and easily replaced if they do fail). Automatic controls become increasingly prone to failure as their complexity increases. Their failure can be due the cessation of hardware functionality, or they can fail because

% of Respondents	% of Distr./ Manf. (n=27)		% of Designer (n=23)		% of Bldg. Off. (n=7)		% of O/D (n=8)	
Control Type	T- 24 Reqt.	Energy Savings	T- 24 Reqt.	Energy Savings	T- 24 Reqt.	Energy Savings	T- 24 Reqt.	Energy Savings
Bi-level switching	67%	44%	87%	22%	100%	29%	9%	13%
Occupancy sensors	67%	59%	48%	39%	86%	43%	26%	26%
Time sweeps	63%	56%	43%	22%	86%	29%	0%	17%
Photocontrols	41%	52%	22%	43%	86%	14%	0%	17%

Figure 5. Reasons for Using Lighting Controls

operations and maintenance personnel lack the sophistication to maintain optimal functionality as building needs change over time or as system components break down. Automatic controls typically require substantial onsite commissioning to adjust and calibrate their operation to local conditions.

Bi-level Lighting Controls

Current Practice

There is very little population data on the penetration of bi-level control in buildings. We make an educated guess that bi-level control has 50–80% penetration rate in commercial square footage, but this still doesn't tell us energy impacts, which depend on occupant behaviors.

An alternative way to implement bi-level control is with the use of personal dimmers. This technology requires dimmable ballasts and a device to control those ballasts; it applies almost exclusively to standard fluorescent lighting (and to some compact fluorescents). Personal dimmers currently appear only in the highest end office and conference room applications. Anecdotal evidence suggests that perhaps 1%–2% of new offices use personal dimmers.

Large Offices

Contractors claim that bi-level switching is not commonly done in large offices. They use occupancy sensors, time sweeps and time clocks to get out of the bi-level control requirement. Contractors generally feel that bi-level switching in large offices doesn't get used when it is installed.

Facility managers interviewed were not able to shed any light on whether bi-level switching is used or not, but did state that any controls that rely on occupant behavior to get maximum utility and energy savings, will not be used as designed (or hoped).

A controlled experiment on this issue indicates that the opposite might be true (Veitch and Newsham 1999). Office workers were put in a situation where half were given control of lighting levels from various sources, and the other half had no control but was subject to the choices of the first group. The researchers found no significant difference in productivity, satisfaction with lighting levels, mood or other effects. The results do support the study's hypothesis that "giving people control over lighting might result in lower lighting energy consumption compared with a fixed lighting design with a lighting power density at the maximum allowed by codes and standards."[2]

Small Offices

Contractors generally feel that occupants don't use bi-level switching and one claimed to have an internal study that supported his contention. Facility managers were not able to answer the question as to how much it gets used by occupants. At least one said, "People just turn on all the lights when they enter a room." Other anecdotal evidence, however, suggests that some individuals prefer the lower lighting levels and use the switches accordingly.

Schools

Though the contractors we talked with install bi-level switching, they still equip each classroom with occupancy sensors. They indicated that both strategies are desirable for classrooms and one is not used to avoid having to install the other.

One contractor who specializes in installing occupancy sensors said that his experience is

[2] The lighting power density most selected by the participants in this study was ~1.4W/ft_, somewhat higher than the 1.3W/ft_ allowed for offices by the area category method of Title24. Since the starting lighting level for the experiment was 2.4 W/ft_, it is possible that the most chosen level might have been lower if the maximum had been closer to the common case in California offices.

that only about 15% of the installed bi-level switching capacity is being used by occupants. However, other research indicates that over 50% of teachers prefer to teach sometimes with some of the lights off (Heschong 2000). Analysis shows that even if the rest never do, the energy savings from those who do makes the whole set of controls cost effective.

Warehouses

Most contractors do not generally do bi-level switching in warehouses. This is not surprising given that it is not required by the code in unconditioned warehouses or due to LPDs less than 1.0 W/ft_. However, one contractor said that even though the code doesn't require bi-level switching, they do it 90% of the time because it saves their customers money on their energy bills. He thought that at least 70% of electrical contractors were also doing it. We didn't hear from any others who do.

Occupancy Sensor Controls

Currently, only about 25–35% of new nonresidential buildings have occupancy sensors (RLW 1999). Within those buildings, occupancy sensors are used on only 16.7% of spaces, and they control 11.6% of the connected lighting load (RLW 2000). The use of occupancy sensors differs by space type, as shown in Figure 6, taken from the same report.

Reports from manufacturers and distributors indicate an expanding market for occupancy sensors. The simplest, wall switch devices, have become commodity items, and larger, more sophisticated controls are also commonplace. The use of occupancy sensors has become very common in schools, office buildings, storage areas and other types of spaces with good savings potential.

There is anecdotal evidence that occupancy sensors are widely used to avoid the installation of bi-level controls and/or of automatic shut-off controls, which are allowed tradeoffs under Title 24. There is also some evidence that occupancy sensors can actually increase lighting energy use, especially in facilities that can make effective use of manual switching controls (Floyd et al. 1996).

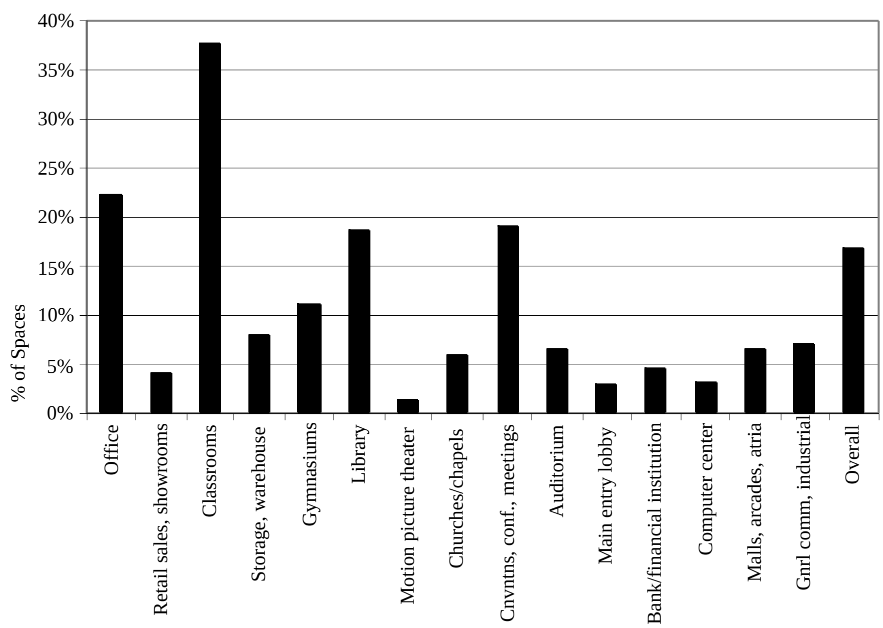

Figure 6. Percentage of Spaces with Occupancy Sensors by Space Type

There is some experience with equipment reliability, as occupancy sensors have been in the market for over 15 years. There is anecdotal evidence of occupants disabling sensors when unhappy with their operation. Also, early occupant sensors often had problems with poor calibration (both for sensitivity and for time delay).

However, there is also evidence that people are becoming accustomed to occupancy sensors, and that occupancy sensors are becoming more reliable in their operation, so that the rate at which they are being disabled is declining.

Commissioning of occupancy sensors is important for energy savings. One study (Floyd et al. 1996) found that the energy savings for occupancy sensors in an office environment doubled when the time delay was reduced from 15 minutes to 7 minutes. Newer devices have improved in simplicity and adjustability, and some are now virtually self-calibrating, but it can still require a knowledgeable operator to adjust them if needed. A population field study would be needed to increase data on the persistence of these devices.

Large Offices

Electrical contractors we talked with routinely install occupancy sensors in large offices. Between 75% and 100% of the projects have occupancy sensors (the exception was one firm that only installs them in about 10% of the large offices they wire). The only areas in large offices that do not regularly get occupancy sensors are reception lobbies and sometimes corridors. Except for small areas (closets and storerooms) ceiling-mounted sensors are the norm. Occupancy sensors are used not just as the alternative to bi-level switching, but also because they satisfy the requirement for automatic shut-off.

Facility managers told us that occupants seem to be satisfied with occupancy sensors; none of the facility managers saw any instances of vandalism or "tricking" of the sensors.

Small Offices

Some contractors only install occupancy sensors in about one-fifth of offices while others do so in three-quarters of the small offices they work on. When they install occupancy sensors, they put them in all spaces except lobbies. Ceiling-mounted occupancy sensors are only used about 10%–30% of the time any occupancy sensor is used, although the cost per office can be about the same ($0–$60 increment over wall-mounted types).

Contractors don't get many calls back about problems with occupancy sensors (about 1 in 100 occupancy sensors). Almost all of these calls are due to equipment malfunction, not customer dissatisfaction. For one contractor, the only call back he got was to replace a stolen unit.

Schools

One contractor offered, "People today would still buy occupancy sensors even if the code did not require it." Roughly three-quarters of classrooms have occupancy sensors, but, according to some contractors, this percentage is declining. It is not clear whether the sensors are being installed in lieu of time clocks or for design (utility) reasons, but it was clear from the interviews that they are not being used as a way to avoid bi-level control requirements. It is important to note that, in school classrooms, the desirable design seems to include both bi-level switching and occupancy sensors.

No contractors mentioned taking the occupancy sensor LPD credit in connection with schools.

Most contractors stated that occupancy sensors are not used in school bathrooms because of vandalism. One pointed out, however, that there are occupancy sensors that are virtually vandal-proof and this contractor commonly installs them in school bathrooms.

Automatic Shut-off Controls

The Standards refer to the control strategy as "automatic shut-off controls," although they are perhaps more widely known as time sweeps because they systematically sweep off all lights left burning after hours. The Standards have required them since 1992 but there is little field evidence as to how widely they are actually used and how vigorously the requirement is enforced.

There are multiple ways to achieve the automatic shut-off function with different kinds of hardware, so it would also be useful to learn which kinds are being most widely used. The market acceptance of time sweep controls is also unknown. There is anecdotal evidence of occupants being unhappy with the seemingly arbitrary shutting off of lights at some predetermined time (it's annoying if you're working late, especially if it's difficult to override the shut-off). They are potentially prone to failure or occupant dissatisfaction if they aren't well maintained.

Energy management systems (EMS), specialty lighting controllers, or building automation systems (BAS) could have all of the necessary functionality of automatic lighting shut-off controls, depending on the capabilities of the system, the programming sophistication and knowledge of its operator, and the successful commissioning of the system.

The penetration of these systems in nonresidential buildings is not known, although there is anecdotal evidence that many school districts and most large commercial buildings have some degree of centralized control.

All types of centralized controls depend on operator sophistication to achieve energy savings and persistence of operation over time. For buildings with permanent operations staff, these controls can be highly reliable and efficacious. There is anecdotal evidence, however, that centralized controls lose their effectiveness, or even become disabled, if knowledgeable operators are not available to maintain them. This can be a continuing problem for building owners due to employee turnover; even if an operator is well trained, if that operator leaves the replacement operator may need to be trained anew.

The technology for centralized controls is rapidly evolving along with other kinds of computer technology. Older systems may become quickly outdated and as a result may need to be replaced. The persistence may ultimately depend on the next generation technology replicating the control functions of the system it replaces. There are growing calls for standardization and greater ease of use for centralized control systems, so these problems may diminish as the control systems become smarter, more user friendly, and better at self-diagnostics that identify and even repair functional failures.

Centralized control systems require a high level of commissioning and functional testing, to assure that their many functions are set up properly to meet the needs of building occupants. They may also require frequent recommissioning as occupant needs change. This requires the ongoing attention of expert controls personnel, which is less of a problem for larger facilities with full-time operations and maintenance staff.

Large Offices

Facility managers reported that about a third of the buildings they manage use occupancy sensors to meet the automatic shut-off requirement, another third use time sweeps/time clocks, and about a fifth use more sophisticated energy management systems (the rest didn't know or didn't use anything).

Time sweeps and time clocks are usually programmed to run on an 8:00 AM to 8:00 PM schedule during workdays, with half-power off on Saturdays and complete shut-off on Sundays and holidays. Some facility managers reported that their time sweep systems are scheduled for 9:00 PM shut-off so the second shift (usually the janitorial crew) would be done with their work by the time the system shuts off the lights. Most override switches are programmed on a two-hour sweep shut-off.

The lighting distributors and manufacturers we spoke with told us the return rate for occupancy sensors is about 5% on average as compared with a 1–2% return rate for time clocks and time sweeps.

Electrical contractors reported that they are called to replace 2% or fewer of the occupancy sensors they've installed. They also told us that 90% of the time these calls are due to equipment malfunctioning, not occupant dissatisfaction with proper functioning of the sensors.

According to contractors, night sweeps are only used in 25% or fewer of large offices. One contractor with hundreds of customers told us that he gets an average of one call per month to fix or replace malfunctioning time switches. Another said that he is called to replace older time switches on 5–10% of his jobs. He replaces them with newer electronic switches that work better and produce higher customer satisfaction.

Small Offices

For small offices, automatic shut-off is usually done by using occupancy sensors. According to lighting contractors, 30–40% of small offices have occupancy sensors. However, our survey of facility managers indicated that they are used in over 80% of small and private offices. One contractor told us that he had installed an energy management system as the automatic shut-off control in one small office. Since the requirement only applies to spaces larger than 5000 square feet, we assume that the bulk of the small offices unaccounted for did not have any automatic shut-off control.

Schools

RLW (1999) found, in new construction in California for the years 1994–1998, that occupancy sensors control about 30% of the lighting of the schools, and about 42.6% of the connected lighting load in classrooms (RLW 2000). This is the most common automatic shut-off strategy for schools.

Retail

From our interviews with facility managers (one of whom is a manager for 142 stores of a large retail chain) and electrical contractors, we conclude that lighting control panels and time clocks are the prevailing technologies used for meeting the automatic shut-off requirement in retail. The basic model is comprised of a six-point panel, a clock, and one or two override switches. This system shuts off and turns on the store lights based on a preset schedule. The more sophisticated model includes multizone controls and multiple programs. The latter is typical practice where different zones of a store have different schedules and hours of operations (e.g., the deli department of a grocery store).

Daylit Area Switching

The hardware situation for daylit area switching is similar to that for bi-level control: it is a strategy, not a technology, which uses standard lighting devices.

It is estimated that adequate daylighting from windows is present in 15%–20% of existing commercial square footage, and that daylighting from skylights is available in 2%–5% of existing square footage. The area served by skylights is probably only 10%–20% of the potential area. In other words, a very large area of roofs could incorporate skylights for daylighting, but do not. Approximately 60% of commercial floor space in the United States is directly under a roof; in California, this number is estimated to be on the order of 90%–95% of floor space (Heschong Mahone Group 2000c).

The daylit area switching strategy has the same characteristics as bi-level control, except that there is probably even less occupant understanding about the reason for the switches. One of the intentions of the Standards was that building owners would find it easier to retrofit automatic photocontrols in the daylit areas, because the necessary circuiting would already be in place. There is no evidence that people are doing this type of retrofitting. No commissioning is needed for daylit area switching.

Automatic Daylighting Controls

The potential floor area for daylighting control is huge, as discussed above. The suitability of different buildings types for photocontrols is shown in Figure 7, which lists from most to least appropriate the building types for which photocontrols would be suitable. Approximately 12% of recently constructed nonresidential buildings incorporate some kind of automatic daylighting controls, with step switching controls (as opposed to continuous dimming) accounting for 90%–95% of daylighting control installations (RLW 2000). This study suggests that this market penetration rate is slowly growing, a finding that is supported by anecdotal evidence from market players. There appear to be recent increases in the market penetration for skylit applications, such as warehouse, manufacturing and big box retail buildings. They also appear to be more common in atrium, lobby and public circulation areas of airports and malls.

Building Type	Fraction
Warehouse	85%
Large Office	79%
Public Bldg	78%
Manufacturing	77%
Schools	76%
Big Box Retail	68%
Grocery	60%
Small Office	57%
Small Retail	48%
Health	46%
Hotel	44%
Restaurant	39%
Religious	28%

Figure 7. Ranked Commercial Building Types Appropriate for Photocontrols

Source: Heschong Mahone Group 2000c

Despite this growth, there remains a large mismatch between the current size of the daylighting control market versus the market potential. Most of the research literature on daylighting controls is concerned with dimming controls for offices, but the actual growth in the market appears to be with switching controls for large open spaces.

All studies, including the Heschong Mahone Group study cited above, report persistent problems with daylighting controls operation and reliability, especially for small, side lit spaces with windows. There is anecdotal evidence that these controls can get out of calibration, become disabled or malfunction. The market potential for daylighting controls is tied to good building design for daylighting, and to integration between controls and the lighting system, none of which are addressed by the Standards.

Figure 8 shows the operating problems (Heschong Mahone Group 2000c) for daylighting controls, as reported by different professions that were interviewed.

Question	3. Operating Problems								
Profession	don't maint proper light	don't achieve opt'm savings	cause lamp or ballast failure	switch too frequently	callibr'n or maint difficult	irritate occup'ts	occup'ts disabled	reason for failure unknown	other
Architects	33%	33%	33%	0%	33%	67%	67%	0%	67%
Contractors	50%	0%	50%	0%	0%	0%	0%	0%	50%
Controls manuf	50%	38%	25%	0%	50%	75%	86%	25%	50%
Engineers	60%	67%	0%	0%	40%	20%	17%	17%	17%
Facility manager	33%	33%	33%	17%	33%	33%	17%	17%	33%
Lighting Rep	57%	14%	29%	43%	33%	33%	33%	0%	71%
Lighting designer	0%	20%	20%	0%	80%	40%	60%	0%	80%
Researcher	50%	50%	25%	25%	75%	75%	67%	25%	50%
Utility	43%	86%	0%	14%	29%	57%	14%	14%	43%
	42%	38%	24%	11%	42%	44%	40%	11%	51%

Figure 8. Common Operating Problems with Daylighting Controls

Commissioning of photosensor controls can be labor intensive because of the large number of sensors in a big building, and it requires specially trained people to adjust and calibrate the controls. Manufacturers' recommendations for these procedures are reported to be unsatisfactory, and even patient researchers have experienced difficulties in commissioning photosensor control systems (Schrum et al. 1996). Until these problems are resolved, however, photosensor controls will remain in the realm of specialty systems, and there will be relatively few installations.

Large Offices

Automatic daylighting controls are not common for office spaces. One electrical contractor installs about two per year. Most reported that they don't install any in large offices.

A study in Florida (Floyd and Parker 1995) showed that dimming ballasts and dimming controls, used as the daylighting strategy, can save 27% of the lighting energy at light levels well above the IESNA standard of 300 lux. They also found an unanticipated level of "difficulties associated with installing and calibrating the control photosensors…" They did not achieve the savings they were anticipating until they recalibrated the sensors and installed shielding, which was supplied by the manufacturer but not previously installed.

Schools

In his study on Durant Middle School, Smiley (1996) found that cooling equipment was downsized 10% and energy use cut 22–64% due to daylighting and lighting controls. The system had occupancy sensors and stepped switching controlled by photosensors. With cooling system savings, payback for lighting controls was less than nine months. Their analysis also showed that the lighting improvements resulted in higher test scores and attendance (Heschong Mahone Group 1999).

Warehouses

The contractors told us that 25%–90% (depending upon size) of warehouses with at least 3% skylight-to-roof area have automatic daylighting controls. Less than 30%–55% of those with less than 2% skylight-to-roof area have automatic daylighting controls. It is more common in the build-to-suit warehouse construction market than in the speculative market. Most of the calls back are for adjusting (fine tuning) but some (approximately 2%) are for failures in controls or sensors. In larger warehouses, fairly sophisticated systems that also provide automatic shut-off for unoccupied hours seem to be pretty common.

Economics

This section discusses the costs and cost effectiveness of lighting controls. Before discussing the economics, however, we discuss some of the broader aspects of lighting controls that affect their cost and the energy/cost savings that result from their operation.

Availability and Cost

A full range of lighting controls, from simple to complex, are readily available in the marketplace. However, because of compatibility issues with lamps, ballasts or other controls specified, the choices may be narrowed sufficiently to make specific product availability for some applications a concern. The lighting controls industry has many more players, and consequently many more choices, than the lamp and ballast industries, which are dominated by a few major manufacturers.

Most of this discussion assumes fluorescent lamp technology, which predominates in nonresidential applications. There are much smaller market niches for controls that are compatible with HID lamps and compact fluorescents, and the product choices are much more limited.

Benefits

The energy savings for lighting controls can be substantial, but they all depend on the occupant interface. Manual controls, of course, require consistent occupant operation over time to save energy. Automatic controls, on the other hand, rely on imperfect occupant behavior to achieve their savings and justify their installation. For most applications involving larger buildings with larger numbers of occupants, the automatic controls appear to be more effective than manual controls.

INDIVIDUAL CONTROL: In occupancies where the individual occupant has a feeling of ownership of the space, research has shown that lighting control strategies that provide individual control of the lighting level seem to have a higher chance of success. Such strategies can provide greater satisfaction with the work experience, potentially increase productivity, and they may even save energy.

ANNOYANCE ISSUE: Dissatisfaction with lights turning off at inappropriate times, with light levels in general, or with apparently arbitrary changes in light levels may lead occupants to disable controls or “fool” the sensors. There are stories of daylighting sensors being taped over so that the sensors think it is dark outside and so turn on the lights. Occupants have tied rags to the blades of rotating fans to “fool” occupancy sensors into thinking rooms are occupied. Lighting controls that are not allowed to function properly, or whose functioning is misunderstood by occupants, will not save energy.

DESIGN FLEXIBILITY THROUGH CONTROL CREDITS: The Standards provide lighting designers with an important degree of flexibility through lighting control credits. Applications that require more lighting power than allowed by the Standards may still comply if optional lighting controls are installed and the lighting control credits are used. There is some debate as to whether this provision of the Standards actually saves energy, because it results in higher installed lighting power levels. Also, the extra lighting energy consumption is only offset if the controls work as intended to save energy. However, the lighting control credits are probably conservative, and so they are likely to save even more energy than is consumed because of the increased lighting power.

WORKER PRODUCTIVITY: There is mounting evidence that some types of lighting, such as daylighting or personal dimming controls, can have significant positive impacts on worker satisfaction and workplace productivity (Heschong Mahone Group 1999). The dollar value of increased productivity can be an order of magnitude greater than the dollar value of the energy savings associated with lighting controls. So there is a very big incentive to get the lighting controls and lighting design to work well from an occupant's perspective. There is also a downside to this aspect of lighting: if the lighting system and controls are poorly designed or functioning, they can have a negative impact on productivity that far outweighs any energy savings.

Bi-level Lighting Control vs. Single-level Control

Because a bi-level controls strategy involves manually operated switches or dimmers, it relies on occupant behavior rather than automatic control technology. There is only limited documented evidence, and a greater range of anecdotal evidence, on the energy effectiveness of bi-level control, so it could be difficult to cost-justify the requirement for this control strategy if it were to be challenged.

Large Offices

In our survey, the range of *cost increments* for installing bi-level switching versus a single switch was from $10/circuit to $200/circuit. It is unclear whether every contractor questioned in our survey understood the question the same way. For example, one contractor who indicated the incremental cost of bi-level switching was $20, said that the base cost for wiring a large office space for a single switch was $50–$55. It is unlikely that this includes the entire cost of running the cable and conduit. Another said it costs approximately $2500. This likely included much more of the full lamp wiring expense.

One electrical contractor told us that it costs about $20 extra to install bi-level switching ($50–$55/room vs. $30–$35/room). Another said the cost increment for the second switch is about $25 ($85 vs. $60). Another said that for ten fixture systems, the total extra cost is about $120 ($200 vs. $80). One said that the cost increment is only $10 ($85 vs. $75). The two contractors in the San Jose area and the one in Bakersfield indicated that bi-level switching results in a 5% to 6.25% cost increment over a single switch (the actual cost varies by office design, but was in the range of $2000-$2500). We conclude from this that the incremental cost is highly dependent on the specifics of each project, but that it is generally small compared to other electrical system costs.

Small Offices

According to the contractors, in small offices, bi-level switching adds about $20–$50 per office.

Schools

One contractor quoted us a price of $50/switch (including the wiring costs), so bi-level switching adds $50–$100 per classroom. For another, the cost increment for bi-level switching is $15/room ($85 vs. $100).

Warehouses

When done (which isn't often), bi-level switching adds about $0.005//ft_ to $0.10/ft_ to warehouse lighting costs.

Cost Effectiveness

The cost effectiveness of bi-level control and automatic shut-off controls must be evaluated for a wide range of space types and control technologies. Although the lack of comprehensive field data does not allow us to perform a complete economic analysis, we can do a "back calculation" that estimates how many hours per year a control strategy must save energy in order to be cost effective.

Figure 9 estimates the costs for bi-level control using manual wall switches (the simplest form of bi-level control) for a variety of typical spaces. These costs are then analyzed using the Commission's cost-

Space type	LPD	Area/Switch	Switch	Wiring	Total Incl. O&P	Total/ft2	CEC Scalar 12.3 Cost-effective Annual h/yr half off
Small office	1.3	150	$ 15.95	$ 1.32	$ 25.90	$ 0.173	187
Large office	1.3	1,000	$ 15.95	$ 8.77	$ 37.08	$ 0.037	40
Large storage	0.6	1,000	$ 15.95	$ 8.77	$ 37.08	$ 0.037	87
Conference	1.3	400	$ 15.95	$ 3.51	$ 29.19	$ 0.073	79
Retail	2	1,000	$ 15.95	$ 8.77	$ 37.08	$ 0.037	26
Grocery	1.6	1,000	$ 15.95	$ 8.77	$ 37.08	$ 0.037	33
Classroom	1.6	900	$ 15.95	$ 7.89	$ 35.76	$ 0.040	35

Figure 9. Bi-level Control Cost Effectiveness

effectiveness criteria: $0.115/kWh for electricity, a 15-year analysis period and a 3% discount rate. The results indicate how many hours per year the control would have to turn off the lights (or half the lights in the case of bi-level switches) for the controls to be cost effective.

For bi-level control, the installed costs range from $0.037/ft_ to $0.173/ft_. The worst economic scenario (small offices) indicates that half of the lights would have to be turned off as much as 187 hours per year (less than 4 hours per week) in order for the controls to be cost effective. The next worst case is large storage areas (such as warehouses), which have lower lighting levels (0.6 W/ft_ in this example). These kinds of spaces have less savings potential, but bi-level control can still be cost effective if it is used less than two hours per week.

In larger spaces the lights need only be off for one or two hours per week. It should be possible for any building owner to realize even greater savings with a modest educational effort to explain to occupants why the bi-level control is being provided, and to encourage them to turn down lights whenever full lighting is not needed. Thus, the economics of bi-level controls can be quite cost effective.

The cost figures come from the 2000 R.S. Means Electrical Cost Data. The base light switch costing assumes there is one light switch per 1000 square feet and 420 feet of 12-gauge THHN solid copper wire. The installed bare cost (not including overhead and profit) is $14.95 per switch and $17.54 for the 420 feet of wire. Recognizing that a single switch needs two wires (the power lead and a switch leg) and a double switch needs three wires (the power lead and two switch legs), adding an extra switch requires half as much wire as installing the initial switch.

Thus the incremental materials needed for adding bi-level control of a 1000-ft_ area requires an additional switch and 210 extra feet of wire. An extra $1.00 per switch was added for the change from single to double gang plaster rings and cover plates. Fifty percent overhead and profit was included. (If the control strategy required two extra wires, the extra cost would be for materials; the labor would be unchanged.) Thus for a large office where the base case is one switch per 1000-ft_ the installed costs are:

[$15.95 (switch and cover plate) + $17.54/2 (wiring)] x 1.50 (overhead and profit) = $37.08

For smaller rooms, the wiring cost is reduced as a proportion of room area. Thus the wiring costs for a 150-ft_ small office are:

$17.54/2 x (150/1000) = $1.32

By dividing the costs by the size of the zone controlled by a switch, the cost density of adding a bi-level switch in terms of dollars per square foot was derived. The real value of the 15-year present worth of electricity used to determine the cost effectiveness of the Standards is $1.42 in 2002 dollars.

We then calculated how many hours half of the lights would have to be off to pay for the costs of the bi-level switch. Since the first costs are given in $/ft_ we could evaluate the energy savings in kWh/yr·ft_ using hours and the LPD (W/ft_) and develop energy cost savings in terms of $/yr·ft_.

$$\text{Hours lights half off} = \frac{\text{Incremental Cost } (\$ / SF) \times 1{,}000 \ (W / kW)}{0.5(\text{Frac.Off}) \times \$0.115 / kWh \times LPD(W / SF)}$$

As an example let us consider the large office area, which costs $0.037/ft_ to add bi-level control, and which contains 1.3 W/ft_ of electric lighting. Applying these numbers to the above equation results in the following number of hours that half of the lights must be off during the period of analysis.

$$\text{Hours lights half off} = \frac{\text{Incremental Cost } (\$0.037 / SF) \times 1{,}000 \ (W / kW)}{0.5(\text{Frac.Off}) \times \$0.115 / kWh \times 1.3(W / SF)}$$

$$= 495 \text{ Hours}$$

If we divide by the scalar ratio used to calculate the cost effectiveness of the Standards, or 12.3, we will obtain the number of hours per year where the energy cost savings of turning half of the lamps off pays for the cost of the extra switch and wiring.

Thus the number of hours per year required for cost effectiveness is 495/12.3 = 40 hours per year. This amounts to less than one hour per week.

Occupancy Sensors vs. Bi-level Switching

OCCUPANCY SENSORS: Costs have been dropping for occupancy sensors as they become commodity items. They are widely available from multiple manufacturers. Additional installation costs are due to the higher equipment cost compared to simple wall switches, unless the product is compared to bi-level switching or time sweeps, which can make for reduced overall costs. Reduced lamp life due to more frequent switching is offset by the increased time between replacements due to reduced operating hours.

Large Offices

One electrical contractor said that ceiling-mounted occupancy sensors cost about $250 each installed, and wall-mounted cost about $125 each but cover a smaller area. Both of these prices are about double what all the others said. The prices given by most contractors indicated that occupancy sensors cost about $0.20 to $0.25/ft_ of floor area.

Small Offices

Wallbox occupancy sensors are reported at a $50–$60 premium over bi-level switching in small offices. The savings from avoiding the cost of time clocks and night sweeps makes occupancy sensors the least cost option in many cases.

Schools

The contractors’ installed cost for wall-mounted occupancy sensors was $50–$55. For the ceiling-mounted type, it was about $150 each. The wall-mounted ones control 150–250 watts, while the ceiling-mounted ones control 250–2000 watts. The cost of commissioning is included in that price. Commissioning generally only takes about 15 minutes per room. For the type of occupancy sensor that one of the contractors likes (adaptive technology), he claims there is zero adjustment time and zero call backs, though the first cost has a $10–$20 premium over other technologies. Considering all types of occupancy sensors, it seems that the call back rate is between 0% and 5%.

Space type	Osensor Type	LPD	Osensor	Wiring	Commisionin	Total	Total/ft2	CEC Scalar 12.3 Cost-effective Annual h/yr of
Warehouse	PIR ceiling	0.6	$ 180.00	$ 76.20	$ 10.00	$ 266.20	$ 0.106	125
Small office	PIR wallbox	1.3	$ 70.50		$ 10.00	$ 80.50	$ 0.537	291
Large office	Dual tech	1.3	$ 150.00	$ 63.50	$ 10.00	$ 223.50	$ 0.224	121
Large office	IR ceiling	1.3	$ 150.00	$ 63.50	$ 10.00	$ 223.50	$ 0.373	202
Conference	PIR wallbox	1.3	$ 70.50		$ 10.00	$ 80.50	$ 0.268	145
Conference	Dual tech	1.3	$ 150.00	$ 63.50	$ 10.00	$ 223.50	$ 0.559	303
Breakroom	Dual tech	1.3	$ 150.00	$ 63.50	$ 10.00	$ 223.50	$ 0.224	121
Restroom	wall box ultrasoni	0.6	$ 85.50		$ 10.00	$ 95.50	$ 0.318	374
Restroom	ceiling ultrasonic	0.6	$ 150.00	$ 63.50	$ 10.00	$ 223.50	$ 0.745	874
Classroom	Dual tech	1.6	$ 150.00	$ 63.50	$ 10.00	$ 223.50	$ 0.248	109
Classroom	IR or US ceiling	1.6	$ 150.00	$ 63.50	$ 10.00	$ 223.50	$ 0.248	109

Figure 10. Occupancy Sensor Cost Effectiveness

Cost Effectiveness

For occupancy sensors, Figure 10 shows a similar analysis to that shown in Figure 9 for bi-level switching. The costs for the occupancy sensors range from $0.106/ft_ to $0.559/ft_, and the worst economic scenario, a small restroom with low LPD and an expensive type of occupancy sensor, indicates that the sensor would have to turn off the lights as much as 874 hours per year (about 17 hour per week) for the controls to be cost effective. For this type of application, however, it is typical for lights to be left on by departing occupants. Turning the lights off a few times a day, or preventing them from being left on overnight once or twice a week, would more than compensate for the cost of the controls.

In most applications, however, the less expensive type of control could be used and the cost effectiveness period would be reduced by more than half. For more typical applications, the required savings would be around 2–6 hours per week; this is less than one or two hours per workday. These savings could easily result from leaving an area for a meeting or lunch.

The costing figures in this analysis come from the R.S. Means 2000 Electrical Cost Data. Cost information was also provided to us by an occupancy control manufacturer (Himonas 2000), which showed lower typical costs, so this analysis is assumed to be conservative. Wiring costs are primarily for power packs—typically a dry contact relay that interrupts the flow of line voltage power to the lighting circuit in response to a low voltage signal from a ceiling-mounted or wall-mounted remote occupancy sensor.

This analysis assumes that most larger areas are controlled with dual technology sensors—these have both passive infrared sensing to prevent false “ons” and active ultrasonic sensing to keep the lights on with minimal movement in a large area. Ultrasonic sensors are used in restrooms since much of the bathroom is not in the “line of sight” needed by a passive infrared sensor.

Automatic Shut-off vs. Manual Switch

There are about a dozen manufacturers of automatic shut-off systems specifically designed for lighting, and a larger number if whole-building EMS systems are included. Costs vary widely depending on capability and sophistication. Control systems are widely marketed. Installation, training and commissioning costs are all significant. Savings depend on how well the system is programmed and maintained.

Type	Bldg type	Control	LPD	Cost per SF	CEC Cost-effective Annual h/yr off
I	Warehouse	Timeclock	0.6	$ 0.114	335
IV	Small Office	Osensor	1.3	$ 0.326	441
II	Large office	Timeclock	1.3	$ 0.272	368
V	Lg Office	Osensor	1.3	$ 0.362	490
II	Retail	Timeclock	2.0	$ 0.625	550

Figure 11. Automatic Shut-Off Control Cost-Effectiveness

Large Offices

The time clock/photocell combination strategy mentioned below costs about $2000 for 5000 ft_ (or $0.40/ft_) in one case, and $3800 for 5000 ft_ (or $0.76/ft_) in the other. This is a fairly sophisticated system that includes programmable lighting control panels, a time clock, and override switches for nighttime shut-off, plus photosensors and step switch controls for daylighting control.

Warehouses

The occupancy sensors, when installed as the automatic shut-off strategy, cost about $750–$1000 per group of controlled fixtures (approximately 10 fixtures per 3 sensors). One estimate for a warehouse lighting control system (LC panels, network and override) was $2500 for buildings between 5000 ft_ and 20,000 ft_. The expense of commissioning the system more than doubles the cost in some cases and only adds about $12 per sensor to the cost in others.

The analysis summarized in Figure 11 was done using a similar methodology to that reported in the previous two sections, except that costs were derived from interviews with electrical contractors. R.S. Means does not provide adequate cost information for automatic shut-off controls.

Cost Effectiveness

Similar to the analysis of occupancy sensors, the cost effectiveness of automatic shut-off controls shown in Figure 11 is based upon a back calculation of how many hours the lights would have to be turned off per year to pay for the installed cost of the automatic shut-off control. For consistency's sake, all of the costs in this analysis are based upon the estimates we received from electrical contractors, including the estimates of costs for occupancy sensors (see Figure 12).

Automatic Daylighting Control vs. Manual Daylighting Control

Daylighting controls are available from about a dozen manufacturers. Costs vary depending on the size of load controlled and the complexity of control—estimates vary between $0.10/ft_ and $3.00/ft_. Use of the technology is limited because there is a

Space Type	Control	Average	Min	Max
Large office	Timeclock	$ 0.272	$ 0.200	$ 0.375
Retail	Timeclock	$ 0.625	$ 0.417	$ 0.833
Large storage	Timeclock	$ 0.114	$ 0.068	$ 0.167
Small Office	Osensor	$ 0.326	$ 0.206	$ 0.722
Lg Office	Osensor	$ 0.362	$ 0.200	$ 0.800

Figure 12. Contractors' Estimates of Automatic Shut-off Control Costs

small number of knowledgeable designers, specifiers and installers. Inexperienced people appear reluctant to assume the liability for making the system operate correctly.

Commissioning costs are significant and can be limiting factor. It is not known how frequently calibration must be adjusted to maintain optimal controls operation.

Large Offices

According to electrical contractors, daylighting controls in large offices, which control hundreds of fixtures, cost about $0.20/ft_ to install. Commissioning/tuning accounts for about $300–$600 of the cost. One contractor said that tuning adds about $600 to the above range for an installation (but this contractor does this kind of work infrequently, about once per year).

Warehouses

Automatic daylighting controls cost about $0.06/ft_ or about $40,000 for a 650,000-ft_ warehouse. In another example, the cost was about $0.08/ft_ or about $66,000 for a 790,000-ft_ warehouse. One contractor declared that some utility programs are providing more money, by way of incentives, than it costs them to add the extra controls.

For smaller warehouses, the common system costs about $1,500–$2,000 for a warehouse up to about 100,000 ft_ ($0.015-$0.02/ft_) plus about $200 more for tuning/commissioning.

Cost Effectiveness

Figure 13 uses the average estimate of daylighting control costs and calculates the number of full load hours the fixtures are turned off. Many daylighting control systems are turning the electric lighting off in stages in response to available daylight in the building interior. As a result, these figures of hours-per-year off can also be treated as a weighted sum: the 285 hours per year the lights must be switched off to pay for the warehouse daylighting control system can be 285 hours per year with all of the lights turned off or 570 hours per year with half of the lights switched off or dimmed to full power.

Bldg type	LPD	Total/ft2	CEC Cost-effective Annual h/yr off
Warehouse	0.6	$ 0.10	285
Med office	1.3	$ 0.19	254

Figure 13. Daylighting Control Cost Effectiveness

Daylighting controls are not frequently used, thus few of the contractors felt they could give us a quick quote. Most of the contractors who had installed warehouse daylighting control systems had done this in large warehouses. Their cost per square foot was lower than for those who had designed small systems. Figure 14 shows the contractors' cost estimates for daylighting control systems.

	Average Cost	Minimum Cost	Maximum Cost
Warehouse	$0.10	$0.02	$0.23
Medium office	$0.19	$0.15	$0.21

Figure 14. Contractors' Estimates of Daylighting Control Systems

Key Stakeholders

This section describes the key stakeholders who are interested in lighting controls and their treatment under Title 24. We begin with a general discussion of these stakeholders, and then proceed to discuss how they are different for each of the lighting control strategies covered in this report.

All Lighting Controls

The primary stakeholders for lighting controls are the manufacturers and lighting designers. Manufacturers, obviously, have a strong financial interest in the market for controls, and the Standards are a powerful influence on that market. Lighting designers have the primary responsibility for specifying these controls and for complying with the lighting control requirements.

Supporting these stakeholders are the utility company market transformation programs, which have offered daylighting control information and incentive programs for many years. The utilities see lighting controls as a good way to reduce electricity usage (both lighting and cooling energy) and, for most controls, to reduce on-peak demand.

To a lesser extent, other market actors in the lighting industry are stakeholders as well. Lighting equipment distributors and electrical contractors play an important role in the sale and installation of lighting controls, but they are primarily responding to the requirements of specifiers and building owners, rather than guiding the market for lighting controls.

Building occupants tend to value lighting controls when they afford greater flexibility and control over the personal environment. When controls operation is not understood or is not appropriate to their needs, they tend to resent or even prevent the “arbitrary” operation of their lighting systems.

Energy efficiency regulators, advocates and environmentalists concerned with the energy impacts of lighting energy use recognize, quite rightly, that lighting controls play an important role in commercial building energy use and its management. Building officials and electrical inspectors have a front-line role in enforcing the lighting control requirements, although our experience has been that these requirements are not top priorities for enforcement.

The final stakeholder group is the building owners and facility managers who pay for and maintain lighting controls. They tend to be interested to the extent they have an economic stake in the operation of the controls to save energy. When they are paying the utility bills, they tend to favor lighting controls as a good way to conserve energy and manage electricity costs. When their tenants pay the utility bills, they tend to view lighting controls as an unnecessary expense for which they will see little direct return.

The variations in these stakeholder perspectives for different types of controls are further discussed below.

Bi-level Lighting Controls

Because occupant behavior affects the ability of bi-level controls to save energy, occupants are a key stakeholder group. If occupants understand that they can contribute to energy efficiency and cost savings by turning off unnecessary lighting, they tend to feel positive about the controls; if they resent the building management, this can, of course, backfire. Also, many occupants appear to value the degree of personal control over their lighting environment that bi-level control affords.

Building owners may resent the expense of installing bi-level control if they do not believe that occupants will use them to save energy, and especially if they are not directly responsible for paying electricity bills. If the real estate market is tight, they may perceive bi-level control as a valuable amenity they can offer their tenants.

Other stakeholders tend to be neutral on the subject of bi-level control.

Daylit Area Switching

The situation for daylit area switching is nearly identical to that for bi-level control (see above), except that there is probably less understanding of the purpose for the extra switching. When occupants understand that there is good reason to turn off lighting in the presence of good daylighting, then they are more likely to use the daylit area switching. If, however, the daylight is inadequate or poorly designed, then the switching is unlikely to be used.

One of the intents of the daylit area switching requirement has been to make it easier for future retrofitting of automatic daylighting controls; there is no evidence that this practice is widespread. For all of these reasons, there is probably less support for Title 24's daylit area switching requirements than for other types of controls.

Occupancy Sensor Controls

The manufacturers of occupancy sensor controls sold in California have been vocal in their support of Title 24 requirements that steer people toward their products. Likewise, they have been vocal in their opposition to any attempts to reduce their share of the market.

Building owners and managers who pay for the electricity bills tend to view occupancy sensors as good devices for controlling costs. Building occupants (and the building managers who deal with their complaints) may be frustrated if the occupancy sensors are not properly calibrated and operate the lights incorrectly (false or slow turn-ons, early turn-offs, etc.). When properly operating, however, building occupants tend to prefer occupancy sensors over automatic time scheduling controls, because they clearly turn lights on and off in response to people's presence.

Automatic Shut-off Controls

The stakeholders for automatic shut-off controls, and their attitudes toward them, directly parallel those for occupancy sensors (see previous section).

Occupants are primarily affected by automatic shut-off controls when they are in the building after hours. Then the ease of using the manual override controls becomes crucial. When it is simple to override the shut-off, there is little dissatisfaction; when the override is difficult and when occupants are left in the dark, the opposition to automatic shut-off controls can be substantial.

Automatic Daylighting Controls

Probably the strongest supporters of automatic daylighting controls are manufacturers of the devices and of skylights, as well as energy efficiency and natural daylighting advocates. Utility-sponsored market transformation programs have also advocated the use of daylighting controls. A small but apparently growing number of corporate building owners are making use of daylighting controls for their economic advantage.

Beyond these advocates, however, there does not appear to be a great deal of support for daylighting controls. There are numerous examples of buildings that have had daylighting controls installed, only to have them removed or disabled. This occurs when occupants do not understand the controls ("Why are you turning off my lights?"), or when the building operators do not understand how to calibrate or operate the controls.

Implementation Strategies and Recommendations

This section discusses the implementation strategies and recommendations that have emerged from this study. We begin with the proposal that was developed in response to the emergency regulations that are being promulgated by the State of California, and then move on to longer-term recommendations for action in the lighting control arena.

AB 970 Proposal: Bi-level and Automatic Shut-off Controls

Introduction

The Pacific Gas and Electric Company (PG&E) presented the following proposal for changes to Title 24 lighting control requirements. This proposal was submitted by PG&E to the California Energy Commission for consideration under the AB 970 emergency rulemaking. We believe this proposal to be a reasonable and effective means to meet the AB 970 mandate, and urge its adoption.

This proposal has the support of a group of lighting experts convened by PG&E and the CEC, and addresses all their concerns.

Bi-level control,[3] at its simplest, is the provision of two light switches in a room, so that the lighting can be uniformly reduced by at least 50%. The same functionality may be achieved with greater flexibility by using dimming controls. Bi-level control is inexpensive, and it offers a very basic level of control to occupants. There is increasing evidence, presented in the annotated bibliography, that a substantial fraction of building occupants take advantage of this mechanism when it is available. From the AB 970 perspective, bi-level control is a built-in way to achieve large, voluntary load reductions through building standards. This proposal assures that all spaces have bi-level control where it can be demonstrated to be cost effective. Furthermore, bi-level control has become a part of standard practice for most lighting systems in California, due to the fact that it has been a mandatory measure in Title 24 since 1985.

Automatic shut-off controls save energy by making sure that lights are automatically turned off. These controls can take many forms, from the most sophisticated energy management systems to the simplest twist timers. Perhaps the most common form of automatic shut-off control, especially for small spaces, is the occupancy sensor. Occupancy sensors assist in turning off unnecessary lighting, both during working hours when people leave rooms unoccupied for a time and at night after people leave for the day. They have become increasingly widespread in their application and more reliable in their operation. Occupancy sensors have long been recognized under Title 24 as an alternative to mandatory bi-level control, and as an alternative way to meet the mandatory automatic shut-off control requirement.

The *Nonresidential Manual, November 1998 edition*, Section 5.2.1 Mandatory Measures, pages 5-10 through 5-19, contains explanation and illustrations of the current controls requirements.

Proposal

This proposal would remove the blanket exceptions to the mandatory bi-level control requirement of Title 24, which allows one to install an occupancy sensor or other automatic shut-off control in lieu of bi-level control. It also would extend the requirements for automatic shut-off controls to all buildings and to spaces with lower lighting power levels. A by-product of these changes will be to encourage the use of dual level lighting, with both bi-level control and automatic shut-off controls to maximize demand reduction potential.

The Standards should be revised as follows:

Title 24, Part 6, Subchapter 4

SECTION 131 – LIGHTING CONTROLS THAT MUST BE INSTALLED

Subsection (a) remains unchanged

(b) Controls to Reduce Lighting. The general lighting of any enclosed space 100 square feet or larger in which the connected lighting load exceeds ~~1.0~~0.8 watts per square foot for the space as a whole, and that has more than one light source (luminaire), shall be controlled so that the load for the lights may be reduced by at least one half while maintaining a reasonably uniform level of illuminance throughout the area. A reasonably uniform reduction of illuminance shall be achieved by:

[3] Throughout this proposal, we use the term "bi-level control" as shorthand for the Title 24 term "controls to reduce lighting." Bi-level control may be accomplished with two switches, or it may be accomplished with dimming controls.

1. Controlling all lamps or luminaires with dimmers; or
2. Dual switching of alternate rows of luminaires, alternate luminaires, or alternate lamps; or
3. Switching the middle lamps of three lamp luminaires independently of the outer lamps; or
4. Switching each luminaire or each lamp.

~~**EXCEPTION 1 to Section 131 (b):** Lights in areas that are controlled by an occupant-sensing device that meets the requirements of Section 119 (d).~~

EXCEPTION 2 to Section 131 (b): Lights in corridors.

~~**EXCEPTION 3 to Section 131 (b):** Lights in areas that are controlled by an automatic time switch control device that has a timed manual override available at each switch location required by Section 131 (a) and that controls only the lights in the area enclosed by ceiling-height partitions.~~

Subsection (c) remains unchanged

(d)Shut-off Controls.

1. For every floor, all interior lighting systems shall be equipped with a separate automatic control to shut off the lighting. This automatic control shall meet the requirements of Section 119 and may be an occupancy sensor, automatic time switch, or other device capable of automatically shutting off the lighting.

~~**EXCEPTION 1 to Section 131 (d) 1:** Buildings or separately metered spaces of less than 5,000 square feet of conditioned space.~~

Remaining sections unchanged

Reason for Proposed Changes

The reasons for the changes are presented below.

Reason for changes to Section 131 (b)

Section 131 (b) requires bi-level control. Exception 1 is for when occupancy sensors are installed. Exception 3 is for when there's an automatic time switch with manual override installed. Bi-level control, for practical purposes, is only required under the current standards for small buildings that are not required to have automatic shut-off controls. This is because the primary methods used to implement the automatic shut-off (occupancy sensors, automatic time switches) are also exceptions to the bi-level control requirement. Any area that must meet the automatic shut-off requirement, that is, buildings 5000 ft_ or larger, can avoid bi-level control. Also, any space with less than 1.0 W/ft_ of lighting is exempt; this typically includes corridors, public bathrooms, warehouses, laundry rooms, etc. By striking these exceptions, the Standards would require bi-level control in all spaces larger than 100 ft_ with a connected lighting load greater than 0.8 W/ft_.

The current exemption for spaces having less than 1.0 W/ft_ was put in place because it becomes increasingly difficult and expensive to implement bi-level control at lower lighting power densities (LPDs). Due to lighting technology and efficiency advances, however, there is now a larger portion of spaces in new buildings that have LPDs below 1.0 W/ft_. The most prominent example of this is warehouse/storage buildings. As of 1994, these buildings accounted for 12% of commercial lighting energy use in California. The mean LPD for warehouses then was 1.0 W/ft_, and all of the warehouse lighting within one standard deviation of this mean fell between 0.75 and 1.25 W/ft_. This means that half of the warehouse lighting in 1994 was less than 1.0 W/ft_, and most of that was greater than 0.75 W/ft_.

Over time, we can expect these numbers to trend even lower. Consequently, leaving the cutoff for bi-level control at 1.0 W/ft_ would exempt a large lighting load, but resetting it to 0.8 W/ft_ would capture much of that load under the bi-level control requirement. A similar argument would apply to many of the other kinds of lower LPD spaces.

The concern about the difficulty of providing bi-level control at lower LPD levels can be addressed with several observations.

First, it should be remembered that bi-level control provides an optional operations capability, not a required operating mode for buildings. Building managers are provided the option of turning off lights when they are not needed for their primary designed purpose. If that never happens, then the capability is superfluous, but if it is used only occasionally it is still cost effective. In most spaces, there are times when reduced lighting is acceptable or even desirable, such as during cleaning, times of vacancy, or times of lower usage.

Second, there are numerous ways to implement bi-level control for any given space or lighting system. It can be implemented with hi-lo ballasts, with dual-lamp fixtures sold in master/slave pairs (separately switched lamps), with dimming controls, or with alternately switched luminaires. It is left to the building owner and the lighting designer to determine the degree of uniformity and the quality of the control, but it can be implemented with simple wall switches.

Finally, the operational flexibility and possibility of lighting savings are valuable to all users. Even a poor quality, cheap version of bi-level control in a low LPD building can provide optional (and valuable) energy savings and demand reduction capabilities to building owners. The only time when it is economical to install bi-level control is during the new construction phase of a building, when the ultimate owner/operator of the building is frequently not represented. By requiring bi-level control capability at this stage of the building's life, we are assuring that future owners and operators will have the flexibility and the savings potential of this simple control strategy.

Reason for changes to Section 131 (d)

This exception exempts small buildings or separately metered spaces less than 5000 ft_ from the automatic shut-off requirements. We do not believe this exemption is justified. The requirement can be met with inexpensive occupancy sensors, and our cost analysis indicates that turning off lights that would otherwise have been left on for a few hours a week will cost justify the controls.

The exemption of small buildings less than 5,000 ft_ from the automatic shut-off requirement has been in place ever since the shut-off requirements were adopted in Title 24 (1992 standards). We do not believe that this exemption is needed any longer. The simplest way to meet the automatic shut-off requirement is with occupancy sensors, although a building-wide time sweep type controller may also be used (provided local override switches are included). Our economic analysis shows that very few hours per week are needed to cost justify occupancy sensors. If automatic shut-off controls make economic sense for larger buildings, they should make equally good sense for smaller buildings.

The exemption was probably put in place when automatic shut-off controls were seen as more like a building automation system, and therefore perceived as relatively expensive and complex. Since the requirement can be met with occupancy sensors, however, and since these controls are now inexpensive and ubiquitous, the economic distinction between large and small buildings is no longer necessary.

In summary, these changes would increase the use of both bi-level control, and of occupancy sensors or automatic time switch controls. For any building that requires automatic shut-off controls, occupancy sensors are and would continue to be a good and low-cost way to meet the requirement. Bi-level control requirements are not generally considered to be burdensome in California. Lighting designers and building occupants usually prefer the extra lighting flexibility. Bi-level control gives owners and facility managers an easy way to manage their lighting costs, because, for example, they can direct cleaning crews to use only one of the switches and operate at partial lighting power.

Bi-level control also provides a simple, voluntary mechanism for buildings to shed load during emergency situations. For example, the Raleys/BelAir grocery chain is turning off two-thirds of its lights during Stage Two power emergencies; without good switching control this would not be possible.

Application Examples

This section provides some examples of current requirements and how they would be affected by the proposed changes:

1) *Large spaces (e.g., open plan offices, retail sales areas, classrooms, etc.) in buildings currently NOT required to have automatic shut-off controls (e.g., in a 4500 ft_ building):*

   a) Option 1. Meet current requirements by installing two wall switches (bi-level control), or by installing dimming controls. Under the proposed changes, add an occupancy sensor or automatic shut-off device.

   b) Option 2. Currently, install an occupancy sensor to control all the lights in a space. This removes the possibility for switching off half of the lights. Under the proposed changes, the occupancy sensor would remain, but a dimming control system or an additional switch for the bi-level control would be added.

   c) Option 3. Currently, install an automatic time switch control with a timed manual override switch. This likewise removes the possibility for switching off half of the lights. Under the proposed changes, the automatic time switch would remain, but an additional switch for the bi-level control would be added.

   d) For all options, emergence egress lighting allowance of 0.5 w/ft_ for the egress path could remain on at all times.

2) *Large spaces (e.g., open plan offices, retail sales areas, classrooms, etc.) in buildings THAT ARE currently required to have automatic shut-off controls (e.g., in a building 5000 ft_ or larger):*

   a) Option 1. Currently, install only one lighting switch and operate it with an occupancy sensor. This meets the automatic shut-off requirement, and qualifies for the bi-level control exemption, but it also removes the possibility for switching off half of the lights. Under the proposed changes, both bi-level control and the occupancy sensor would be required.

   b) Option 2. Currently, install an automatic time switch with a timed manual override switch. This likewise meets the automatic shut-off requirement, and qualifies for the bi-level control exemption, but it also removes the possibility for switching off half of the lights. Under the proposed changes, both bi-level control and the automatic time switch would be required.

   c) For all options, emergence egress lighting allowance of 0.5 W/ft_ for the egress path could remain on at all times.

3) *Large storage areas (and other large spaces with less than 1.0 W/ft_) in buildings are currently NOT required to*

have automatic shut-off controls (e.g., in a building 5000 ft_ or smaller):

a) Option 1 – Installed lighting power is 0.8 W/ft_ or lower. Currently, bi-level control is not required (it's less than 1.0 W/ft_). Under the proposed changes, it would continue to be exempt from bi-level control, because it's 0.8 W/ft_ or lower. It would, however, be required to have an automatic time switch (see next section).

b) Option 2 – Installed lighting power is between 0.8 W/ft_ and 1.0 W/ft_. Currently, bi-level control is not required (it's less than 1.0 W/ft_). Under the proposed changes, bi-level control would be required. Also, an automatic time switch would be required (see next section).

In all of these cases, emergency egress areas throughout the space would be allowed to have 0.5 W/ft_ of lighting left on at all times.

4) Large storage areas (and other large spaces with less than 1.0 W/ft_) in buildings THAT ARE required to have automatic shut-off controls (e.g., in a building 5000 ft_ or larger):

a) Option 1 – Installed lighting power is 0.8 W/ft_ or lower. Currently, bi-level control is not required (it's less than 1.0 W/ft_). Under the proposed changes, it would continue to be exempt from bi-level control, but only because it's 0.8 W/ft_ or lower. So there would be no change. In both cases, the automatic shut-off requirement would apply to all of the lighting (except emergency egress lighting). This could be met with occupancy sensors or automatic time switches.

b) Option 2 – Installed lighting power is between 0.8 W/ft_ and 1.0 W/ft_. Currently, bi-level control is not required (it's less than 1.0 W/ft_). Under the proposed changes, bi-level control would be required. In both cases, the automatic shut-off requirement would apply to all of the lighting (except emergency egress lighting). This could be met with occupancy sensors or automatic time switches.

5) *Other cases:*

a) Small rooms less than 100 ft_. Any small room, no matter the occupancy, is and would still be exempt from the bi-level control requirements, and would continue to be subject to the automatic shut-off requirements, as applicable.

b) Corridors. These are, and would continue to be, exempt from bi-level control requirements. Moreover, corridors in high-rise residential buildings and hotel/motels would continue to be exempt from automatic shut-off requirements.

c) Hotel/motel guest rooms, high-rise residential lodging areas. These are, and would continue to be, exempt from all lighting control requirements.

d) Private offices, conference rooms and similar. These fall under the same requirements as Large Spaces (see above).

e) Daylit areas. These would continue to be treated as they are under the current Standards: They are subject to the same requirements for control as if they were not daylit, except that the daylit areas in spaces larger than 250 ft_ must be separately controlled from adjacent non-daylit areas.

Questions for Stakeholders

Commission staff and others have raised a number of questions about the implications of this proposal. These concerns were raised during a series of conference calls that included designers, policy makers, and utility program managers familiar with lighting control.

The following questions, and our answers for them, are provided for discussion and feedback purposes.

1. *Is there any occupancy for which the proposed new bi-level control will be a hardship?*

   Building owners, who do not believe anybody will actually use the bi-level control strategy, or who pass all of their operating costs on to their tenants, will not view this as a useful or cost-effective strategy. But this group exists now and has generally come to accept bi-level control where the current Standards require the strategy. In nearly all new construction applications, bi-level control is inexpensive to implement. It's less cost effective for smaller spaces than for larger ones, but the size cutoff eliminates the requirement for very small rooms. The cost effectiveness goes down as lighting power densities diminish in some occupancies, because the savings potential gets smaller. Nevertheless, even the worst case scenarios presented above are reasonably cost effective.

2. *Does bi-level control actually save energy?*

   For an individual space, it depends on lighting system layout, occupant preferences, and a number of other factors. On a population basis, the answer is almost certainly yes. There is some research data, mostly case studies of particular buildings (see Annotated Bibliography). There is also a great deal of anecdotal evidence that people make good use of the controls. Classroom teachers who have bi-level controls report that they prefer to use the lights at half power, or to turn them off altogether, because it makes the classroom more pleasant and cooler. Office workers with computer displays report that they often prefer the lower lighting levels because it improves screen visibility. Retailers report that they use the half-level lighting for stocking and cleaning, and only use full lighting when customers are in the store.

   On the flip side, there are clearly buildings where the bi-level controls are poorly configured, where turning off half of the lights produces a spotty light distribution with bright and dark areas under alternating luminaires. There are clearly some occupants who either turn all the lights on or all the lights off. But it does not take many occupants making good use of the controls to make the cost of bi-level controls cost effective at the building-wide level. In the population of new California buildings, bi-level control should be expanded.

3. *How will retrofits be affected by the proposed new bi-level control requirement?*

   Current lighting retrofit requirements do not need to change. The Standard states that remodels that do not entail changes to the wiring are not required to rewire for bi-level control. The requirement for treatment of a lighting system as new when 50% of the fixtures are replaced only governs the lighting power density requirements, not the bi-level control requirement.

4. *Are there any occupancies for which the proposed new automatic shut-off control requirements will be a hardship?*

   Since the requirement only changes for small buildings less than 5000 ft_, the hardship would only be apparent for this class of buildings. Since the 1992 Standards adoption, the various technologies that may be used to implement automatic shut-off control have become more widely available and less expensive. The Standards do not require costly central control solutions; simple occupancy sensors or time clocks may be used. Also, the difficulty of installing these controls is least in a new construction situation. We do not see these requirements as any more burdensome for small buildings than for large, and the energy, demand and economic benefits should be just as great.

5. *Are there cases where the use of occupancy sensors may increase lighting energy consumption?*

   Yes, if the controls are not adjusted properly to the characteristics of a particular application, the sensors may leave the lights on too long, or may improperly turn them on because of false signals. The adjustments needed to fix these problems are simple and need not be readjusted unless the space configuration or occupancy patterns change significantly. There is ample economic incentive and occupant satisfaction motivation for owners to get the controls adjusted properly.

6. *Will it be difficult to combine bi-level control with occupancy sensors or with automatic time switch controls?*

   No. Conversations with controls representatives indicate that there are a variety of simple ways to arrange wiring and controls to make this happen.

7. *Will designers still be able to get control credits for occupancy sensors and automatic time switch controls?*

   Yes. Under the current Standards, owners are allowed to take lighting control credits whenever they use these controls. This proposal would not change this. A more ambitious proposal might seek to eliminate the credits, but many people feel that the credits are needed to assist lighting designers in developing solutions for difficult situations.

Additional Standards Recommendations

The previous section presented the full proposal for our AB 970 lighting controls modification to the Standards. The following sections address other lighting control implemenation strategies and recommendations.

Bi-level Lighting Control

The AB 970 proposal shown on the preceding pages will substantially expand the use of bi-level control in California and make it nearly universal standard practice. Even if that proposal is not fully adopted into the Standards, we should continue to pursue that objective. One of the weaknesses of the effort to support bi-level control is the lack of substantial field data documenting user behavior in operating bi-level control throughout the range of building spaces in commercial buildings. We recommend conducting such a field study to quantify the hours and patterns of bi-level control operation to save lighting energy, and to better understand the best/worst applications. This data will give us a better understanding of ways to realize the full benefits of bi-level control. It will also provide better input into cost effectiveness calculations.

Occupancy Sensors

If our AB 970 proposal becomes part of Title 24, then we can expect an expansion of the number and breadth of occupancy sensor applications in commercial buildings.

The occupancy sensor control strategy has received most of the research attention, compared to other control strategies, and we have learned a lot about the effectiveness of occupancy sensors for saving energy. Nevertheless, most of these studies have been detailed case studies whose findings are difficult to generalize for the entire population. There is a study currently underway (by D. Felts, funded by PG&E) which will summarize field data from a larger population of buildings. There may still be a need for a more comprehensive field study of occupancy sensor savings in a representative population of new buildings, depending on how conclusive the Felts study is (it is due for completion by the end of 2000).

Future refinements to the Title 24 controls requirements might consider eliminating the control credits for occupancy sensors, or limiting them to applications with the strongest potential savings. These control credits will become less valuable if occupancy sensors become more universal. Rather than encouraging the use of occupancy sensors, the credits will have the effect simply of increasing the available LPD for ordinary building spaces.

If extensive field studies are conducted, it might also become apparent that there is a need to adjust the control credits if studies show larger or smaller savings on aggregate. Studies could show a large standard deviation in savings potential among different applications, in which case some judgment would be needed to set the appropriate credit levels in Title 24.

There may also be issues of controls commissioning. Sometimes the controls have excessive time delays, which leave lights burning long after rooms have been vacated. In other cases, improperly calibrated sensors mistakenly register movement outside the control zones and turn on lights that aren't needed. There have been reports of dissatisfaction with lights turning off at inappropriate times due to obstacles preventing the sensors from registering enough movement, which may lead occupants to disable controls or "fool" sensors. There are anecdotal stories of occupants fooling the sensors into thinking rooms are occupied by such tricks as tying rags to the blades of rotating fans.

Occupancy sensors that do not function properly, or whose functioning is misunderstood by occupants, will not save energy. This is doubly so when the installation of the occupancy sensors lead to the elimination of bi-level switching. Fortunately, our survey respondents indicate that dissatisfaction with the performance of occupancy sensors in current installations is not a large issue in California.

One possible solution to poorly functioning or calibrated occupancy sensors could be an education program for building operators and occupants on the correct calibration and operation of sensor. Another possible solution could be to encourage the use of occupancy sensors that automatically adapt their operation to the behavior patterns of the occupants.

Automatic Shut-off Controls

Our AB 970 proposal will have the effect of extending and expanding the use of automatic shut-off controls. At the same time, the technologies and field experience with ever more sophisticated versions of these controls is growing.

The research on automatic shut-off controls is very case study specific, which makes it difficult to generalize about their effectiveness across the population of buildings. There is a need for additional field studies to validate the operation and energy savings of time sweeps and other forms of automatic shut-off controls.

An important aspect of successful automatic shut-off control operation is the way that manual override is used. When it is difficult for users (for example, people working late) to override the shut-off, there is a strong likelihood that the shut-off controls will be deactivated. If the field studies indicate widespread difficulties with manual override controls, then there will be a need for education and technical assistance to overcome the problems.

Lighting control strategies implemented through energy management systems or building automation systems (EMS) have potentially more flexibility and savings potential, but their success depend on both the capabilities of the EMS and the sophistication of the building operator who programs it. Again, there may be a need for education and assistance if the field studies indicate significant problems here.

There has been growing interest in the potential of lighting control systems to implement emergency load shedding in times of impending brown-outs. Especially when dimming ballasts and controls are installed, it would be possible to make modest reductions in delivered light levels while achieving significant reductions in demand. There is even the potential to make these load shedding controls addressable over an Internet connection, so that the load reductions can be dispatched by the local utility in times of emergency.

While this is an appealing prospect from an emergency management perspective, it appears that the load shedding technologies are probably too complex at present to consider mandating them in the Title 24 Standards. They may be appropriate as an allowable alternative under Title 24, if a time-dependent valuation methodology is adopted. They are certainly appropriate for voluntary load management programs by the utilities, and this is probably the next most appropriate step toward their eventual adoption under Standards.

Daylit Area Switching

For daylit area switching, we recommend the same basic treatment as for the previously described bi-level control requirement. As described earlier, a study of individual perimeter offices with windows and bi-level switching indicates that about 36% of users make active use of bi-level switches, while other users occasionally use them (Jennings et al. 2000). Overall savings amounted to about 33% in one test bed trial over seven months. Most of these offices were small (112 to 480 ft_, with the average being 188 ft_) and so would not be required to have separate daylit area switching, but would instead be covered under the general requirement for bi-level switching (since all areas were greater than 100 ft_). Currently the general bi-level switching requirement in Title 24 that applies to small offices does not necessarily ensure that circuiting for daylit area switching complements the illuminance patterns of daylight.

Daylit area switching may be more problematic for window areas in large open spaces with desk occupants, because many people share the daylit zone and there may not be agreement on how or when to utilize the separate daylit area switching or dimming capability. Similar to the cultural issues associated with the use of bi-level switching in non-daylit open plan offices, high light levels are rarely perceived as uncomfortable, and changing light levels are seen as a distraction. Thus in many of these situations, light levels rise to the highest common denominator (lights all on).

This may be less of a problem when the occupants are moving and not tied to private desks or workstations (as in retail, or public circulation areas). The daylit area switching is most problematic in medium-size spaces, such as 30-ft deep conference rooms, where nearly half of the area may be daylit and the remainder non-daylit; these kinds of spaces require extra switching compared to non-daylit rooms, and it may be unlikely that the separate switching will be used in practice. These problem areas should be examined through (separate) field studies, and consideration given to providing a more narrow focus to the daylit area switching requirement, perhaps limiting it to a smaller number of spaces that are most likely to work successfully under this strategy or perhaps requiring the use of automatic daylighting controls for large daylit areas.

Automatic Daylighting Controls

We recommend revisiting the control credits, which don't effectively distinguish between multilamp switching, dimming and the newer step ballast HID technologies. Research using the SkyCalc tool[4] indicates

[4] SkyCalc software for daylighting and skylight design available from Energy Design Resources

that the current control credits may have values of the dimming and step daylighting control credits backwards for California climate zones. PG&E or the CEC should also consider providing more detailed guidance in utility programs, in the Standards, or in the Nonresidential Manual to assure that daylighting controls are properly applied to achieve the targeted savings.

There should also be research to address more specific questions, such as:

- What characteristics separate a successful (persistent) from an unsuccessful photocontrol system?
- Can successful strategies be usefully categorized by building type, occupant type, location or other identifiers?
- How many systems are out of calibration? Why?
- What common design or commissioning errors could be avoided?
- How do actual savings compare to estimated savings?

These questions can best be answered through field study of the actual operation of photocontrols.

Other Recommendations

CERTIFICATION OF CONTROLS. The detailed operation of automatic lighting controls does need to be carefully specified at the time of permitting, under the mandatory provisions of Title 24. These provisions should be revisited to assure that they are up-to-date with current technology. In addition, the Commission should live up to its longstanding obligation to implement a certification program for lighting controls. This would greatly help to assure that only capable controls are used in new construction, which would enhance the reliability of the energy savings from lighting controls.

PERSONAL DIMMERS AND DIMMING BALLASTS. Some people have suggested that the Standards ought to encourage the use of personal dimming controls, the idea being that people will tune their lighting levels down to suit their personal needs, and thereby save energy. Others have suggested that this would be a bad idea because it would rule out controls with proven track records of savings, such as occupancy sensors. Facility managers in particular expressed a strong distrust of manual controls versus automatic controls. This is currently a small, niche technology as a control type; it may not be ready for mandatory treatment under the Standards.

It might be advisable, however, to consider give a modest dimming ballast credit (perhaps 5%–10%) to encourage the technology and gain the savings potential. This type of credit could be independent of the operating control type. Then an additional credit could be awarded for persistent control types.

Dimming ballasts may be a better way to meet the bi-level switching requirement, and they make possible and cost effective a much wider range of additional control strategies, particularly during a tenant improvement or retrofit. Dimming ballast technology has advanced significantly in recent years, and these products are now much more widely available in the market. It may be time for Title 24 to encourage dimming ballast technology. Before this could be done, however, we need a good field verification method from manufacturers, which would allow building officials to reliably to confirm that dimming ballasts have been installed.

LIGHTING EFFICIENCY REQUIREMENTS IN UNCONDITIONED SPACE. Title 24 does not apply to buildings with no heating or cooling (unconditioned space). While this makes sense in terms of HVAC and envelope requirements, it makes less sense for lighting. If the Title 24 lighting requirements are economically justified for conditioned space, they would be nearly

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at www.energydesignresources.com/ tools/skycalc.html equally justified in unconditioned space (the secondary cooling energy savings would be the only difference). The CEC should explore whether it needs to seek legislative authority to extend Title 24 lighting efficiency requirements to unconditioned space.

OUTDOOR LIGHTING CONTROLS (MOTION DETECTORS). Title 24 has little to say about outdoor lighting energy efficiency, but it does require astronomical time clocks or photosensor controls to ensure that outdoor lighting is not turned on during daylight hours. For many outdoor lighting applications, combined photocell/motion detector controls for outdoor lights would save substantially more energy than either of these required controls. It is not clear, at this point, if there is a way to grant a credit for users who apply motion detector controls in this manner, but we will continue to examine the question.

Additionally, there should be field study to quantify savings from the currently required outdoor lighting controls, and to identify the potential for additional savings from the addition of motion sensor capability.

MULTISCENE PROGRAMMABLE CONTROLS CREDIT. This measure is limited to a few select space types, and the controls are used primarily for the convenience of building occupants in selecting between different lighting configurations. The controls do not necessarily save any energy, except to make it easier for occupants to choose a lower lighting level configuration. In any case, the savings are highly dependent on how well the controls are programmed and used. We recommend that the CEC drop the lumen maintenance control credit from the Standards.

TUNING CONTROLS CREDIT. The effectiveness of tuning controls is unknown. It depends on a sophisticated building operator making space-by-space reductions in design illuminance to match user needs. If that happens, savings will occur. However, the system requires dimmable ballasts, good controls and calibration, and ongoing maintenance in order for the controls to continue to function as intended. Lacking any evidence that this is happening, we recommend that the CEC drop the tuning control credit from the Standards.

LUMEN MAINTENANCE CONTROLS CREDIT. There is currently no evidence that these controls are used, or that they are even capable of saving much energy, given the improvements in lumen depreciation with new lamp technologies. We recommend that the CEC drop the lumen maintenance control credit from the Standards.

CONSIDER DROPPING ALL CONTROL CREDITS. If our AB 970 proposal is incorporated into the Standards, then there will be little remaining justification for awarding control credits for manual dimming, occupancy sensors and automatic shut-off controls, because these controls will be almost universally applied. The control credits for lumen maintenance, tuning and multiscene programmable controls, as discussed above, are not well justified.

This leaves only the daylighting control credits. Those may be valuable to keep, in order to encourage the technology, but the same effect could be achieved through adoption of better ACM calculation methods to directly estimate lighting energy savings for the particular system design in question. Removing all control credits would simplify the Title 24 lighting requirements, which is always a desirable goal.

Appendix A – Title 24 Excerpt – Lighting Controls

Title 24, Part 6, Subchapter 4

SECTION 131 – LIGHTING CONTROLS THAT MUST BE INSTALLED

(a) **Area Controls.**

1. Each area enclosed by ceiling-height partitions shall have an independent switching or control device. This switching or control device shall be:

   A. Readily accessible; and

   B. Located so that a person using the device can see the lights or area controlled by that switch, or so that the area being lit is annunciated; and

   C. Manually operated, or automatically controlled by an occupant-sensing device that meets the requirements of Section 119 (d).

2. Other devices may be installed in conjunction with the switching or control device provided that they:

   A. Permit the switching or control device to override the action of all other devices; and

   B. Reset the mode of any automatic system to normal operation without further action.

EXCEPTION 1 to Section 131 (a): Up to one-half Watt per square foot of lighting in any area within a building that must be continuously illuminated for reasons of building security or emergency egress, if:

A. The area is designated a security or emergency egress area on the plans and specifications submitted to the enforcement agency under Section 10-103 (a) (2) of Title 24, Part 1; and

B. The area is controlled by switches accessible only to authorized personnel.

EXCEPTION 2 to Section 131 (a): Public areas with switches that are accessible only to authorized personnel.

(b) **Controls to Reduce Lighting.** The general lighting of any enclosed space 100 square feet or larger in which the connected lighting load exceeds 1.0 Watts per square foot for the space as a whole, and that has more than one light source (luminaire), shall be controlled so that the load for the lights may be reduced by at least one half while maintaining a reasonably uniform level of illuminance throughout the area. A reasonably uniform reduction of illuminance shall be achieved by:

1. Controlling all lamps or luminaires with dimmers; or
2. Dual switching of alternate rows of luminaires, alternate luminaires, or alternate lamps; or
3. Switching the middle lamps of three lamp luminaires independently of the outer lamps; or
4. Switching each luminaire or each lamp.

EXCEPTION 1 to Section 131 (b): Lights in areas that are controlled by an occupant-sensing device that meets the requirements of Section 119 (d).

EXCEPTION 2 to Section 131 (b): Lights in corridors.

EXCEPTION 3 to Section 131 (b): Lights in areas that are controlled by an automatic time switch control device that has a timed manual override available at each switch location required by Section 131 (a) and that controls only the lights in the area enclosed by ceiling-height partitions.

(c) **Daylit Areas.** Daylit areas in any enclosed space greater than 250 square feet shall meet the requirements of Items 1 and 2 below

1. Such areas shall have at least one control that:

   A. Controls only luminaires in the daylit area; and

   B. Controls at least 50 percent of the lamps or luminaires in the daylit area, in a manner described in Section 131 (b) 1 through 4, independently of all other lamps or luminaires in the enclosed space. The other luminaires in the enclosed space may be controlled in any manner allowed by Section 131 (b) 1 through 4.

2. Such areas shall have controls that control the luminaires in each vertically daylit area separately from the luminaires in each horizontally daylit area.

EXCEPTION 1 to Section 131 (c): Daylit areas where the effective aperture of glazing is equal to or less than 0.1 for vertical glazing and 0.01 for horizontal glazing.

EXCEPTION 2 to Section 131 (c): Daylit areas where existing adjacent structures or natural objects obstruct daylight to the extent that effective use of daylighting is not feasible.

(d) **Shut-off Controls.**

1. For every floor, all interior lighting systems shall be equipped with a separate automatic control to shut off the lighting. This automatic control shall meet the requirements of Section 119 and may be an occupancy sensor, automatic time switch, or other device capable of automatically shutting off the lighting.

   EXCEPTION 1 to Section 131 (d) 1: Buildings or separately metered spaces of less than 5,000 square feet of conditioned space.

   EXCEPTION 2 to Section 131 (d) 1: Where the system is serving an area that must be continuously lit, or lit in a manner requiring manual operation of the lighting.

   EXCEPTION 3 to Section 131 (d) 1: Lighting in corridors, guest rooms, and lodging quarters of high-rise residential buildings and hotel/motels.

   EXCEPTION 4 to Section 131 (d) 1: Up to one-half Watt per square foot of lighting in any area within a building that must be continuously illuminated for reasons of building security or emergency egress, if:

   A. The area is designated a security or emergency egress area on the plans and specifications submitted to the enforcement agency under Section 10-103 (a) 2 A of Title 24, Part 1; and

   B. The area is controlled by switches accessible only to authorized personnel.

2. If an automatic time switch control device is installed to comply with Section 131 (d) 1, it shall incorporate an override switching device that:

   A. Is readily accessible; and

B. Is located so that a person using the device can see the lights or the area controlled by that switch, or so that the area being lit is annunciated; and

C. Is manually operated; and

D. Allows the lighting to remain on for no more than two hours when an override is initiated; and

E. Controls an area not exceeding 5,000 square feet.

EXCEPTION to Section 131 (d) 2 D: In malls and arcades, auditoriums, single tenant retail spaces, industrial facilities, and arenas, where captive-key override is utilized, override time may exceed two hours.

EXCEPTION to Section 131 (d) 2 E: In malls and arcades, auditoriums, single tenant retail spaces, industrial facilities, and arenas, the area controlled may not exceed 20,000 square feet.

3. If an automatic time switch control device is installed to comply with Section 131 (d) 1, it shall incorporate an automatic holiday "shut-off" feature that turns off all loads for at least 24 hours, then resumes the normally scheduled operation.

EXCEPTION to Section 131 (d) 3: Retail stores and associated malls, restaurants, grocery stores, churches, and theaters.

Appendix B – References

Floyd, D. B., D. S. Parker, and J. R. Sherwin. 1996. Measured field performance and energy savings of occupancy sensors: Three case studies. Florida Solar Energy Center. Online publication FSEC-PF309, August.

Floyd, D. B. and D.S. Parker. 1995. Field commissioning of a daylight-dimming lighting system. Florida Solar Energy Center, April.

Heschong, L. H. 2000. Follow-on study, teacher survey. October (unpublished preliminary results).

Heschong Mahone Group. 2000a. C&I new construction and retrofit lighting design and practices—Market characterization study, final report (unpublished). Submitted to Sacramento Municipal Utility District, October.

Heschong Mahone Group. 2000b. Nonresidential new construction market assessment & evaluation: Market transformation barriers and strategies study. Submitted to Southern California Edison, February.

Heschong Mahone Group. 2000c. Photocontrol operations study: Phase I—preliminary report. Submitted to Pacific Gas and Electric Co., February.

Heschong Mahone Group. 1999. Daylighting in schools: An investigation into the relationship between daylighting and human performance. Submitted to Pacific Gas and Electric Co., August.

Himonas, J. 2000. Novitas, Inc. Personal communication with D. Mahone, October 26.

Jennings, J. D., F. M. Rubenstein, D. DiBartolomeo, and S. L. Blanc. 2000. Comparison of control options in private offices in an advanced lighting controls testbed. *Journal of Illuminating Engineering Society*, Summer.

RLW Analytics, Inc. 2000. Non-residential new construction baseline follow-on study—Project 1: final report, November 6.

RLW Analytics, Inc. 1999. Non-residential new construction baseline study, final report, July 8.

Schrum, L., D.S. Parker and D.B. Floyd. 1996. Daylight dimming systems: Studies in energy savings and efficiency. Florida Solar Energy Center FSEC-PF-310, August.

Smiley, F. 1996. Durant Middle School. *Architectural Lighting Magazine, February*.

Veitch, J. A. and G. R. Newsham. 1999. Individual control can be energy efficient. *IAEEL Newsletter*, January.

Appendix C – Annotated Bibliography

This bibliography provides a summary of the various studies and other data that support the proposals for bi-level control, occupancy sensor use and building time controls for lighting. There are controlled experiments, use studies and summaries of expert opinion. The following subsections provide summaries organized by control strategy (individual controls, occupancy sensors, etc.).

Individual Controls

Boyce, P. R., N. H. Eklund, and S. N. Simpson. Individual lighting control: Task performance, mood and illuminance. *IESNA Conference Proceedings, 1999.*

Providing individual lighting controls saves energy compared to the lighting being full on (though the maximum level in the rooms controlled exceeded IESNA recommendations for office lighting). It does not improve performance or mood, but does improve satisfaction with the environment and perception of task difficulty. The study was too short to show any absenteeism or other health effects.

Heschong, L. H. Follow-on study, teacher survey. October 2000 (unpublished preliminary results).

In this study, researchers surveyed 250 teachers in the Capistrano Unified School District (Capistrano, CA). 40% of the teachers surveyed indicated they occasionally teach with all the lights off, and 54% occasionally teach with at least some of the lights off. The number one reason given by these teachers for choosing a specific classroom was the ability to “control the environment,” and the most common control they listed was the ability to turn off the lights or darken the room.

Jennings, J. D., F. M. Rubenstein, D. DiBartolomeo and S. L. Blanc. Comparison of control options in private offices in an advanced lighting controls testbed. *Journal of Illuminating Engineering Society*, Summer 2000.

Found that allowing occupants to dim lighting system to their desired levels saved 43% when the multilevel control switching was the only control installed, and still saved 23% over occupancy sensors alone.

Lighting Controls Association. The National Dimming Initiative. Advance Transfer Co. 1999.

The National Dimming Initiative produces a CD-ROM, one of the purposes of which is to help designers figure out compatibility issues between controls relays lamps and ballasts.

Morrow, W. Designing with dimming. *Consulting Specifying Engineer*. April 1997.

Morrow, W. Personal environments and productivity in the intelligent building. Intelligent Building Institute Intellibuild ‘95. June 1995.

Rea, M. S. The quest for the ideal office controls system. *LRC Lighting Futures* 1998, Vol. 3, No. 3.

A lighting controls retrofit and study conducted at the National Center for Atmospheric Research concluded that allowing people in offices to chose between multiple levels of lighting power saves energy: “On average, while occupants were in the offices, the lights were dimmed 28% of the time and were off 24% of the time.” People in interior spaces kept their lights off only 3% of the time, but against the north wall, occupants had the lights off 57% of the time they were in their offices. The

researchers conclude that the multilevel switching controls accounted for a 61% savings in lighting energy.

Slater, A., B. Bordass and T. Heasman. Give people control of lighting controls. *IAELL Newsletter*, March 1996.

Veitch, J. A. and G. R. Newsham. Individual control can be energy efficient. *IAEEL Newsletter*, January 1999.

Reports on a controlled side-by-side comparison of satisfaction of people given lighting level control choice and those who were subjected to light levels selected by others. Provides evidence that there is a high correlation between being able to control light levels (both above and below IESNA RP-1 recommended levels) and energy efficiency. Participants who did not have control of lighting levels were as satisfied with the lighting conditions as those who controlled the lighting arrangements, and lighting levels were generally significantly below the maximum possible from the research setup, the IESNA recommended levels, and the ASHRAE/IESNA 90.1-1989 LPDs. The most frequent level chosen was 1.6 W/ft_ (the data was reported in increments of 0.2 W/ft_, so this actually represents everything between 1.5 and 1.7 W/ft_). Lighting levels over this were selected 34% of the time, and below this 39% of the time. The maximum lighting level allowed by the experiment was 2.4W/ft_, well above the current level allowed for offices by Title 24. Concludes that “the lit environments people selected for themselves had, on average, lower power requirements compared with environments in line with the recommendations in existing codes and standards.”

Occupancy Sensors

Energy Ideas Clearinghouse. Lighting Controls. Energy Solutions Database. 6/12/00.

Fifteen manufacturers of infrared type occupancy sensors in the United States are listed along with a link to comparative test results.

Floyd, D. B., D. S. Parker and J. R. Sherwin. Measured field performance and energy savings of occupancy sensors: Three case studies. Florida Solar Energy Center, online publication FSEC-PF309. August 1996.

Researched the performance, energy savings and occupants’ acceptance of occupancy sensors in a small office building and two elementary schools. Lighting energy savings reached 19% with a net energy savings of approximately 2,060 kWh/year in lighting energy for the small office setting after proper commissioning of the sensors. In the two school settings an analysis of pre- and post-retrofit of the sensors indicated an average lighting energy savings of 10.8% (26,420 kWh/year) in one of the schools and a negative savings in the other. Attributes the negative savings of the second school to the sporadic occupancy patterns that occur in classrooms, which might have increased the lighting energy consumed due to the sensor set-up delay period.

Jennings, J. D., F. M. Rubenstein, D. DiBartolomeo and S. L. Blanc. Comparison of control options in private offices in an advanced lighting controls testbed. *Journal of Illuminating Engineering Society*. Summer 2000.

Researchers attempted to determine the energy usage of office spaces with occupancy sensors against those without sensors. They compared spaces with manual switching only to those with occupancy sensors only and to those with both occupancy sensors and bi-level switching. They found that occupancy sensors saved "20–26% lighting energy compared to manual switching alone." The savings increased to 46% when the sensors were "properly commissioned." In private offices with nearly constant occupancy during work hours, sensors, not surprisingly, only saved about 7% - during lunch hour. In private offices with variable occupancy schedules, occupancy sensors save an average of 23–26%.

Leviton Web Site. Occupancy sensor lighting controls. Accessed June 15, 2000.

Article on the Web site quotes Electric Power Research Institute (EPRI) report that average savings from occupancy sensors are from 25%–30% for private offices, 25%–45% for schools, 35% for conference rooms, 40% for restrooms, and 60%–80% for warehouses, hotel meeting rooms, small storage rooms and hospital rooms.

Maniccia, D. Specifier reports: Occupancy sensors. Lighting Research Center. October 1992 and May 1997.

Principle problems with occupancy sensors are failure to detect small motion (e.g., typing) and false switching of lamps.

Maniccia, D. They turn off the lights. *IAEEL Newsletter*. March 1996.

Summarizes the variety of occupancy sensor technologies available and their characteristics. Reports that "case studies for offices buildings in the United States show savings of 25 to 75 percent" for occupancy sensors, with estimated pay back periods of 1.5 to 3 years.

Pacific Gas and Electric Company. Case study—Occupancy sensor commissioning. *1998 Building Commissioning and Building Performance Tools Program.* September 29, 1998.

A study of pre- and post-commissioning of occupancy sensors in five spaces in an office building, including perimeter and interior offices, and an interior break room. Contains measured savings and observations about occupant behavior with occupancy sensor controls. Shows that number of hours lights are turned off by occupancy sensors, compared to the hours they are left on by occupants and manual switching, is highly variable and depends on individual behavior.

Pigg, S., M. Eilers and J. Reed. Behavioral aspects of lighting and occupancy sensors in private offices: A case study of a university office building. *ACEEE Summer Study Proceedings.* 1996.

Provides a comparison of savings between perimeter offices with windows with occupancy sensors (standard), and with the occupancy sensors in place collecting data about occupancy but not turning off lights (control). These offices have window wall ratios (WWR) of 25%, are 11 by 15 ft., and have two 3-lamp (T-8) fixtures per room (LPD = 1.05). Both groups of rooms have bi-level switching. Power consumption of fixtures was monitored every minute for one year. Occupancy sensors (dual technology IR and ultrasonic) were installed with time delays ranging from 6 minutes to 21 minutes.

The rooms were primarily offices for university lecturers and teaching assistants in the Business Administration Department. This study found that active occupancy sensors reduced the amount of manual switching of lights by occupants and slightly reduced the amount of time people would use their lights at half level. Those with occupancy sensors used full illumination 95% of the time whereas those without occupancy sensors used full illumination 89% of the time. It is hypothesized that people with occupancy sensors manually switch their lights less frequently and thus make less decisions about how many lights should be on.

Since people turn off their lights immediately when they leave, whereas occupancy sensors wait the time delay period of 10 minutes, taking this into account reduced the annual savings from occupancy sensors from 234 hr/yr to 70 h/yr.

Rea, M. S. The quest for the ideal office controls system. *LRC Lighting Futures 1998,* Vol. 3, No. 3.

In the LRC/NCAR study, occupancy sensors saved 46% of the lighting energy in the areas where they were installed.

Richman, E. E., A.L. Dittmer and J.M. Keller Field analysis of occupancy sensor operation: Parameters affecting lighting energy savings. *Journal of Illuminating Engineering Society.* Winter 1996.

In the PNNL study, a cross section of eight buildings containing offices and laboratory spaces was monitored for occupancy patterns and electric light consumption during two periods: from November 1991 to February 1992 and January to August 1993. The space types monitored included 13 different space types, which use occupancy sensors as a lighting control technology. The results indicated that the number of hours of wasted-light is dependant on the patterns of use, occupants type and space type. Projections for yearly savings of different space functions were also presented.

Southern California Edison. Energy Design Resources design brief—lighting controls. June 2000.

Typical ranges of energy savings from occupancy sensors are 13%–50% for private offices, 20%–28% for open plan offices, 40%–46% for classrooms, 22%–65% for conference rooms, 30%–90% for restrooms, 30%–80% for corridors, and 45%–80% for storage areas. One detailed study on occupancy sensors at a large complex showed a savings of 50% of the lighting energy across 8000 offices, labs conference rooms and other work areas. Given the cost of the sensors, the payback period was 1.1 years.

U.S. EPA. Case study: Whitehill Lighting and Supply. EPA Web site. Accessed June 2000.

Installing occupancy sensors in a 7000–ft_ warehouse cut lighting energy use by 75%.

U.S. EPA. Application profile: Occupancy sensor control in education spaces. EPA Web site. Accessed June 2000.

In the installation on which this study was based, the cost of the sensors was $61,504 and the annual energy savings was 36% of the energy, or 374,063 kWh/year. Given an average cost of $0.10.kWh, that is a 1.7-year payback period.

Daylighting Controls

Energy Efficiency and Renewable Energy Clearinghouse. Daylighting for commercial and industrial buildings. U.S. DOE. February 1996.

Energy Center of Wisconsin. Daylighting in Wisconsin: A program study." ECW. 1999.

Energy Design Resources. SkyCalc software for daylighting and skylight design. Available at www.energydesignresources.com/ tools/skycalc.html.

Energy Design Resources. Skylighting guidelines. Available at:

www.energydesignresources.com/ publications/skylighting/index.html.

Erwine, B. and L. Heschong. Daylight: healthy, wealthy & wise. *Architectural Lighting Magazine*. March/April 2000.

Floyd, D. B. and D. S. Parker. Field commissioning of a daylight-dimming lighting system. Florida Solar Energy Center. April 1995.

Researchers monitored the light levels and energy usage for a dual-purpose (auditorium/cafeteria) schoolroom before and after the installation of more efficient dimmable ballasts and fluorescent lamps. Initially they found very little improvement other than what could be attributed to the efficiency improvements of the lamps and ballasts alone. After re-commissioning the photosensors and dimming controls, they saw better than a 25% improvement in lighting energy use with lighting levels still 1/3 higher than IESNA recommended levels.

Heiser, S. Controllable ballast retrofit using load-shedding and daylight-harvesting strategies reduces lighting costs by 76%. Powerline.com. 1998.

Heschong Mahone Group. Photocontrol operations study: Literature review. Submitted to Pacific Gas and Electric Co. September 1999.

Heschong Mahone Group. Photocontrol operations study: Phase I—preliminary report. Submitted to Pacific Gas and Electric Co. February 2000.

Heschong Mahone Group. Daylighting in schools: An investigation into the relationship between daylighting and human performance. Submitted to Pacific Gas and Electric. June 1999.

Found that daylight improves performance in the classroom. One of the findings was also that teachers like to vary light levels depending upon the task and often teach with the electric lights dimmed or off.

Kinney, L. Practical control strategies for harvesting daylight savings. E Source. June 2000 draft.

Simple dimming controls that cover a wide daylit area where people are in motion are cost effective. The more complex controls, for the more complex environment of individual offices and other areas where people "own" the space, are currently not cost effective. The control equipment and strategies for these areas are not too far off on the horizon however. It will take a combination of more sophisticated sensors, improved daylighting designs and personal control devices (with enhanced communications technologies) to make such applications effective.

Kinney L., E Source. Personal conversation, June 19, 2000.

Biggest issue is to get the daylighting design done right in the first place. "You can't fix a bad daylighting design with a "good" controls design."

Knoop, T., K. Ehling, S. Aydinli and H. Kaase. Investigation of daylight redirecting systems and daylight responsive lighting control systems. *Right Light 4 Proceedings.* 1999

Kohler, J. Enlightening designs: Collaborative to ease simple daylighting into mainstream construction. ECW. 1999.

Lee, E. and S. Selkowitz. Integrated envelope and lighting systems for commercial buildings: A retrospective. *ACEEE 1998 Summer Study Proceedings.*

Notes that experience of daylighting cannot necessarily be "reduced to 'measurable' terms." Implication is that personal control is a valuable element of good design. Also argues that technology is the largest barrier to wider acceptance; “Daylighting controls in the U.S. have fundamental design flaws that simplify installation and reduce cost but decrease reliability.” Controls unable to adjust to changing patterns of light from daylight sources. Commissioning guidelines need further development.

McHugh, J., Heschong Mahone Group. Personal conversations, June 12–21, 2000.

By focusing on the more difficult and variable problem of daylight and dimming in offices instead of going after the “low hanging fruit” of warehouses, atria and retail spaces—and dealing with sidelighting instead of toplighting—national labs, utilities and ESCOs may be doing daylighting a disservice. Better to prove —and take—the value of daylighting where it is easier and is less prone to failures. Likewise, open loop systems where the photosensor is placed in or below the skylight well (and only sees the light from above), are easier to calibrate and commission.

Schrum, L., D. S. Parker and D. B. Floyd. Daylight dimming systems: Studies in energy savings and efficiency. Florida Solar Energy Center, FSEC-PF-310.

Smiley, F. Durant Middle School. *Architectural Lighting Magazine.* February 1996.

Cooling equipment downsized 10% and energy use cut 22%–64% due to daylighting and lighting controls. … stepped switching on photosensors plus occupancy sensors. With cooling system savings, payback for lighting controls was less than 9 months. … also resulted in higher test scores and attendance.

General Lighting Control Issues

California Energy Commission. *Building Energy Efficiency Standards. Title 24 Pt. 6.* July 1999.

Energy standards require lighting controls used for compliance with the standards to meet certain mandatory measures for performance and certain certification. There are also mandatory requirements for switching of lighting and controls to reduce lighting. Designers may take either a prescriptive approach or a performance approach to meeting the lighting energy budget. very specific allowances and requirements are listed in the prescriptive approach including a table providing playing power adjustment factors for a large range of control types. The same factors are used when calculating building energy use under the performance method. There are factors for occupant sensors depending upon size of the space, for manual and programmable dimming controls for certain occupancies, for lumen maintenance controls, for tuning controls, for automatic time switch control devices (for certain size spaces), for combined controls depending upon the occupancy and size of the space, and for automatic daylighting controls (both stepped and dimming) depending upon the glazing type window/wall ratio for sidelighting, and the percentage of gross exterior roof area in skylights for toplighting.

Dilouie, C. Manual vs. dimming controls. www.Lightforum.com/technology/dimming.html. Accessed June 22, 2000.

Duarte, R., A. Martins. A comparative analysis of automatic lighting control strategies in buildings. *Right Light 4 Proceedings.* 1999.

Energy Center of Wisconsin. Review of energy efficient measures in Wisconsin commercial construction, 1986–1990. ECW. 1999.

Energy Ideas Clearinghouse. Lighting—operations and maintenance. *Energy Solutions Database.* Washington State University. Accessed June 15, 2000.

Switching fluorescent lamps off repeatedly during the day does not reduce energy savings or lamp life. A control that turns off the lamp for even five seconds saves more energy than the inrush current would use turning it back on again. Turning a lamp off and on fourteen times in a day will reduce the hours of lamp life by approximately 12.5%, but increase the years of lamp life by approximately 75%.

Energy Ideas Clearinghouse. Lighting—controls: Question and answer. *Energy Solutions Database.* Washington State University. Accessed June 12, 2000.

Heschong Mahone Group. Nonresidential new construction market assessment & evaluation: Market transformation barriers and strategies study. Submitted to Southern California Edison. February 2000.

This research involved assessing attitudes and experiences of commercial new construction participants on energy efficiency related matters through a series of focus groups. The report outlines designers', owners' and builders' perceptions on energy technologies, energy modeling tools, the codes and utility programs, and the effects of their interactions with the various other participants.

Heschong Mahone Group. C&I new construction and retrofit lighting design and practices—Market characterization study, final report (unpublished). Submitted to Sacramento Municipal Utility District. October 2000.

Jankowski, W. Specifiers' wish list. *Architectural Lighting Magazine.* July 1999.

Benya: industry needs to evolve (mature) so that what is specified by the lighting consultant is actually delivered - not substitutions that are either less effective or incompatible. Need "standard format" for product information so that specifiers can make product comparisons. Ergas: We need comparable information, particularly on cost and dimensions. Monk: Faster access to good information about lighting system products. Shulman: … better data on fixtures and compatibility.

Jennings, J., F. Rubenstein, D. DiBartolomeo and S. Blanc. Comparison of control options in private offices in an advanced lighting controls testbed. *IESNA 1999 Conference Proceedings.*

Ji, Y. and R. Wolsey. Lighting answers: Dimming systems for high-intensity discharge lamps. LRC. September 1994.

Liao, A. Specifiers discuss the systems. *Architectural Lighting Magazine.* March/April 2000.

Haas: Dimming controls costs are often paid for by the savings in maintenance costs die to longer lamp life. Theatrical lighting controls manufacturers are moving into architectural controls and bringing a more user-friendly quality to controls. Flexibility, reliability, affordability and compatibility - with the order changing by project. Kaczkowski: Simplicity of operation is the key issue. Bakin: Specifies a building lighting control system that controls all the lamps and which can be programmed from a phone by an electrician with a 2"X4" card of codes. Van der Heide: Prefers controls manufacturers who "have their roots in the theater" (same reasons as Haas). Yancey: "Smarter" controls improve energy savings and user satisfaction.

Mills, E. Commissioning: A neglected opportunity. *Architectural Lighting Magazine*. February 1994.

To be very effective lighting controls have to be commissioned in a way that is specific to the building and occupants—including after-hours personnel such as guards and housekeeping. Otherwise there will be a large discrepancy between designed energy use and actual performance.

Morrow, W., B. Rutledge, D. Maniccia and M. Rea. High performance lighting controls in private offices: A field study of user behavior and preference. *World Workplace Conference Proceedings.* October 1998.

RLW Analytics, Inc. Non-residential new construction baseline study, final report. July 8, 1999.

Commercial buildings in California are being built to be more energy efficient than required by the Standards. Approximately three-quarters of the additional (beyond the Standards) energy efficiency is directly attributable to lighting energy efficiency. Much of the remainder is indirectly attributable to lighting energy efficiency by reducing cooling and fan energy requirements. Occupancy sensors are the most common type of installed lighting controls although their specification and use appears to be declining. Although 22%–38% of the buildings in the study had occupancy sensors, the researchers found that only about 15% of new construction participates in utility energy efficiency programs. For new construction in California for 1994–1998 occupancy sensors control about 30% of the lighting of the schools and nearly 25% in offices.

RLW Analytics, Inc. Non-residential new construction baseline follow-on study—Project 1: final report. November 2000.

The researchers found that occupancy sensors were installed in about 17% of the new nonresidential spaces in California. This compares with about 1% each for stepped and dimming daylighting controls. Approximately 2/3 of 1% of the spaces had both occupancy sensors and daylighting controls. Offices, classrooms, libraries and conference and meeting rooms had the highest use of occupancy sensors (over 18% each). Retail spaces, computer centers, banks, lobbies, movie theaters and retail spaces had the least (less than 5% each). Lighting controls of all types control less than 20% of the connected lighting load in nonresidential new construction.

Romm, J. and W. Browning. Greening the building and the bottom line: Increasing productivity through energy efficient design. Rocky Mountain Institute. 1994

Rubenstein, F., D. Avery, J. Jennings and S. Blanc. On the calibration and commissioning of lighting controls. *Right Light 4 Proceedings.* 1999.

Calibration and commissioning of lighting control systems pose significant barriers to greater acceptance and adoption given the current state of complexity and inconvenience in the processes. In common designs, calibration cannot be performed accurately because the operator effectively blocks the ambient light just getting close enough to calibrate the sensors. If not properly calibrated and commissioned "lighting controls will fail (not provide occupant satisfaction). If the controls fail, the lighting system will generally use more energy than if no automatic controls had been installed."

Runquist, R., T. McDougal and J. Benya. Lighting controls: Patterns for design. Electric Power Research Institute. 1996.

Vorsatz, D., L. Shown, J. Koomey, M. Moezzi, A. Denver and B. Atkinson. Lighting market sourcebook for the U.S. Berkeley, CA: Lawrence Berkeley National Laboratory, December 1997.

Wolsey, R. Interoperable systems: The future of lighting control. Lighting Research Lab. 1997.

Wolsey, R. Lighting answers: Controlling lighting with building automation systems. LRC. May 1997.

Appendix D – Survey Sample and Lessons Learned

This study included a modest survey effort. The purpose was to gather current data and information on lighting control application and usage in California. The results of these surveys have been incorporated throughout this report. The following sections describe the respondents and how they were selected, and provide a brief overview of the findings from the facility manager and lighting distributor surveys; the electrical contractor surveys were too detailed to summarize in this manner. At the end of this Appendix is a brief description of the methodology lessons learned from this survey activity.

Facility Managers

We developed a list of California-based facility managers using the International Facility Managers Association (IFMA), California Chapters Web sites. The list generated includes a total of 52 facility managers representing different geographic and metropolitan areas in California. The names and contacts were based on IFMA-registered chapters who have active and updated information on their respective Web sites. These are:

- Central Coast (Santa Barbara, Ventura)
- East Bay (Oakland & San Leandro), Santa Rosa, San Fernando
- San Francisco, and Silicon Valley
- Los Angeles, Orange County
- Sacramento

In addition, we compiled a list of building and real estate management companies who manage facilities for owners or who own and manage their facilities. These contacts were compiled from two separate lists of 77 facility managers. These lists were supplied by the Institute for Market Transformation in San Francisco, who developed them for other studies they conducted. After screening out those companies and organization that have no facilities or practice in California, the total number of contacts dropped to 41 facility managers. Fourteen of them are employed by real estate management companies and the remainder (27) are facility managers for companies that own and manage their own facilities (for example, Costco, Hewlett Packard, Pacific Bell).

The total number of facility managers interviewed was 15. Our sampling method ensured that they were representative of the different locations in California. Their responsibilities ranged from facilities and property management to being director of facilities and director of new construction for big corporations such as Pacific Bell or Warner Bros. There were two facility management consultants among the respondents interviewed as well.

The most common way of shutting off the lights for buildings over 5000 ft_ is described below.

Offices:

- 33% use occupancy sensors
- 33% use time sweeps/time clocks
- 20% use a more sophisticated EMS
- 14% don’t know or don’t use any

Retail and Warehouse:

Most of the unconditioned warehouses use wall switching and no automatic lighting controls. Most retail or grocery stores use time sweeps or a sophisticated EMS. There are different zones in the retail/grocery stores that are controlled on different schedules (for example, Raleys have 12 zones, display, main retail, bakery, coffee shop, register, store front, etc.; each of these has a different schedule and hence requires a more sophisticated EMS).

Industrial:

Time clocks seem to be the most common way with two override switches, one in the manager's office and one next to the main board. The sweep to the program of these override switches is usually two hours.

Schools

We don't have enough data on this building type (a sample of one). From our limited data it seems that time clocks are the prevalent system with occupancy sensors controlling some confined areas like bathrooms and common areas.

In general, 80% of the facility managers interviewed thought that the technologies they have are saving energy. In general they thought that if you leave it up to the occupants to manually turn off the lights, less energy will be saved. They also agreed that these strategies are essential and they pay off their original cost when compared to the amount of energy costs they are saving. The remaining 20% doesn't know and were more hesitant in making this guess, as they have not collected data to back it up.

Most of the facility managers interviewed (73%) thought that the occupants are satisfied by the technology that they have. Thirteen percent of them felt that occupancy sensors are better than the EMS or time sweeps that they currently have and would be more acceptable to their occupants.

Lighting Manufacturers and Distributors

We developed a list of over 100 lighting control suppliers by searching the Internet . We began at six different lighting technology manufacturers' sites and searched for distributors of their products. Some names were duplicates since they handle more than one product line. We eliminated the duplicates. Some are branches (in different locations) of the same parent distributor. We did not exclude multiple branches of the same company. The distributors are well dispersed across the state in both urban and rural locales. The sample represents distributors with relatively small annual sales and those with millions of dollars in sales. Some specialize in specific systems, and others sell individual controls not designed as a part of a system. Although those who sell one system might more easily be characterized as manufacturers, for the purposes of this report we characterize them as distributors.

We tested the phone survey instrument on three distributors and modified it based on their responses. We interviewed a total of 21 lighting distributors or manufacturers. Our sampling method ensured that they are representative of different locations in California. Their responsibilities ranged from vice president of the organization to sales accountant for lighting controls.

Control Type Penetration: 65% of the lighting distributors interviewed knew the type of buildings where their products are installed in, while 35% didn't have the information necessary to answer this question.

Lighting Controls Price Trend:

- 35% believe that controls are increasing in price in general with an average rate of 10%.
- 30% believe that prices have been the same for all technologies with the advantage that they are getting better in terms of performance and specifications while they are keeping their prices in the same range.
- 15% think that the price of lighting controls is decreasing in general with an average rate of 10–15%.
- 85% believe that wall switches prices have been stable for the past five years.
- 50% of the respondents believe that occupancy sensors and manual fluorescent dimming prices are increasing in general with an average rate of 10%.

Return rate. See Figure 15.

	Return Rate
Wall Switches	1%
Dimming	2%
Occ. Sensors	5%
Time Clocks	2%
Time Sweep	1%
Twist	2%
Step Photo	2%
Dim. Photo	3%

Figure 15. Distributors' Estimates of Lighting Controls Return Rate

Electrical Contractors/Cost Estimators

Our experience with the telephone interviews led us to believe that it was more feasible to conduct in-person guided interviews with electrical contractors or their cost estimators ("contractors"). Typically, these professionals are reluctant to provide much information over the phone, and often do not feel they have the time to spare for a survey. Knowledgeable lighting researchers conducted the in-person interviews, and the subjects were offered a $100 honorarium to partially offset the value of their time on the survey.

We developed the list of contractors from utility program managers and field representatives, from names provided by building departments we talked to, and from phone directories. We interviewed a total of 9 contractors; 5 of them were from Los Angeles, 2 from San Jose and Silicon Valley, and 2 from Bakersfield and Central Valley areas. The interviews lasted 45 minutes each and were scheduled by appointments with the person in charge of new construction, or cost estimates and bids. Although the sample of contractors was small, the one-on-one interviews resulted in richer and more detailed data than would have been possible through telephone interviews.

Building Officials/Inspectors

Our original intention in this study was to interview a sample of building officials or electrical inspectors to learn about Title 24 compliance practices in regard to lighting controls. Before we could begin, however, we completed a set of similar interviews with building officials/inspectors for another study we were conducting. From this experience, we concluded that most building officials are not a good source of the kind of information we wanted to learn about lighting controls. This is because building officials are generalists who are responsible for a wide range of building code compliance topics. For most of them, Title 24 lighting control requirements and compliance practices make up a small part of what they do. Consequently, few of them pay enough attention to our topics of interest to provide useful overview data.

There are probably a few building officials with an interest in lighting control issues who would be able to provide valuable insights, but we do not know how to find them among the general population of building officials. Because of this, we abandoned the building official survey.

Lessons Learned

This section describes some of the lessons we learned in this survey activity, and contains recommendations for how best to conduct future surveys of this sort.

For building operations and control practices: Facility managers were less useful in providing this information than we had expected. Most of them had little direct knowledge of occupant behavior and operation of manual controls, and they had only general knowledge about the automatic controls in their buildings. In general, facility managers are involved at a higher level in their buildings. In future, we believe more useful information can be gathered by onsite visits to buildings to observe lighting control configuration and operation directly. For some facilities, where there is an onsite facility manager who has a hands-on involvement with the lighting controls, interviews onsite would be effective.

For Title 24 compliance practices: We believe it would be more useful in future to visit building departments and examine lighting plans and Title 24 documentation directly, making use of a knowledgeable lighting controls expert who can understand what the plans are showing about lighting control practices.

For equipment price and market penetration: We found lighting equipment distributors to be less useful for this purpose than we had hoped. When they were able to provide us with this information, costs were for the equipment alone, rather than installed cost which is more useful. Also, the prices given depend on the make and model, of which there are hundreds; it is difficult to generalize to a class of product, and it is often unclear what the features and characteristics of the cited product are.

Distributors' ability to describe the penetration and application of their products was also very limited, as they generally know little about what happens once the products leave their warehouses. Actual sales volume data is generally not available or, if it is, is confidential. Even when a distributor volunteers the data, it is difficult to know what fraction of the overall market is represented.

In the future, we believe it would require either a much more comprehensive survey with financial incentives to acquire more controlled and accurate data, or else it would require a large sample of onsite surveys of new buildings, to obtain good data on lighting control penetrations in the market. Cost information is better obtained from electrical contractors who can also provide the labor and installation components.

For installed equipment costs and characteristics: We found the focused, in-person interviews with electrical contractors to be the most valuable of the surveys we did. They also represented the smallest number of surveys because they were the most costly and time-consuming to complete. Nevertheless, by appearing in person and offering $100 for the contractors' time, we were able to get in-depth information.

One problem we encountered was in making the question responses comparable to each other. For example, when asked about large office lighting controls, one contractor priced bi-level switching for moderate size offices inside a large building, while another priced it for large, open plan offices. Such differences make it difficult to generalize and compare responses. In the future, these types of surveys should be done in greater numbers, to assure a broader consensus in the answers. There should also be specific sample building designs to use as the focus of the questioning. This would allow for more comparable cost data. Finally, the questions should be limited to a few key space types and not building types, as well as limited to specific control configurations. Without these limitations, the responses tend to describe non-comparable cases.

Use of published cost data: We were able to make good use of published cost data from R.S. Means, for only a limited number of standard types of controls (switches, occupancy sensors). The lighting control market encompasses a much broader array of equipment and technologies than those reported in Means' documents. This problem is familiar from past attempts to characterize the costs of energy efficiency measures. It is expensive and time consuming to collect enough cost data on enough lighting controls to provide general averages, but this kind of effort is required if broadly applicable cost data is to be developed.