AB 970 Nonresidential Standards Proposals

Codes and Standards Enhancement (CASE) Study

Lighting Controls

High Albedo Roofs

Site Built Fenestration Rating

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Draft - November 17, 2000

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This report was prepared by Pacific Gas and Electric Company and funded by California utility customers under the auspices of the California Public Utilities Commission.

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Acknowledgements

The New Buildings Institute developed this Codes and Standards Enhancement Initiative for the Pacific Gas and Electric Company under Contract 4600010614, part of PG&E's Codes and Standards Program for 1999. Project managers for PG&E included Jennifer Barnes, Patrick Eilert, Gary Fernstrom and Marshall Hunt.

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Introduction

This CASE Initiative is a factual Codes And Standards Enhancement (CASE) study that presents arguments for inclusion of a specific energy efficiency technology or practice into existing energy codes, thereby providing a platform for consensus making among stakeholders. This CASE study includes:

- a description of the technology,
- current practice,
- economics,
- key stakeholders, and
- implementation options and recommendations for inclusion into codes.

Lighting Controls in Current Title 24

The Energy Efficiency Standards for Nonresidential Buildings (Standards) generally applies all nonresidential occupancies, and also to the common areas of hotel/motel buildings 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 code and are subject instead to the residential lighting requirements; these space types will not be discussed in the remainder of this section.

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. Control strategies embodied in the mandatory measures quickly become "standard" practice in California construction. As a result, these requirements are very powerful 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. This strategy is referred to in the Standards as "controls to reduce lighting"; less formally, it is known as bi-level control. There are a number of different techniques to accomplish that intent including:

- switching that turns off half the lights in a given 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 luminaries.

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 sf, spaces with only one luminaire, or spaces with less than 1.0 W/sf of installed lighting power.

The Standards allow an exception where 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 fifty percent 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 multi-story 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 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 shutoff 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.

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

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 come into play whenever partitions are re-arranged, 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 to be replaced, then the lighting power density would limited as if it were a new building (see following), but 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 (2,000 Watts) are subtracted from the installed lighting power. This adjusted lighting power of 8,000 Watts makes it easier to meet the limitation on LPD. In effect, there is a trade-off 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 paper 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 install automatic shut-off controls, and to include manual override controls in the individual rooms. At the same time, a lighting control credit is earned. It is assumed that the automatic controls will save energy, compared to manual controls.

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 Daylight Control vs. Manual Daylight Control

The Standards allow the option of using automatic daylighting controls (which 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. This is one of the most promising technologies for addressing power reliability in new buildings.

Description of the Technology

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", which 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 and 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 anecdotal.

Besides alternative control strategies, two issues of technology 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 re-educate 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/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/ classroom on 2-4 switches, with switching by row. Another common scenario they described is 12 fixtures/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 treats 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[1] found that 22%-38% of the buildings in the study had occupancy sensors. In the "Market Transformation Barriers and Strategies Study[2]," designers, which included electrical contractors, told us that if the Standard and the utility programs were to "go away," certain lighting advances (e.g., T-8 lamps) would remain but lighting controls "would disappear." In the same study we found that many building owners had 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, ultra-sonic 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

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[1] RLW Analytics, Inc. *Non-Residential New Construction Baseline Study, Final Report.* July 8th, 1999.

[2] Heschong Mahone Group. *"Nonresidential New Construction Market Assessment & Evaluation: Market Transformation Barriers and Strategies Study."* Submitted to Southern California Edison. February, 2000.

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 mount 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 per lineal 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/lf 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 that "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 re-strike 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 storm events). Rather than responding to a pre-defined 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 set-up is a hassle. Of the two contractors who were exceptions, one said that it's about 50:50 between occupancy sensors and central lighting control systems, 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 by-pass control for building sweeps.

Small Offices

Facility managers reported that, for nighttime shut-off, occupants prefer occupancy sensors over 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 sanguine about savings from these technologies. Another facility manager said that "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 emergency to get them out of the building. Another facility manger 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

Hallways and corridors according to the majority of the facility managers interviewed 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 the night and week-end hours.

Schools

It is now becoming common for schools to have district-wide building automation systems that are capable of controlling the lighting on a pre-determined schedule.

Retail

Most retail/grocery stores use time sweeps or sophisticated EMS to meet the automatic shutoff 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.

Occupancy sensors are a fairly distant third and sensors are rarely installed for this purpose. 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.

In larger warehouses, lighting management systems, installed primarily as daylighting controls, served as the automatic shutoff 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[3], 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 daylight control technology: step switching controls and dimming controls. The step switching controls typically turn off one lamp per fixture at a time (e.g. first lamp goes off at 25 footcandles of daylighting, second lamp goes off at 50 footcandles, etc.), using a simple on/off control. 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.

[3] We use the term "daylight control" here to refer to the lighting controls which respond to availability of daylight, rather than to devices which control the distribution or intensity of the daylight itself as it enters the building.

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 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 manufacturers 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 turn-key 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:

- Multi-scene programmable controls,
- Lumen maintenance controls, and
- Tuning controls.

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 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 on-site 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 (52ksf 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 1[4]. This is taken from the RLW Baseline sample of buildings, 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 daylight controls, which control 19.1% of retail lighting. Also of note in this figure is the high percentage of classroom lighting power (42.6%) that is automatically controlled.

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 1 - Percentage of Lighting Connected Load with Lighting Control Type by Space Type

[4] RLW Analytics, Inc. *Non-Residential New Construction Baseline Follow-on Study - Project 1: Final Report.* November 6, 2000.

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 2 - Use of Automatic Lighting Controls and Control Credits

These findings are similar to what was recently learned in a survey of teachers.[5]

In a recently completed lighting market characterization study[6] 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 the use automatic lighting controls and control credits in meeting the Standards lighting power density (LPD) requirements. Their responses, by group, are shown in Figure 2. 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 people.

We also asked about specific types of lighting controls, and the primary reasons for using each type. The results, by group are shown in Figure 3. 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 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 on-site commissioning to adjust and calibrate their operation to local conditions.

% 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 3 - Reasons for Using Lighting Controls

[5] Heschong, Lisa H. Preliminary findings in *"Follow-On" Study, Teacher Survey*. October, 2000 (unpublished preliminary results).

[6] 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.

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 a guess that 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 exactly the opposite might be true[7]. 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 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."[8]

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 that only about 15% of the installed bi-level switching capacity is being used by occupants. However, other research[9]

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[7] Veitch, Jennifer A., and Guy R. Newsham: *"Individual Control can be Energy Efficient."* IAEEL Newsletter. January 1999.

[8] It should be noted that the lighting power density most selected by the participants in this study was ~1.4W/sf, somewhat higher than the 1.3W/sf allowed for offices by the area category method of Title24. Since the starting lighting level for the experiment was 2.4 W/sf, 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.

[9] Heschong, Lisa H. Preliminary findings in *"Follow-On" Study, Teacher Survey*. October, 2000 (unpublished preliminary results)

indicates that over 50% of teachers prefer to teach sometimes with some of the lights off. 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

Bi-level switching in warehouses is not generally done by most contractors. 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/sf. However, we talked with one contractor who said that even though the code doesn't require bi-level switching, they do it anyway 90% of the time because it saves their customers money on their 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[10]. Within those buildings, occupancy sensors are used on only 16.7% of spaces, and they control 11.6% of the connected lighting load[11]. The use of occupancy sensors differs by space type, as shown in the Figure 4, taken from the same report.

Reports from manufacturers and distributors indicate an expanding market for occupancy sensors. The simplest, wall switch mounted 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 trade-offs 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[12].

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, and early occupant sensors often had problems with poor calibration (both for

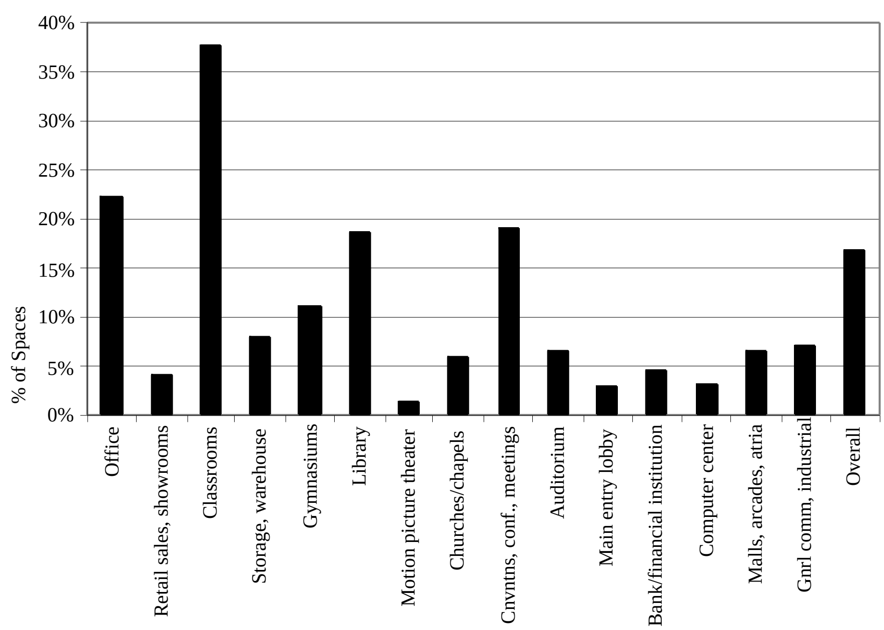

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Figure 4 - Percentage of Spaces with Occupancy Sensors by Space Type

sensitivity and for time delay). Countering these problems, there is also evidence that people are becoming accustomed to occupancy sensors, and that they are becoming more reliable in their operation, so that the disabling rate is declining. Commissioning of occupancy sensors is important for energy savings. One study[13] 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 (the exception was one who said their firm only installs them in about 10% of the large offices they wire) have occupancy sensors. 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. They use occupancy sensors not just as the alternative to bi-level switching, but also because they satisfy the requirement for the automatic shut-off.

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

[13] Floyd, David B., Danny S. Parker, and John R. Sherwin. *"Measured Field Performance and Energy Savings of Occupancy Sensors: Three Case Studies."* Florida Solar Energy Center, On-line Publication. FSEC-PF309. August, 1996.

Small Offices

Some contractors only install occupancy sensors in about 1/5 of offices while others do so in 3/4 of the small offices they work on. When they install them, 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 though the cost per office can be about the same ($0-$60 increment over wall mount types).

There aren't many calls-back (~1 in 100 occupancy sensors), and almost all 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 that "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 <u>both</u> 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 refers 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 their lights at some pre-determined time (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 there is functional degradation due to unsophisticated maintenance practices.

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 sophistication of its operator programming and knowledge, 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 may need to be replaced as a result. 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 there is reason to believe that 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 re-commissioning as occupant needs change. This requires the on-going attention of expert controls personnel, which is less of a problem for larger facilities with full-time O&M staff.

Large Offices

Facilities 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 a 8:00AM to 8:00PM schedule during workdays and 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 9:00PM shutoff 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 less 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 less 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 shutoff control.

Schools

RLW[14] found, in new construction in California for the years 1994-1998, that occupancy sensors control about 30 percent of the lighting of the schools, and about 42.6% of the connected lighting load in classrooms[15]. This is the most common automatic shut-off strategy for schools.

Retail

From our interviews with facility mangers (one of which is a manger 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 lights of the store based on a pre-set schedule. The more sophisticated model includes multi-zone controls and multiple programs. The latter is typical practice for stores where different zones of the store have different schedules and hours of operations (e.g., the meat 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, that uses standard lighting devices. There is no particular manufacturer.

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; i.e. a very large

[14] RLW Analytics, Inc. *Non-Residential New Construction Baseline Study, Final Report.* July 8th, 1999.

[15] RLW Analytics, Inc. *Non-Residential New Construction Baseline Follow-on Study - Project 1: Final Report.* November 6, 2000.

area of roofs could make use of daylighting from skylights, but do not. Approximately 60% of commercial floor space in the US is directly under a roof; in California, this number is estimated to be on the order of 90%-95% of floor space[16].

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 needed for daylit area switching.

Automatic Daylight Controls

The potential floor area for daylighting control is huge, as discussed in the preceding paragraphs. The suitability of different buildings types for photocontrols is shown in Figure 5[17], which lists from most to least appropriate the building types that are appropriate for photocontrols. Approximately 12% of recently constructed nonresidential buildings incorporate some kind of automatic daylighting controls, with step switching (as opposed to continuous dimming) controls accounting for 90%-95% of daylighting control installations[18]. This study suggests that this market penetration rate is slowly growing, a finding that is supported by anecdotal evidence from market actors. There appear to be recent increases in the market penetration for skylighted 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 5 - Ranked Commercial Building Types Appropriate for Photocontrols

Despite this growth, there remains a large mismatch between the current size of the daylighting control market versus the market potential. Most of research literature on daylighting controls concerns is 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 one cited above, report persistent problems of 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.

[16] Heschong Mahone Group. *"Photocontrol Operations Study: Phase I: Preliminary Report."* Submitted to Pacific Gas and Electric Co. February, 2000.

[17] Heschong Mahone Group. *"Photocontrol Operations Study: Phase I: Preliminary Report."* Submitted to Pacific Gas and Electric Co. February, 2000.

[18] RLW Analytics, Inc. *Non-Residential New Construction Baseline Follow-on Study - Project 1: Final Report.* November 6, 2000.

The table in Figure 6 shows the operating problems reported[19] for daylighting controls, as reported by different professions that were interviewed.

Commissioning of photosensor controls can be labor intensive because of the large number of sensors in a big building, and it and 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[20]. Until these problems are reliably 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 2/year. Most reported that they don't do any in large offices.

A study in Florida[21] 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 re-calibrated the sensors and installed shielding, which was supplied by the manufacturer but not previously installed.

Schools

In his study on Durant Middle School,[22] Smiley found that cooling equipment was downsized 10% and energy use cut 22-64% due to daylighting and lighting controls that were installed. The system had occupancy sensors and stepped switching controlled by photosensors. With cooling system savings, payback for lighting controls was less than 9 months. Their analysis also showed that the lighting improvements resulted in higher test scores and attendance.[23]

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 (~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.

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 6 - Common Operating Problems with Daylighting Controls

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 lamp types 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 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 may even save energy.

ANNOYANCE ISSUE: Dissatisfaction with lights turning off at inappropriate times, with light levels or apparently arbitrary changes in light levels may lead occupants to take personal control by disabling controls or "fooling" 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. Occupancy sensors have been fooled into thinking rooms are occupies by tying rags to the blades of rotating fans. Lighting controls that do not 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 by installing optional lighting controls and using the lighting control credits. There is some debate as to whether this provision of the Standards actually saves energy, because it results in higher installed lighting power levels and 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 are likely to save even more energy than the increased lighting power causes to be consumed.

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[24]. 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 this 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

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

Where done (which isn't often), bi-level switching adds about 0.5 to 10 cent/sf to warehouse lighting costs.

[24] Heschong Mahone Group. *"Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance."* Submitted to Pacific Gas and Electric. June, 1999.

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 7 - Bi-Level Control Cost Effectiveness

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 7 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-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/sf to $0.173/sf. 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 hrs/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/sf in this example). These kinds of spaces have less savings potential, but still can make bi-level control 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 dual 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 much more attractive than just minimally cost-effective.

The cost figures come from the 2000 RS 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 1,000 square foot 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. 50% 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 1,000 square feet 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 square foot 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 $/sf we could evaluate the energy savings in kWh/yr·sf using hours and the LPD (W/sf) and develop energy cost savings in terms of $/yr·sf.

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

As an example let us consider the large office area, which costs $0.037/sf to add bi-level control, and which contains 1.3 W/sf 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.

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

$$= 495\ Hours$$

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/yr. This amounts to less than one hour per week.

Occupancy vs. Bi-Level Switching

OCCUPANCY SENSORS – Costs have been dropping 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 trading off against 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/sf 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, apparently makes occupancy sensors the least cost option in many cases.

Schools

The contractors' installed cost for wall mount type of occupancy sensors was $50-55. For the ceiling mount 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 is generally only about 15 minutes/room. For the occupancy sensor

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 8 - Occupancy Sensor Cost Effectiveness

type that one of the contractors likes (adaptive technology), he claims there is zero adjustment time and zero callbacks, though the first cost is at 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%.

Cost Effectiveness

For occupancy sensors, a similar analysis to that shown above for bi-level switching is shown in Figure 8. The costs for the occupancy sensors ranges from $0.106/sf to $0.559/sf, 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 hrs/week) in order 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 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 hrs/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 RS Means 2000 Electrical Cost Data. Cost information was also provided to us by an occupancy control manufacturer[25], 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. It is assumed 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 systems specifically designed for lighting; a larger number if whole building EMS

[25] Himonas, J. Novitas, Inc. Personal communication with D. Mahone. Octover 26, 2000.

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 9 - Automatic Shut-Off Control Cost-Effectiveness

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 system is programmed and maintained.

Large Offices

The time clock/photocell combination strategy mentioned below cost about $2,000 for 5000sf (or $0.40/sf) in one case, and $3800 for 5000sf (or $0.76/sf) 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 photo-sensors and step switch controls for daylighting control.

Warehouses

The occupancy sensors, when installed as the automatic shut-off strategy, cost about $750-$1000/group of controlled fixtures (approximately 10 fixtures/3 sensors). One estimate for a warehouse lighting control system (LC panels, network and override) was $2500 for buildings between 5ksf and 20ksf. The expense of commissioning the system more than doubles the cost in some cases and only adds about $12/sensor to the cost in others.

The analysis summarized in Figure 9 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 occupancy sensors is based upon a back calculation of how many hours would the lights 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.

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 10 - Contractors' Estimates of Automatic Shut-Off Control Costs

Automatic Daylight Control vs. Manual Daylight 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/sf and $3.00/sf. The application of the technology is limited by 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 cost about $0.20/sf to install (controlling hundreds of fixtures) in large offices. 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 was from a contractor that does this kind of work infrequently, about once per year).

Warehouses

Automatic daylighting controls cost about 6¢/sf or about $40,000 for a 650ksf warehouse. In another example, the cost was about 8¢/sf or about $66,000 for a 790,000 sf 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 sf ($0.015-$0.02/sf) plus ~$200 more for tuning/commissioning.

Cost Effectiveness

Figure 11 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 daylight control system can be 285 hrs per year of all of the lights being turned off or 570 hr/yr half of the lights are switched off or dimmed to full power etc.

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 12 - Daylighting Control Cost Effectiveness

Daylighting controls are not frequently used, thus the sample of contractors who felt they could give us a quick quote was small. Most of the contractors who had constructed warehouse daylighting control systems had been for large warehouses. Their cost per square foot was lower than for those who had designed small systems.

	Average	Min	Max
Warehouse	$ 0.10	$ 0.02	$ 0.23
Med office	$ 0.19	$ 0.15	$ 0.21

Figure 11 - 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 had daylighting control information and incentive programs in place 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 at the top of their priorities for enforcement.

The final stakeholder group is the building owners and facility managers who must 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 the operation of these controls to save energy depends on the behavior and understanding of the occupants, they are a key stakeholder group. If occupants understand that they can make a personal contribution to energy efficiency and cost savings through their cooperation in 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 in California have been vocal in their support of Title 24 requirements that steer people toward their products. Likewise, they have been vocal in opposition to any attempts to reduce their influence in 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 with the operation of occupancy sensors if they 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 peoples' 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 operation of the manual override controls becomes crucial. When it is simple to override the shut-off, then there is little dissatisfaction; when the override is difficult and when occupants are left in the dark, then 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 advantages.

Beyond these advocates, however, there does not appear to be a great deal of support for daylighting controls. There are numerous examples of buildings which 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/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[26], at it's 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

[26] Throughout this proposal, we use the term "bi-level control" as a 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.

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:

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 (a)

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, i.e., buildings 5,000 sf or larger, can avoid bi-level control. Also, any space with less than 1.0 w/sf 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 sf with a connected lighting load greater than 0.8 W/sf.

The current exemption for spaces having less than 1.0 W/sf 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/sf. 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/sf, and all of the warehouse lighting within one standard deviation of this mean fell between 0.75 and 1.25 W/sf. This means that half of the warehouse lighting in 1994 was less than 1.0 W/sf, and most of that was greater than 0.75 W/sf. Over time, we can expect these numbers to trend even lower. Consequently, leaving the cut-off for bi-level control at 1.0 W/sf would exempt a large lighting load, but re-setting it to 0.8 W/sf 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 (as shown below). Most spaces experience times when reduced lighting is acceptable or even desirable, as for 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 sf 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 <5,000 sf 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 this 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, at the end of this paper, 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 change to remove the exemption from automatic shut-off control requirements for small buildings removes another special status provision of Title 24. We believe that this exemption is no longer needed; the savings from improperly burning lights after hours are equally valuable to small buildings as too large. The exemption was probably put in place when automatic shut-off controls were seen as more like a building automation system, and therefore 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, as an 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

Some examples of current requirements and how they would be affected by the 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 sf 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/sf 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 sf 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/sf for the egress path could remain on at all times.

3) *Large storage areas (and other large spaces with less than 1.0 w/sf) in buildings are currently NOT required to have automatic shut-off controls* (e.g. in a building 5000 sf or smaller):

a) *Option 1 – Installed lighting power is 0.8 w/sf or lower* – Currently, bi-level control is not required (it's less than 1.0 w/sf). Under the proposed changes, it would continue to be exempt from bi-level control, because it's 0.8 w/sf 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/sf and 1.0 w/sf* - Currently, bi-level control is not required (it's less than 1.0 w/sf). 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 0.5 W/sf of lighting to be left on at all times.

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

a) *Option 1 – Installed lighting power is 0.8 w/sf or lower* – Currently, bi-level control is not required (it's less than 1.0 w/sf). Under the proposed changes, it would continue to be exempt from bi-level control, but only because it's 0.8 w/sf 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/sf and 1.0 w/sf* - Currently, bi-level control is not required (it's less than 1.0 w/sf). 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 sf* - 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 sf must be separately controlled from adjacent non-daylit areas.

Questions for Stakeholders

There are a number of questions that have been raised by Commission staff and others 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. They have provided advice and feedback in answering these questions.

The following lists of 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 cut-off 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 in the affirmative. There is some research data, mostly case studies of particular buildings (see appendix). 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 re-wire 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 <5000 sf, 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 to be 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 re-adjusted 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 AB970 lighting controls modification to the Standards. The following sections address other lighting control implemenation strategies and recommendations.

Bi-Level Lighting Control

The AB970 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 AB970 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 study shows larger or smaller savings on aggregate. The study 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 take personal control by disabling controls or "fooling" 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 which automatically adapt their operation to the behavior patterns of the occupants.

Automatic Shut-Off Controls

Our AB970 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 studies to field 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 functionality is implemented. When it is difficult for users (e.g. 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 towards 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 in the previous sections, 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 make occasional use[27]. Overall savings amounted to about 33% in one test bed trial over seven months. Most of these offices were small (112 to 480 square feet, with the average being 188 sf) 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 square feet). 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).

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[27] Jennings, Judith D., Francis M. Rubenstein, Dennis DiBartolomeo, and Steven L. Blanc. *"Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed."* Journal of Illuminating Engineering Society. Summer 2000.

This kind of problem may be less so 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 multi-lamp switching, dimming and the newer step ballast HID technologies. Research using the SkyCalc tool[28] indicates 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 are common design or commissioning errors that could be avoided?
- How do actual savings compare to estimated savings?

These questions can best be answered in 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 Energy Commission should live up to its long-standing 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 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. Facilities 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 (5%-10%?) to

[28] Energy Design Resources. "*SkyCalc*" software for daylighting and skylight design. On the web at: www.energydesignresources.com/tools/skycalc.html

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 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, that 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 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.

MULTI-SCENE 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 on-going 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 AB970 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 multi-scene 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 – Annotated Biography

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 divided not by the type of the study but by the strategy (e.g, 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 1999 Conference Proceedings.**

  Providing individual lighting controls saves energy compared to the lighting being full on (though the max 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.

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- **Heschong, Lisa H. Preliminary findings in *"Follow-On" Study, Teacher Survey*. October, 2000 (unpublished preliminary results)**

  In this study, the researchers surveyed 250 teachers in the Capistrano Unified School District,(Capistrano, CA). 40 percent of the teachers surveyed indicated they occasionally teach with all the lights off, and 54 percent 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, Judith D., Francis M. Rubenstein, Dennis DiBartolomeo, and Steven L. Blanc. *"Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed."* Journal of Illuminating Engineering Society. Summer 2000.**

  This study found that allowing occupants to dim lighting system to their desired levels saved 43% when the multi-level 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.

- **Lighting Research Center. *"Lighting Futures: The quest for the ideal office control system."* LRC. 1998.**

  Vargas: "The ideal system accommodates every occupant…" The industry needs to better understand the non-energy benefits of good lighting control systems. Peterson: "… major obstacle to overcome is the integration of these different components into standardized packages…" No clear and compelling reasons for the building owner to buy best systems. Mix (Wattstopper): "[Occupancy sensors] are the most efficient energy-saving technology out there, but you want to give control of the space to the person using the space."

- **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, Mark S. *"The Quest for the Ideal Office Controls System."* LRC Lighting Futures. Volume 3, Number 3. 1998.**

  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 percent of the time and were off 24 percent of the time." People in interior spaces kept their lights off only 3 percent of the time, but against the north wall, occupants had the lights off 57 percent of the time they were in their offices. The researchers conclude that the multi-level switching controls accounted for a 61 percent savings in lighting energy.

- **Slater, A., B. Bordass, and T. Heasman. *"Give People Control of Lighting Controls."* IAELL newsletter. March 1996.**

- **Veitch, Jennifer A., and Guy R. Newsham: *"Individual Control can be Energy Efficient."* IAEEL Newsletter. January 1999.**

  The study this report deals with was a controlled side-by-side comparison of satisfaction of people given lighting level control choice and those who were simply subjected to the levels selected by others. The study was also able to provide 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 the 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 set-up, the IESNA recommended levels, and the ASHRAE/IESNA 90.1-1989 LPDs. The most frequent level chosen was 1.6 W/sf (the data was reported in increments of 0.2 W/sf, so this actually represents everything between 1.5 and 1.7 W/sf). 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/sf, well above the current level allowed for offices by Title 24. The researched concluded 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 were listed along with a link to comparative test results.

- **Floyd, David B., Danny S. Parker, and John R. Sherwin. *"Measured Field Performance and Energy Savings***

***of Occupancy Sensors: Three Case Studies.*" Florida Solar Energy Center, On-line Publication. FSEC-PF309. August, 1996.**

The study 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. The author attributed 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, Judith D., Francis M. Rubenstein, Dennis DiBartolomeo, and Steven L. Blanc. *"Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed."* Journal of Illuminating Engineering Society. Summer 2000.**

  In this study, the 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."* 6/15/00**

  Article on the site quoted 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.**

  This report mostly summarized the variety of occupancy sensor technologies available and their characteristics. It also reported that "case studies for offices buildings I 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 29th, 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, Scott, Mark Eilers, and John Reed. *"Behavioral Aspects of Lighting and Occupancy Sensors in Private Offices: A Case Study of a University Office Building."* ACEEE Summer Study Proceedings. 1996.**

This study 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, Mark S. *"The Quest for the Ideal Office Controls System."* LRC Lighting Futures. Volume 3, Number 3. 1998.**

In the LRC/NCAR study, occupancy sensors saved 46 percent 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 8,000 offices, labs conference rooms and other work

areas. Given the cost of the sensors, the pay-back period was 1.1 years.

- **U.S. EPA. *"Case Study: Whitehill Lighting and Supply."* EPA Web Site. June, 2000.**

  Installing occupancy sensors in a 7000 square foot warehouse cut the lighting energy use by 75%.

- **U.S. EPA. *"Application Profile: Occupancy Sensor Control in Education Spaces."* EPA Web Site. 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 pay-back 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. On the web at: www.energydesignresources.com/ tools/skycalc.html**
- **Energy Design Resources. *"Skylighting Guidelines."* On the web 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.**

  In this study, the researchers monitored the light levels and energy usage for a dual purpose (auditorium/cafeteria) school room 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.**

  This study 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, Larry. *"Practical Control Strategies for Harvesting Daylight Savings."* (draft) E Source. June, 2000 draft.**

Simple dimming controls that cover a wide day lit 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, 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. 1998.**

  Note that experience of daylighting cannot necessarily be "reduced to 'measurable' terms." Implication is that personal control is a valuable element of good design. Also argue 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., HMG [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 side lighting instead of top lighting, 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, D.B. Floyd. *"Daylight Dimming Systems: Studies in Energy Savings and Efficiency".* FSEC-PF-310. Florida Solar Energy Center.**

- **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 side-lighting, and the percentage of gross exterior roof area in skylights for top-lighting.

- **Dilouie, C. *"Manual vs. Dimming Controls."* www.Lightforum.com/technology/dimming.html [accessed 6/22/2000].**
- **Duarte, R., A. Martins. *"A Comparative Analysis of Automatic Lighting Control Strategies in Buildings."* Right Light 4 Proceedings. 1999.**
- **Energy Ideas Clearinghouse. *"Lighting - Operations and Maintenance."* Energy Solutions Database. 6/15/00.**

  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 ~12.5%, but increase the years of lamp life by ~75%.

- **Energy Center of Wisconsin. *"Review of Energy Efficient Measures in Wisconsin Commercial Construction, 1986-1990".* ECW. 1999.**
- **Energy Solutions Database. *"Lighting - Operation and Maintenance."* Washington State University - Energy Ideas Clearinghouse. [accessed 6/15/2000].**
- **Energy Solutions Database. *"Lighting - Controls: Question and Answer."* Washington State University. [accessed 6/12/2000].**
- **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, 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 8th, 1999.**

  Commercial buildings in California are being built 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 percent of new construction participates in utility energy efficiency programs. For new construction in California for 1994 1998 occupancy sensors control about 30 percent of the lighting of the schools and nearly 25 percent 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 one percent 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 Commissiong 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, 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."* Lawrence Berkeley National Laboratory. Dec. 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 C – 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 Mangers (FM) using the International Facility Managers Association (IFMA), California Chapters web sites. The list generated includes a total of 52 FMs representing different geographic and metropolitan areas in CA. 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. 14 of them are employed by real estate management companies and the remainder (27) are FMs for companies that own and manage their own facilities (e.g. Costco, Hewlett Packard, Pacific Bell).

The total number of FMs interviewed were 15. Our sampling method insured 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.

1. The total number of FM interviewed were 15, Theoretical sampling insured that they are representative of the different locations in CA. 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.
2. The Most common way of shutting off the lights for buildings over 5,000 sq. ft.

   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 (e.g. Raileys have 12 zones, display, main retail, bakery, coffee shop, register, store front, etc., each one of these have a different schedule and hence requires a more sophisticated EMS).

Industrial

Time clocks seem to be the most common way with two over-ride switches, one in the mangers office and one next to the main board. The sweep to the program of these over-ride switches is usually two hours.

Schools

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

3. In general, 80% of the FM interviewed thought that the technologies they have are saving energy and in general they thought if you leave it up to the occupants to manually turn off the lights, they will save less energy. 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 remainder 20% doesn’t know and were more hesitant in making this guess, as they have no collected data to back it up.
4. Most of the Facility Managers interviewed thought that the occupants are satisfied by the technology that they have (73%). 13% of them felt that occupancy sensors are better than EMS or Time sweeps that they currently have and would be more acceptable by their occupants.

Lighting Manufacturers and Distributors

We developed a list of over 100 lighting control suppliers through searches of 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. The total number of Lighting Distributors or Manufacturers interviewed was 21. Our sampling method insured that they are representative of the different locations in California. Their responsibilities ranged from vice president of the organization to sales accountant for lighting controls.

3. The total number of Lighting Distributors or Manufacturers interviewed were 21, Theoretical sampling insured that they are representative of the different locations in CA. Their responsibilities ranged from Vice president of the organization to Sales Accountant for Lighting Controls.
4. 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.

3. 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. (Similar to all technology, e.g. PCs).
   - 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%.
4. Return rate – see table at bottom of this page.

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. The in-person interviews were conducted by knowledgeable lighting researchers, 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.

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

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 on-site visits to buildings to observe lighting control configuration and operation directly. For some facilities, where there is an on-site facility manager who has a hands-on involvement with the lighting controls, interviews on-site 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 them, 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 it is volunteered by a distributor, it is difficult to know what fraction of the overall market is represented. In 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 on-site 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 future, these types of surveys should be done in greater number, 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 questioning should be limited to a few key space types and not building types, as well as limiting the questions 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.

High Albedo (Cool) Roofs

Codes and Standards Enhancement (CASE) Study

November 17, 2000

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This report was prepared by Pacific Gas and Electric Company and funded by California utility customers under the auspices of the California Public Utilities Commission.

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Acknowledgements

The New Buildings Institute developed this Codes and Standards Enhancement Initiative for the Pacific Gas and Electric Company under Contract 4600010614, part of PG&E's Codes and Standards Program for 1999. Project managers for PG&E included Jennifer Barnes, Patrick Eilert, Gary Fernstrom and Marshall Hunt.

The New Buildings Institute, Jeffrey A. Johnson, Senior Program Director managed this project.

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Eley Associates
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Introduction

This Codes And Standards Enhancement (CASE) study presents arguments for inclusion of a specific energy efficiency technology or practice into existing energy codes, thereby providing a platform for consensus making among stakeholders. This CASE study includes:

- a description of the technology,
- current practice,
- economics,
- key stakeholders, and
- implementation options and recommendations for inclusion into codes.

Description of the Technology

Cool roofs have both a high reflectance and a high emittance. The high reflectance keeps much of the sun's energy from being absorbed. The high emittance allows radiation to the sky.

Cool roofs are typically white and have a smooth texture. Commercial roofing products that qualify as cool roofs fall in two categories: single ply and liquid applied. Examples of single ply products include:

- White EPDM (Ethylene-Propylene-Diene-terpolymer Membrane)
- White PVC (polyvinyl chloride)
- White CPE (chlorinated polyethylene)
- White CPSE (chlorosulfonated polyethylene, e.g. Hypalon)
- White TPO (thermoplastic polyolefin)

Liquid applied products may be used to coat a variety of substrates. Products include:

- White elastomeric coatings
- White polyurethane coatings
- White acrylic coatings
- White paint (on metal or concrete)

Figure 1 depicts how roof reflectance affects roof surface temperatures, heat transfer and air temperature.[1]

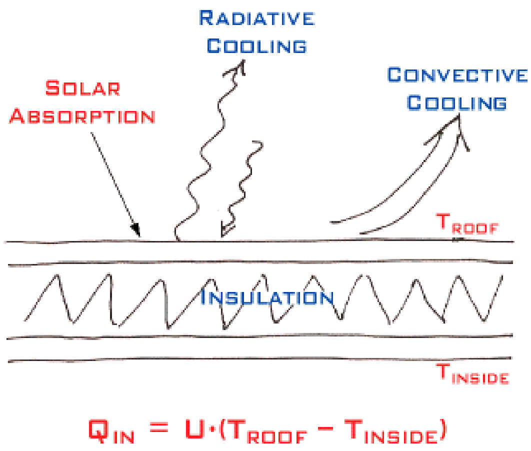

Figure 1. Roof Heat Transfer

Where:

Q_{in} = Total energy flux into the building,
U = U-factor of roof assembly,
T_{roof} = The temperature of the outside roof surface, and
T_{inside} = The temperature of the inside of the roof surface.

Table 1 on the following page shows reflectance and emittance for some typical roofing products. Some important points to note are that:

- All colors of asphalt shingle have poor reflectance (0.03 - 0.26). White asphalt shingles are slightly better (0.31).
- White elastomeric coatings have a high reflectance (0.65 - 0.78).
- White single-ply membranes have a high reflectance (0.69 - 0.81).
- Other coated white roofing systems (such as white metal roof and painted concrete) have high reflectance (0.67 - 0.85).

[1] Diagram courtesy of LBNL's web site.

Table 1. Solar Reflectance and emittance of different roofing materials

	Material	Total Solar Reflectance	Emittance
Reflective coatings	Kool seal elastomeric over asphalt shingle	0.71	0.91
	Aged elastomeric on plywood	0.73	0.86
	Flex-tec elastomeric on shingle	0.65	0.89
	Insultec on metal swatch	0.78	0.90
	Enerchon on metal swatch	0.77	0.91
	Aluminum pigmented roof coating	0.30 - 0.55	0.42 - 0.67
	Lo-mit on asphalt shingle	0.54	0.42
White metal roofing	MBCI Siliconized white	0.59	0.85
	Atlanta Metal products Kynar Snow White	0.67	0.85
Single-ply roof membrane	Black EPDM	0.06	0.86
	Grey EPDM	0.23	0.87
	White EPDM	0.69	0.87
	White T-EPDM	0.81	0.92
	Hypalon	0.76	0.91
Paint	White	0.85	0.96
	Aluminum paint	0.80	0.40
Asphalt shingles	Black	0.03 - 0.05	0.91
	Dark Brown	0.08 - 0.10	0.91
	Medium Brown	0.12	0.91
	Light Brown	0.19 - 0.20	0.91
	Green	0.16 - 0.19	0.91
	Grey	0.08 - 0.12	0.91
	Light grey	0.18 - 0.22	0.91
	White	0.21 - 0.31	0.91

Note: Shaded products all have a reflectivity greater than 0.70 and an emittance greater than 0.70.

Compiled from Berdahl and Bretz 1995, Akbari 1990,Parker et al. 1993, LBNL Cool Roofing Materials Database.
Shaded area indicates materials with high solar reflectance and high emittance

Several organizations have definitions of cool roofs (or are working on them): the Cool Roof Rating Council (CRRC), the US Environmental Protection Agency (EPA), and Lawrence Berkeley National Laboratory.

The Cool Roof Rating Council (CRRC) is working on standards that encompass both the reflectivity and emissivity of materials. CRRC's first meeting was held in September 1997. CRRC members include industry members, government representatives and researchers. For different roofing products, the group will provide information about initial reflectivity, durability of reflectivity, product durability, life-extension properties of coatings, and installation and compatibility issues (Pacific Energy Center, 1998). The role of the CRRC is still being researched.

The EPA has a voluntary EnergyStar™ Roof program. For roof products that may be applied to either low-slope or steep-slope roofs, such as roof coatings and single-ply membranes, Energy Star compliant products are required to have an initial solar reflectance of greater than or equal to 0.65, and a solar reflectance of greater than or equal to 0.50 after 3 years. For products only applicable to steep-slope roofs, Energy Star compliant products are required to have an initial solar reflectance of greater than or equal to 0.25, and a solar reflectance of greater than or equal to 0.15 after 3 years (US EPA, 1998). The Energy Star roof products program does not include emittance as a qualifying criterion. In order to use the Energy Star label, a manufacturer must sign a memorandum of understanding with the EPA. Energy Star products must be tested using ASTM E 903 to measure initial reflectance. To measure aged reflectance of low-slope roofing products and coatings, manufacturers are required to use ASTM E 1918. To measure aged reflectance of steep-slope roofing products and coatings, manufacturers are required to use the procedure outlined by EPA, in the roof products Memorandum of Understanding. Alternately, the manufacturer may test for solar reflectance of product after three years by taking samples from existing roofs as identified above, and having them tested per ASTM E903.

LBNL is developing a rating system called the solar reflectance index (SRI) to indicate the temperature of materials in the sun (see Figure 2). The extremes of white and black paint define the SRI. Solar reflectivity for this study is measured according to ASTM E903.

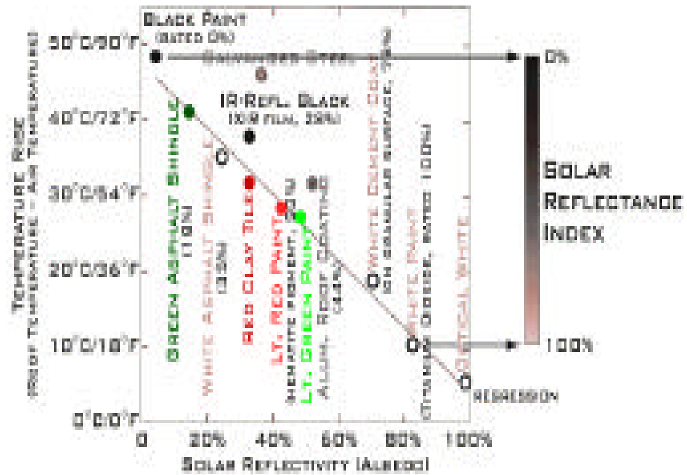

Figure 2. Solar Reflectance Index and Solar reflectance of various roofing products

Source: Berdahl, 2000.

Code Requirements

Several existing energy codes address cool roofs.

- *ASHRAE/IES Standard 90.1-1999.* Cool roofs were not considered in the developing the stringency of Standard 90.1, but the standard offers credits by allowing a U-factor adjustment based on heating degree days (see Appendix A). In effect, this enables a trade-off against insulation. The qualifying criteria for the cool roof are a minimum total solar reflectance of 0.70 and minimum thermal emittance 0.75 (ASHRAE, 1999).
- *Hawaii.* The Hawaii Energy Code defines prescriptive criteria for opaque roof surfaces based on the "Roof Heat Gain Factor" (RHGF). The RHGF accounts for three elements of roof design - color (reflectivity), insulation and the presence of a radiant barrier (see Appendix B). The RHGF is also use for compliance using the system performance criteria. Unlike the Standard 90.1, the Hawaii code does not include emittance as a qualifying criterion (Eley Associates, 1993).

- *Guam and American Samoa.* This energy code offers alternative prescriptive packages for roof compliance where a cool roof permits less insulation (see Appendix C). Like Standard 90.1, the qualifying criteria for the cool roof are based on a threshold limit for total solar reflectance and thermal emittance (Eley Associates, 1998).
- *Florida 2001 Energy Code.* Florida follows a similar procedure as ASHRAE using both reflectance and emissivity criteria.

California Title 24 does not currently address roof coatings. However, many types of applications for cool roof coatings call for a spray-applied polyurethane foam. Title 24 does require minimum levels of roof insulation.

Life and Failure Rate of Technology

Two issues affect the long-term performance of cool roofs. Degradation of performance occurs as roof membranes age. In addition, future replacement of cool roofs will eliminate savings in some cases.

Factors commonly contributing to degradation are mildew, dust, peeling (for painted surfaces) etc. Insolation (particularly ultra-violet radiation), moisture (both humidity and precipitation), temperature (primarily the time-averaged temperature of the roof), and natural and anthropogenic pollutants (particularly aerosols and acid rain) are the major elements that degrade roof coatings (Akbari and Bretz, 1997).

Several resources address the issue of degradation.

- Studies done by the Florida State Energy Center (FSEC) indicate 8-11% degradation in solar reflectance of white roof coatings over a period of 2 years.
- Studies done by Griggs and Ship in 1988 indicate that white roofing membrane can lose up to 30% of their reflectance in just two years, although the degradation slows down after that point.
- Studies by Byerley and Christian in 1994 show a drop of 20% in solar reflectance for white roof coating (Akbari and Bretz, 1997).
- Anecdotal observation suggests that degradation can be influenced by roofing system geometry, surface smoothness, pitch, nearby sources of dust and local humidity, and microbial resistance. Pitched standing seam metal roofs seem to have the least problems in this regard (Gartland et al. 1998).
- 10% - 30% of the contractors in California consider algae/ mildew to be a degradation problem (Akbari and Bretz, 1997).
- A LBNL study on loss of reflectance for roof coatings for some residential buildings in California and Florida indicates that up to 70% of the drop in solar reflectance for the entire first year occurred within the first two months of exposure. The degradation slowed after the first year, with data indicating small losses in albedo after the second year. A study conducted in Sacramento, California indicates a 20% reduction from first year energy savings for all subsequent years (2-10 years).
- Sloping roofs minimize dirt accumulation, water ponding and relevant biological growth and are recommended over horizontal roofs (Akbari et al. 1992[a]).

As of 1997, there were no standards for measuring albedo degradation, the ability of coatings to retain high albedo and high emissivity, or assessing a coating's resistance to dirt pick-up or cleaning. LBNL is reported to be working on developing a standard that could be combined with ASTM E903, to produce laboratory measurements of relative weather ability (Akbari and Bretz, 1997).

No information was discovered regarding the rate of replacement of cool roofs with darker roofs or the relative lifetime of cool roofs and other roofs.

Current Practice

The current distribution of commercial roof types has not been determined. Table 2 shows the 1991 values for the nonresidential roofing market in California. Note that that 83% of the elastomeric/plastomeric market in 1985 was dark colored (Akbari et al., 1992[a]).

The literature also states that in Sacramento the commercial zone represents 25% of the total urban area of which 43% is occupied by roof surfaces. In addition, 60% of new roofing construction is in the commercial sector and 40% in the residential roofing products.

Table 2. 1991 Nonresidential roofing markets in California

Source: Akbari et al., 1992[a]

Type	$ Million	% of Total
Built-up roofing	440	47.5
EPDM	70	7.2
Hypalon	20	2.2
PVC	30	3.3
Other single-plies	10	1.1
Polyurethane foam	20	2.2
Liquid -applied coating	10	1.1
Metal	55	6.1
Modified bitumen	130	14.9
Tile	35	3.9
Asphalt Shingles	70	7.7
Other	25	2.8
Total	**915**	**100.0**

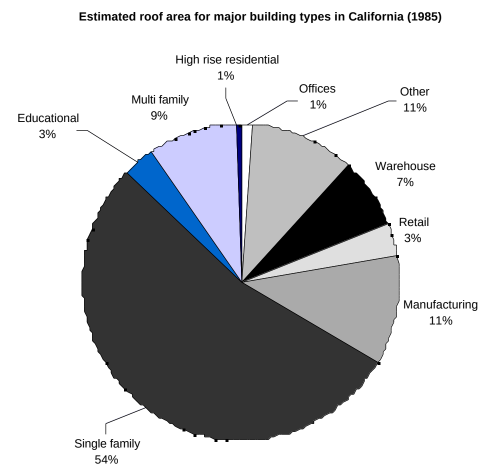

Figure 3. Estimated roof area for major building types in California.

Source: Akbari, 1992[a]

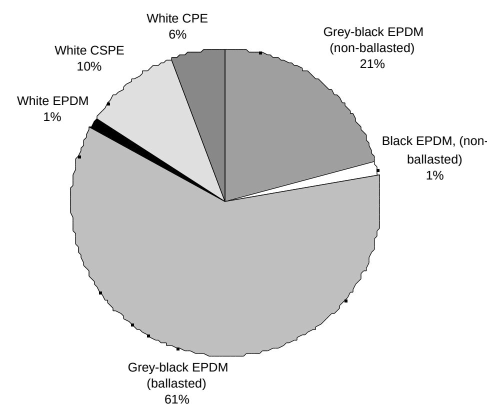

Figure 4. National elastomeric/ plastomeric roofing sales (1985)

Source: Akbari et al. 1992a

Barriers

High albedo roofing is relatively new, so there is considerable skepticism within the construction industry about its use. Skepticism stems mainly from the inexperience of contractors and facility managers with installation and system performance.

Since the education process has just begun, industry acceptance may be several years away.

According to the Heat Island Group at Lawrence Berkeley Lab, there are several reasons why reflective roofs are not widely accepted.

- For building owners and managers, the primary function of a roof is to protect the building. Energy savings are perceived as a secondary issue.
- Material durability is also a factor. As a reflective roofing material weathers and collects dust, its reflectivity and capability to save air-conditioning energy decreases.
- Building owners and architects like to have a choice of colors when selecting roofing materials, particularly for sloped roofs.
- Most existing data document savings for homes. Research on commercial buildings shows great potential, and more field data are needed to verify the potential benefits.
- Lack of information and incentives for building owners and roofing contractors is a significant barrier.

Economics

Cool roof technologies are available for nearly every application. Some cost no more than alternatives while others require additional investment. Besides cost, the major constraint to application is that cool roofs are usually white and are sometimes undesirable for aesthetic reasons. In addition, many roofing contractors do not have experience with technologies such single-ply membranes.

Several studies report on costs of different roofing technologies and are summarized in Table 3 and Table 4. The cost for a white roof coating is usually less than $\$1.00/ft^2$. Lighter asphalt shingles do not cost any more than dark colored ones.

Table 3. Cost related data for roofing technologies

Source: Akbari et al., 1992[a]. Note: Cost estimates are from 1989.

Technology	Installed cost ($/ft2)	Annualized cost ($/ft2)	Lifespan
For steep roofs			
Dark Asphalt Shingles	0.87	0.082	20
Light Asphalt Shingles	0.87	0.082	20
Smooth roll asphalt with reflective paint	1.00	0.094	20
Untreated cedar shingles	1.83	0.19	15 – 18
Concrete tiles	1.83	0.134	50
White concrete tiles	2.37	0.172	50
White paint	0.30	0.089	3 – 5
For flat and gently sloped roofs			
Dark built-up asphalt	1.83	0.147	20
Light built-up asphalt	1.83	0.147	20
Built-up asphalt with white coated gravel	1.83	0.147	20
Built-up asphalt with reflective white paint	1.83	0.147	20
Single-ply white polymer coating	1.83	0.147	20
Painting only	2.5	0.074	3 – 5

Table 4. Cost Data for Elastomeric Coatings and Single Ply

Compiled from Akbari et al., 1992[a].

Technology	Material cost ($/ft2)	Cost of application/ installation ($/ft2)	Lifespan
Superprep (1985)	0.20	0.05	15
Acryshield (1991)	0.19	0.25 - 0.50	15
Solarshield (1991)	0.19	0.25 - 0.50	15
Black EPDM (1991)	0.36	1.90 - 2.50	20
White EPDM (1991)	0.54	2.40 - 3.00	10
Enerchron (1991)	0.90	0.55	

Benefits

Reflective roof surfaces clearly reduce roof temperature. Energy savings depend on several factors such as climate and the amount of roof insulation. Energy performance characteristics include:

- The lower the insulation value of the ceiling/roof, the greater the impact of implementing a high albedo roof. Cooling energy savings is greatest where ceiling insulation levels tend to be lower. For new construction, adding a reflective roof is more favorable than adding extra insulation because the ceiling insulation level is already high.
- Absolute cooling energy savings are greater in hot and sunny locations (in the Sun Belt, below 37^0). In heating dominated climates, increasing the level of insulation has higher benefits than reflective roofing.
- For the same level of roof insulation, high albedo roofs are significantly more effective if the air conditioning ducts are located in the attic space than if they are located in the conditioned space. DOE2.1E with special modifications was used to quantify the benefits (Gartland et al., 1998).

Other benefits include -

- Longer roof life attributed to lessened thermal expansion and contraction and better UV protection (while using white roof coating) (Akbari and Bretz, 1997).
- Reducing urban heat island effect (Akbari and Rosenfeld, 1995 and Taha, 1997). When albedo is modified through an entire city, the energy balance of the whole city is modified, producing citywide changes in climate and energy use. (Akbari and Rosenfeld, 1990). For every 1 deg F rise in temperature above 65 deg C peak cooling demand in mid-latitude cities increases by 1.5%. Increasing the average urban albedo from 0.13 to 0.26, results in reducing the peak power consumption in downtown Los Angeles by 0.6 to 1.2 GW, worth between $100,000/h and $200,000/h, of which 50% of the surface modeled were roofs (Akbari et al., 1995). Increasing the average albedo of roof areas would result in lower temperature rise in the urban microclimate, reducing overall peak energy demand. This also implies a reduction in urban air pollution produced during generating power to meet peak loads. Elevated temperatures associated with heat islands also accelerate the formation of smog, which can be reduced by reducing the overall urban albedo. Preliminary results for a moderate change in albedo (approximately from 0.25 to 0.5 for sloping roofs, 0.25 to 0.75 for flat roofs and 0.15 to 0.40 for roads) indicate an overall reduction in smog of about 10% (Akbari et al., 1995).
- High albedo urban surfaces can reduce the formation of smog by lowering the urban temperature (Akbari et al., 1989). More recent studies in Sacramento confirm this fact. By increasing the albedo of the residential roof surfaces by 0.30, nonresidential roof surfaces by 0.40, and roads etc. by 0.20, and tree cover by 15% a 10% reduction in smog was recorded (Gartland, 2000).

Statewide Analysis

Table 7 shows predicted statewide savings over the next ten years due to mandatory cool roof requirements. This is not the recommended code modification approach for 2001 but provides an idea of potential savings. This scenario assumes that all new buildings in operation at the end of 2001 have cool roofs. The baseline condition is an estimate of the current market penetration of cool roof technologies.

Assumptions

Table 5 shows assumptions for absorptivity and installed cost for several roof type categories. For this analysis, all roofs are grouped into one of four types, each with light and dark options:

- Built-up
- Modified bitumen
- Single ply
- Other

Table 5 also lists market share assumptions for the baseline and predicted case. The assumption is that each type maintains its total market share but shifts completely to the cool roof options.

Baseline market share assumptions are based roughly on a market study reported in Western Roofing Magazine, Nov/Dec 1999 that reports the market share by installed cost for 13 roofing categories. Those values have been translated to roof area market shares with assumptions about average installed cost for each roof type. Based on this method, the estimate for total new roof area in California is about 211 million ft^2 per year for the commercial market. Of that total the breakdown is 32% built-up, 33% modified bitumen, 20% single ply, and 15 % other.

Installed costs assumptions are based on a variety of sources, including manufacturers and a current survey by LBNL of roof costs.

Absorptivity for each roof type is assumed to be 0.8 for dark roofs and 0.45 for light roofs.

For comparison purposes the energy impact of roof absorptivity is calculated using results of two different studies.

The first calculation uses a weighted average coefficient based on DOE2.1E simulations for 600+ buildings in the California Nonresidential New Construction (NRNC) Database. The roof absorptivity for each building was varied to calculate its impact on energy consumption for the average new building in California. The standard DOE 2.1E model inputs for absorptivity were used and all roofs are assumed to be over conditioned space (i.e. no attics). In addition, floor- area to roof-area ratios were derived from the NRNC Database and represent typical new construction in California.

The second calculation uses coefficients calculated during research for the development of cool roof credits in ASHRAE Standard 90.1-1999. This calculation used the total square footage of each roof type from the baseline market information and applies the 90.1 coefficients to an assumed R-19 average roof insulation installed above deck. A floor- to roof-area ratio of 1.5 was assumed in this analysis.

The ten-year savings forecast is based on a simple model that assumes the same new construction rate over whole period. However, the model also assumes that 20% of roofs are replaced after 5 years eliminating their savings. It also reduces the new savings each year by 5 percent compared to the previous year to account for cool roof market penetration that would have occurred in absence of the code modification.

Results

As mentioned earlier, the new construction rate is estimated to be 211 million ft^2 per year. Predicted electricity savings are 0.146 $kWh/yr/ft^2$ and demand savings are 0.249 W/ft^2 using the NRNC database results. The same values using the Standard 90.1 coefficients are somewhat higher: 0.272 $kWh/yr/ft^2$ and 0.166 W/ft^2.

Table 7 shows that potential cumulative savings after ten years reach 215,000 MWh/yr and 367 MW using the more conservative NRNC energy impact results.

Table 5. Potential Statewide Savings Using NRNC Database Analysis

Roof Type	Absorp-tivity	Instal-led Cost	Base-line	All New Roofs
		($/sf)		
Built-up (dark)	0.80	1.50	30%	0%
Built-up (light)	0.45	2.00	2%	32%
Mod. bitumen (dark)	0.80	2.00	26%	0%
Mod. bitumen (light)	0.45	2.30	7%	33%
Single ply (dark)	0.80	2.50	10%	0%
Single ply (light)	0.45	2.80	10%	20%
Other (dark)	0.80	2.50	11%	0%
Other (light)	0.45	3.00	4%	15%
Weighted Average Absorptivity			0.72	0.45
Weighted Average Installed Cost ($/sf)			2.09	2.41
Incremental Installed Cost ($/sf)			na	0.32
Electricity Savings (kWh/sf/yr)			na	0.146
Gas Savings (therms/sf/yr			na	-.006
Electric Demand Savings (W/sf)			na	0.249
Energy Cost Savings ($/sf/yr)			na	0.011
Lifecycle Energy Savings ($/sf)			na	0.106
Lifecycle Cost ($/sf)			**na**	**-0.21**
Simple Payback Period (years)			**na**	**30**
Total Electric Demand Savings (MW/yr)			**na**	**57**

Table 6. Potential Statewide Savings Using ASHRAE 90.1 Analysis

Roof Type	Absorp-tivity	Installed Cost	Base-line	All New Roofs
		($/sf)		
Built-up (dark)	0.80	1.50	30%	0%
Built-up (light)	0.45	2.00	2%	32%
Mod bitumen (dark)	0.80	2.00	26%	0%
Mod bitumen (light)	0.45	2.30	7%	33%
Single ply (dark)	0.80	2.50	10%	0%
Single ply (light)	0.45	2.80	10%	20%
Other (dark)	0.80	2.50	11%	0%
Other (light)	0.45	3.00	4%	15%
Weighted Average Absorptivity			0.72	0.45
Weighted Average Installed Cost ($/sf)			2.09	2.41
Incremental Installed Cost ($/sf)			na	0.32
Electricity Savings (kWh/sf/yr)			na	0.272
Gas Savings (therms/sf/yr			na	-.004
Electric Demand Savings (W/sf)			na	0.166
Energy Cost Savings ($/sf/yr)			na	0.024
Lifecycle Energy Savings ($/sf)			na	0.245
Lifecycle Cost ($/sf)			**na**	**-0.07**
Simple Payback Period (years)			**na**	**13**
Total Electric Demand Savings (MW/yr)			**na**	**28**

According to this analysis, the simple payback period for the cool roof requirements is high: 30 years or 13 years depending on calculation method.

The differences in the analyses are due to the following factors:

- ASHRAE Roof U-Factor Multipliers (Table 5.3.1.1B in ASHRAE/IESNA 90.1-1999) were derived relative to heating degree-days while the NRNC Database analysis used actual CA weather data and weighted the results based on the distribution of building size and type throughout CA.

- The floor- to roof-area ratio used in the ASHRAE analysis was assumed to be constant throughout CA while the NRNC Database varied by building type and climate.

Table 7. Electricity and Demand Savings Forecast for Mandatory Cool Roof Requirements

Year	Added Savings Due to New Construction	Lost Savings due to Early Replacement	Cumulative Savings
	MWh/yr		
2002	30,930	0	30,930
2003	29,384	0	60,314
2004	27,915	0	88,229
2005	26,519	0	114,747
2006	25,193	6,186	133,754
2007	23,933	5,877	151,811
2008	22,737	5,583	168,965
2009	21,600	5,304	185,261
2010	20,520	5,039	200,742
2011	19,494	4,787	215,449
	MW		
2002	53	0	53
2003	50	0	103
2004	48	0	150
2005	45	0	196
2006	43	11	228
2007	41	10	259
2008	39	10	288
2009	37	9	316
2010	35	9	342
2011	33	8	367

Key Stakeholders

Key stakeholders include: roofing materials manufacturers, roofing consultants, roofing companies, energy service providers, building owners and operators, government officials, utilities and environmental groups. Representatives from these groups are working together in the Cool Roof Rating Council (CRRC) to help code officials, utilities and building industry representatives assess the energy performance of reflective roofing products. The group is also working to educate the public on the benefits of cool roof products. The CRRC is similar to the National Fenestration Rating Council in that their primary focus is to develop a stakeholder-accepted procedure for rating roofs.

Implementation Strategies and Recommendations

Improved high albedo roofs should be implemented through building energy standards and voluntary programs. PG&E recommends the following implementation options.

Cool Roof Credit in Title 24

The following methodology should be incorporated into the AB 970 Rulemaking and take effect prior to June 2001.

Proposed Methodology - Overall Envelope Method

The proposed methodology would differ from previous methods incorporated into ASHRAE in three ways:

- The credit would only allow tradeoffs against other cooling measures rather than against roof insulation that impact heating energy consumption.
- Minimum criteria would be based on labeled products rather than products that require extensive testing to determine compliance.
- A one-to-one tradeoff would be used against cooling energy to account for DOE-2's underestimation of energy and demand reductions associated with cool roofs.

This simple model depicts the heat gain in a building resulting from solar radiation. It ignores some effects including how insulation performance varies with temperature, the effect of an attic, or uninsulated ceiling cavity, and the impact of attic temperatures on ducts located in the attic. The basic form of the proposed overall envelope approach results from this model.

The current overall envelope approach has two components: heat gain and heat loss. Heat loss uses a mass corrected U-factor times area (UA) approach to determine the instantaneous performance of the building envelope in a heating mode. Heat gain uses a mass corrected UA approach with a temperature factor to normalize opaque element heat gain with respect to solar gains from fenestration.

The existing overall heat gain equations would be modified as follows:

$$\sum (A_{roof} \times U_{roof} \times \alpha \times SF_{roof})$$

where:

A_{roof} = roof area

U_{roof} = roof U-factor

α = roof absorptivity

SF_{roof} = Roof Solar Factor, which depends on climate zone and roof mass.

The basic form of this equation is similar to that proposed in the work done by Eley Associates for this workshop except that it would be applied to the overall heat gain equation rather than the overall heat gain and loss equations. This eliminates insulation tradeoffs that increase gas consumption and focuses on cooling benefits only.

Roof Absorptivity

Roof absorptivity is determined according to a number of test protocols as identified in the Appendix. These tests require various levels of rigor to implement.

Laboratory estimates of roof reflectivity are specified by ASTM E903– Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres. Field measurements can be made Using ASTM E1918 - Standard Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field. This test is used to measure roof aging and requires a large section of roof area (10 m^2) versus roughly 1/2 sq. in. for lab measurements in E903. EnergyStar uses roof reflectance as the primary technical criteria.

Laboratory estimates of emissivity are specified in ASTM E408 -- Standard Test Method for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques. Field measurements are more difficult as the instrumentation for field measurement of emissivity is not as commonly available as reflectivity. ASHRAE/IESNA Standard 90.1-1999, Standard 90.1 and proposals in the State of Florida utilize emissivity and reflectivity as criteria.

The proposed credit would be based on products that achieve an Energy Star rating and are labeled as such. This makes inspection possible as roofing products are required to bear the Energy Star logo. The alternative would require code officials to obtain ASTM test reports for products that are used to obtain a credit. Only products that have a minimum initial reflectivity of 0.65 would qualify for the credit.

Emissivity criteria can be established but may not be enforceable as the Energy Star rating does not require emittance criteria in qualifying products. If established, it would be in the standards and could be modified when the Cool Roof Rating Council finalizes their rating method.

In addition, the "new roof" absorptivity would be reduced by a factor to account for degradation. The Energy Star roof criteria requires roofs to have a long-term reflectivity at a minimum of 0.5 or a 23% reduction in reflectivity.

The proposed credit would use a 25% degradation factor to modify the initial reflectivity to account for dirt, dust and long term degradation.

To summarize, the roof absorptivity for the proposed design would be determined as follows:

$$\alpha = 1 - (\rho_{initial} \times .75)$$

where:

$\rho_{initial}$ = Initial roof reflectivity per ASTM E903

0.75 = degradation factor applied to initial reflectivity

The standard design would use a roof absorptivity of 0.7.

Roof Solar Factor

The roof solar factor can be derived from the set of regressions proposed in the Eley Associates report. They recommend the following:

"Calculate a set of regression coefficients for each of the 16 California climate zones similar to those described for the ASHRAE 90.1 method described above. The equation will provide total source energy for cooling and heating. The DOE2.1E model will also be similar to the ASHRAE Standard 90.1 model except that other envelope constructions and internal gain assumptions will be set to match Title 24 prescriptive criteria. Two sets of schedules will be used: nonresidential and residential."

This set of regressions can be used to derive the roof solar factors for each climate zone and roof construction type.

Proposed Methodology - Whole-building Performance

To modify Alternative Calculation Methods (ACM) procedures, rules for roof absorptivity on the standard building and proposed building models would need to be added to the ACM Manual. The recommended approach is to assume an absorptivity of 0.7 for the standard building and the adjusted absorptivity for the proposed building if a qualifying cool roof is specified. Emissivity would be constant between the proposed design and the budget building.

The roof absorptivity would be determined as follows:

$$\alpha = 1 - (\rho_{initial} \times .75)$$

where:

$\rho_{initial}$ = Initial roof reflectivity per ASTM E903

0.75 = degradation factor applied to initial reflectivity

This is consistent with the approached proposed for the Overall Heat Gain method.

Additional Recommendations

The solar performance of roof surfaces should be accounted for in the Standard. Given the lack of a specific industry supported rating procedure to label roofs, the Institute recommends that the Pacific Gas and Electric Company support a credit (recommendations #2 and #3 in the Eley Associates workshop report) that promotes the use of cool roofs in California. It should not support the reduction of roof insulation levels that increase winter gas consumption through reduced insulation levels.

Develop a Rating Methodology

The Cool Roofs Rating Council could develop a rating methodology similar to the National Fenestration Rating Council that would be referenced in Building Energy Standards. PG&E is currently supporting such an effort.

Provide Direction for Voluntary Programs

To encourage installation of cool roof products in new construction lies in the education and acceptance of new technologies and practices into the marketplace. Voluntary programs at the local, state, and national level have proven that they are capable of transforming markets and accelerating acceptance of new technologies and practices.

PG&E should cooperate with current research efforts aimed at developing new technologies and practices to improve the performance of roofs.

These efforts include:

- Research underway at Lawrence Berkeley Laboratory, Oak Ridge National Laboratory and the Florida Energy Center.
- Consensus building and testing and acceptance procedures under consideration by the Cool Roofs Rating Council.
- The EnergyStar Roof Products Program, a voluntary partnership designed and implemented by the US Environmental Protection Agency and the US Department of Energy.
- Market Transformation groups in Hot and Humid Climates.

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Western Roofing Association Magazine, 1999

Appendix

Cool Roof Code Exerpts

ASHRAE/IESNA Standard 90.1 - 1999

5.3.1.1 Roof Insulation.

All *roofs*, including *roofs with insulation entirely above deck*, *metal building roofs*, and *attics and other roofs*, shall have a *rated R-value of insulation* not less than that specified in Table 5.3. *Skylight* curbs shall be insulated to the level of *roofs with insulation entirely above the deck* or R-5 (R-0.85), whichever is less.

Exception to 5.3.1.1: This exception applies to exterior roofs other than roofs with ventilated attics and does not apply to semiheated spaces. For demonstrating compliance, the U-factor of the proposed roof is allowed to be decreased by the multipliers in Table 5.3.1.1B provided the exterior roof surface:

1. has a minimum total solar reflectance of 0.70 when tested in accordance with ASTM E903, and
2. has a minimum thermal emittance of 0.75 when tested in accordance with ASTM E408.

Table 5.3.1.1B

Roof U-Factor Multipliers for Exception to 5.3.1.1

HDD65	*(HDD18)*	Roof U-Factor Multiplier
0-900	(0-500)	0.77
901-1800	(501 - 1000)	0.83
1801 - 2700	(1001-1500)	0.85
2701 - 3600	(1501 - 2000)	0.86
> 3600	(>2000)	1.00

Hawaii Energy Code

Sec. 8.3 Calculation procedures and basic requirements.

(f) Roof heat gain factor (RHGF).

The solar heat gain limits for opaque roof constructions are expressed in terms of the Roof Heat Gain Factor (RHGF) which is described in Equation 8-8. The maximum allowed limits are listed in subsection 8.4(a).

Equation 8-8

$$RHGF = U_r \times \alpha \times RB$$

Where:

RHGF = Roof Heat Gain Factor. [Btu/ft²-h-°F].

U_r = overall thermal transmittance value for the gross area of opaque roof surfaces, as defined in subsection (c). [Btu/ft²-h-°F].

α = roof surface absorptivity. Between 0.3 and 1.0 [unitless].

RB = Radiant Barrier credit. Equals 0.33 if a radiant barrier is installed and 1.00 otherwise [unitless]. Radiant barrier installation must comply with subsection (g) to qualify for credit.

Sec. 8.4 Prescriptive criteria.

(a) Opaque roof surfaces

(1) The Roof Heat Gain Factor (RHGF) for opaque roofs shall be less than 0.05 when calculated as described in subsection 8.3(f).

(2) Exception.
Roofs which are completely shaded from direct sunlight or attics with one square foot of free area for ventilation per ten square feet of attic floor area shall be exempt from the requirement in subsection (a).

Guam and American Samoa Energy Code

1 Mandatory Provisions

4.2.7 High Albedo Roof Surface. Approved high albedo roof surfaces (typically white in color and smooth in texture) shall have a minimum total solar reflectance when tested according to ASTM E-903 of no less than 0.70. The test sample shall also be tested for its infrared emittance using ASTM E-408 and have an emittance no less than 0.75. Testing shall be performed by an approved independent laboratory. The roof surface must have a slope of at least 1 inch per foot of run.

4.3 Prescriptive Building Envelope Requirements

Roofs must meet the requirements of Table 4.3.1.

Table 4.3.1

Class	Nonresidential and High-Rise Residential	Low-Rise Residential
Mass	(a) High albedo roof surface; (b) R-11 Insulation in interior furring space; (c) 2 inches of continuous insulation; or (d) any other construction with a U-factor less than or equal to 0.12.	(a) High albedo roof surface; (b) R-11 Insulation in interior furring space; (c) 2 inches of continuous insulation; or (d) any other construction with a U-factor less than or equal to 0.12.
Metal Buildings	(a) 6 inches of insulation; or (b) any other construction with a U-factor less than or equal to 0.07	(a) 6 inches of insulation; or (b) any other construction with a U-factor less than or equal to 0.07
Other Roofs	(a) R-19 insulation or (b) any other construction with a U-factor less than or equal to 0.06	(a) R-19 insulation or (b) any other construction with a U-factor less than or equal to 0.06
Mass roofs include concrete of 4 inches or greater thickness or any other construction with an HC greater than 7.0 or a weight greater than 35 lb/ft^2.		

4.4 Building Envelope Trade-Off Option

The building envelope complies with the code if the proposed building satisfies the Mandatory Requirements and the envelope performance factor of the proposed building is less than or equal to the envelope performance factor of the budget building.

4.4.1 The envelope performance factor shall be calculated using the following equations.

$$\mathrm{EPF_{Total}} = \mathrm{EPF_{Roof}} + \mathrm{EPF_{Wall}} + \mathrm{EPF_{Fenest}}$$

where

$$EPF_{Roof} = c_{Roof,Mass}\sum_{s=1}^{n} U_s A_s \alpha_s + c_{Roof,MtlBldg}\sum_{s=1}^{n} U_s A_s \alpha_s + c_{Roof,Other}\sum_{s=1}^{n} U_s A_s RBF_s$$

$$EPF_{Wall} = c_{Wall,Mass}\sum_{s=1}^{n} U_s A_s + c_{Wall,MtlBldg}\sum_{s=1}^{n} U_s A_s + c_{Wall,MtlFrm}\sum_{s=1}^{n} U_s A_s + c_{Wall,Other}\sum_{s=1}^{n} U_s A_s$$

$$\begin{aligned} EPF_{Fenest} = {} & c_{Fenest,North}\sum_{w=1}^{n} A_w SHGC_w M_w + \\ & c_{Fenest,East}\sum_{w=1}^{n} A_w SHGC_w M_w + \\ & c_{Fenest,South}\sum_{w=1}^{n} A_w SHGC_w M_w + \\ & c_{Fenest,West}\sum_{w=1}^{n} A_w SHGC_w M_w + \\ & c_{Fenest,Skylight}\sum_{s=1}^{n} A_s SHGC_s \end{aligned}$$

where

EPF_{Roof}	Envelope performance factor for roofs. Other subscripts include walls and fenestration.
A_s, A_w	The area of a specific envelope component referenced by the subscript "s" or for windows the subscript "w".
$SHGC_w$	The solar heat gain coefficient for windows (w). $SHGC_s$ refers to skylights.
M_w	A multiplier for the window SHGC that depends on the projection factor of an overhang or sidefin. These values are determined by the procedures in 4.4.2.
U_s	The U-factor for the envelope component referenced by the subscript "s".
RBF_s	Radiant barrier factor for roof surface "s". A radiant barrier factor (RBF) of 0.33 shall be assumed for roof constructions with a qualifying radiant barrier, otherwise RBF shall be assumed to be 1.00.
α_s	For mass and metal building roofs, an absorptance (α) of 0.70 shall be assumed for roofs that do not qualify as high albedo. For high albedo roofs, an absorptance (α) of 0.30 shall be assumed. The coefficients for use in the EPF equations are contained in Table 4.4.1.
$c_{Roof,Mass}$	A coefficient for the "Roof, Mass" class of construction. Values of "c" are taken from Table 4.4.1 for each class of construction.

Table 4.4.1 - Envelope Performance Factor Coefficients		
	Guam	
Component, Class	Daytime	24-Hour
Roofs, Mass	1.47	3.61
Roofs, MtlBldg	15.83	25.26
Roofs, Other	2.84	3.82
Wall, Mass	2.53	6.14
Wall, MtlBldg	6.36	9.28
Wall, MtlFrm	6.36	9.28
Wall, Other	6.36	9.28
Fenest, East	53	86
Fenest, North	31	51
Fenest, South	58	98
Fenest, West	50	85
Fenest , Skylights	101	163

Definitions and Standards

***Albedo* –** Hemispherically and wavelength integrated reflectivity (Taha, 1997).

***Thermal Emittance* –** The ratio of the radiant heat flux emitted by a specimen to that emitted by a black body at the same temperature and the same conditions.

***Total Solar Reflectance* –** The weighted average of the energy distribution in the standard solar spectrum (5% in the ultra-violet (UV), 46% in the visible spectrum and 49% in the near infra-red (IR) .

***ASTM E408* –** Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques.

Developed by ASTM Committee E21 on Space Simulation and Applications of Space Technology.

***ASTM E903* –** Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres.

Developed by ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources

***ASTM E1918* –** Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field.

ASTM E1918 was developed at LBNL under ASTM Subcommittee: E06.21on Performance of Buildings. This test method covers the measurement of solar reflectance of various horizontal and low-sloped surfaces and materials in the field, using a pyranometer. The test method is intended for use when the sun angle to the normal from a surface is less than 45 degrees.

Nonresidential Fenestration Rating

Codes and Standards Enhancement (CASE) Study

October 30, 2000

:
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This report was prepared by Pacific Gas and Electric Company and funded by California utility customers under the auspices of the California Public Utilities Commission.

Table of Contents

1. Proposal

This is a proposal to modify portions of California's Administrative Regulations (Title 24, Part 1) and the Building Energy Efficiency Standards (Title 24, Part 6). This proposal is being submitted by PG&E to the California Energy Commission under the AB970 emergency rulemaking. Commission staff and PG&E's consultants have already been in discussions with the National Fenestration Rating Council (NFRC) staff and other stakeholders regarding this proposal. Some objections and concerns raised with earlier iterations of this proposal are addressed in this final proposal. Most notably: (a) there is an exemption to the new requirement for site built products being installed in nonresidential buildings under 100,000 square feet, and (b) the language proposed has been changed to make it clear that the exemption only applies to site-built fenestration systems in those buildings, not manufactured products.

The essence of this proposal is that the California Energy Commission adopt NFRC 100-SB as the product rating and certification methodology for commercial, site-built fenestration.

Fenestration (doors, windows, skylights and curtain walls) often have more impact on a building's comfort and energy use than any other building element, and those interactions are also very complex. The primary purpose for fenestration is obviously to bring outdoor light and views into the interior, but it also lets heat in or out. Among the important properties of fenestration are: ability to transmit visible light or heat, ability to reflect visible light or heat, ability to conduct heat, to radiate heat, and to prevent air leakage. If designers are to be able to choose between products, in order to meet their design goals, and to be able to properly size and select HVAC equipment, they need to have reliable information on how competing fenestration products and systems perform. Similarly, for substantiating compliance with Title 24, local jurisdictions need fair, accurate and credible reporting and certification of product performance.

Since 1992, California's Title 24, Parts 1 and 6, have referenced the National Fenestration Rating Council's (NFRC) U-factor rating and certification procedures for residential fenestration products. Since 1998, the standards have also referenced NFRC SHGC ratings and certification for residential products. Recently the fenestration industry, working through NFRC, devised and adopted procedures for rating and certifying commercial building fenestration systems, which are typically site built. Reference to this procedure, NFRC 100-SB, within Title 24 can help to bring the same credibility and fairness to comparisons of competing curtain wall systems as NFRC's residential certification program did to manufactured fenestration products.

This proposal expands the applicability of the rating and certification procedures to nonresidential fenestration systems not previously covered. Manufactured products (as opposed to "site-built") were covered for U-factor and SHGC by the 1992 and 1998 revisions to the standards, respectively. The proposal below is worded so that the exemption for buildings under 100,000 will not be interpreted to be an expansion of the exemption to allow installation of "manufactured products" without rating and certification.

The purpose of this proposal is to amend the nonresidential portions of Title 24, Part 1 and Part 6.

The specific proposed changes to the Standards language are:

1. *Title 24, Part 1, Section 10-111 (a). – Change to read:*

   a) ***Labeling Requirements.***

      1. **Temporary labels.** Every fenestration product or fenestration system installed in construction subject to ~~the~~ Title 24, Part 6, shall have attached to it a clearly visible temporary label or label certificate that lists the U-factor ~~value~~, the solar heat gain coefficient ("SHGC") of that product and the method used to derive those values, and certifies compliance with air leakage ~~infiltration~~ requirements of Section 116(a)1. To meet this set of requirements, products shall comply with subsections "A," "B," or "C"; subsections "D," or "E"; and subsection "F."

         A. *If the product U-factor ~~value~~ rating*

            [Throughout this section and all later sections, every time the term "U-value" is used, replace it with "U-factor." This is the term that the industry decided is the proper name for conductance term for fenestration thermal performance. Although we recommend this change to be universal throughout Title 24, we do not repeat this recommendation at every instance where "U-value" is in the current standards.]

[We also recommend removing the text about default SHGCs from this subsection and creating a separate subsection for it. That will make it clearer that a fenestration manufacturer needs to comply with A, B or C of this section, plus D or E, and F. See "D" below.]

B. *If the product U-factor ~~value~~ rating is derived from the NFRC Rating Procedure, then placing the* …[No other change to this paragraph.]

The "NFRC Rating Procedure" as used in this subparagraph B means the National Fenestration Rating Council's ~~NFRC 100-91: Procedure for Determining Fenestration Product Thermal Properties (currently limited to U-values)(1991), or~~ NFRC 100: Procedure for Determining Fenestration Product U-factors (1997) also known as "NFRC 1000," incorporated herein by reference.

[We recommend deleting the reference to the outdated rating procedure. The reason for leaving it in there during the 1995 and 1998 revisions to the standards is no longer valid. Products to be installed in buildings after the effective date of this edition of the standards, and that are rated through NFRC procedures, will have ratings in accordance with the newer, revised procedure.]

C. If the fenestration system U-factor is derived from the NFRC rating procedure and the system is a glazed wall system or overhead glazing that is site constructed, then issuance of a complete and valid "NFRC Label Certificate (for Site-Built Products)," containing the words, "Manufacturer stipulates that this rating was determined in accordance with applicable NFRC procedures" (or equivalent language) followed by the rating procedure number and certified U-factor on the Label Certificate, meets the requirements of paragraph 1.

The "NFRC Rating Procedure" as used in this subparagraph C means the National Fenestration Rating Council's ~~NFRC 100-91: Procedure for Determining Fenestration Product Thermal Properties (currently limited to U-values)(1991), or~~ NFRC 100: Procedure for Determining Fenestration Product U-factors (1997) also known as "NFRC 1000," incorporated herein by reference.

D. If the product SHGC is taken from the Commission's default table, then placing the words "CEC Default SHGC," followed by the appropriate default SHGC from Section 116, Table 1-E, on the temporary label meets …"

E. If the product SHGC rating is derived from the NFRC Rating Procedure, placing …[No change other than paragraph numbering.]

F. *The temporary label* [No change other than paragraph numbering.]…

2. **Permanent labels.** *If a product is rated using the NFRC Rating Procedure, it shall be permanently labeled with either a single series of marks on the frame, glass, and/or spacer which can be used to trace the product to certification information on file with the certifying organization or to a directory of certified products, published … and the year of certification. A completed NFRC Label Certificate for Site-Built Products, attached to the building plans filed with the inspection jurisdiction and provided to the building owner meets the requirement of this paragraph.*

EXCEPTION to Section 10-111 (a): Ground floor storefront glazing, glazed wall systems, and field fabricated overhead glazing, in buildings under 100,000 square feet, which are covered by the nonresidential standards. [This extends the rating and labeling requirements to larger nonresidential buildings without providing an exemption for manufactured products installed in nonresidential buildings. Expanding the rating and certification requirements in a "staged" manner (larger buildings only, for now) will allow the industry to adjust with minimal disruptions. For a similar reason, the state of Washington exempts the first floor of all nonresidential buildings.]

B. *Section 10-111 (b) Certification Requirements.*

1. ***Certification to default ratings.*** *If a product* …[No change other than to change "U-value" to "U-factor."]

2. ***Certification to NFRC Rating Procedures.*** *If a product's …*[No change to opening paragraph other than to change "U-value" to "U-factor."]

A. *A temporary label affixed to the product, or Label Certificate (for Site-Built Products) affixed to the construction plans submitted to the building inspection jurisdiction, meeting the requirements of Section 10-111(a)(1)~~(B) or 10-111(a)(1)(C)~~ certified…*

[We recommend deleting the subsection labels [e.g., "(B)", "(C)"] from the text.]

B. An "independent certifying …licensed by NFRC~~, or during the start-up period, NFRC itself,~~ shall be …

[This phrase is no longer valid and could serve to confuse people.]

C. The "supervisory entity" means …

[No change to the subsection above.]

EXCEPTION to Section 10-111 (b): Temporary and permanent labels are not required for glazed wall systems and site built overhead glazing in buildings under 100,000 square feet which are covered by the nonresidential standards.

[Restricting the applicability of this exception to only site built fenestration product in the smaller nonresidential buildings is the main thrust of our recommendation.]

C. Modify Section 10-111 (d)11. *The entity shall provide or authorize the use of labels and Label Certificates (for Site-Built Products) that can be used to meet the requirements of Sections 116(a)1 and 2, ~~paragraphs B and C,~~ and this section.*

D. Modify Section 116(a). ***Certification of Fenestration Products and Exterior Doors.*** *Any fenestration product and exterior door, other than field fabricated fenestration products and field fabricated exterior doors being installed in nonresidential buildings under 100,000 square feet, may be installed …"*

E. Modify Section 116(a)2

"B. Have a temporary label or label certificate (for site-built products) meeting … [No other change to this subsection.]

C. Have a permanent label or label certificate (for site-built products) meeting …

[No other change to subsection C.]

EXCEPTION to Section 116(a): Fenestration products removed … [No change to this exception.]

EXCEPTION to Section 116(a)2: Glazed wall systems and site built overhead glazing in buildings under 100,000 square feet which are covered by the nonresidential standards shall have SHGCs and U-~~values~~ factors determined in accordance with NFRC simulation procedures or default values set forth in Section 116(a)2A. Temporary and permanent labels are not required."

[The first sentence in this exception provides some comparability of ratings by assuring that at least the same calculation procedures for determining ratings are used. The second is an exception that we recommend continuing from the 1998 standards as a **temporary** means of easing the industry's transition to the NFRC rating and certification procedures.]

2. Discussion

There are numerous ways that a manufacturer of curtain walls and other fenestration systems for either residential or nonresidential applications can arrive at a U-factor. For example, they could use NFRC 100, AAMA 1503, the ASHRAE defaults, a finite element program, ASTM c976, ASTM E1423, or ASTM C236 (which is the test method in both NFRC 100 and AAMA 1503, but which has insufficient guidance as to all the testing details). The NFRC came into existence over ten years ago because this variety of rating procedures led to non-comparable results and questionable certification safeguards in the residential window market. At the time that the Commission adopted NFRC's rating and certification programs, the procedures were specific to "manufactured" fenestration products. There was no way to obtain an NFRC rating and certification for site built products.

During the intervening decade, the industry, through NFRC, has worked out a set of procedures that allows fair, accurate and credible ratings for curtain wall systems and other site-built fenestration systems. The process, known as NFRC 100-C or NFRC 100-SB, relieves the "manufacturer" from having to place a label on every "window" - an unworkable tenet at best. It also relieves the building inspector from having to check a label on every fenestration opening. Using NFRC 100-SB, the inspector would only have to examine the "Label Certificate," much as s/he does for the engineering on a curtain wall system.

There are really only three options for this issue:

A. Do nothing: if the language in the standards were left as is, manufacturers could continue to choose between reporting U-factors using the Commission's default table, using the NFRC 100 procedure (with great difficulty) or using some technique not authorized by the Commission.

B. Reference AAMA 1503 (which also relies on ASTM C283) and AAMA's certification program.

C. Reference NFRC 100-SB.

Making no change in the standards will perpetuate the confusion that currently exists. Manufacturers report performance criteria in their literature, often using the testing criteria that gives them the best results compared to their competition. Since fenestration systems for commercial buildings are not labeled, architects and other designers use the published numbers, right or wrong, and building officials have little recourse but to accept them. This puts curtain wall manufacturers who have spent R&D resources developing a more energy efficient product at a disadvantage - their product looks no better, and sometimes worse, than their competitors on a tilted playing field.

Turning to option "B" would give the Commission less assurance that a fair, accurate and credible comparison can be made between products. AAMA's procedures do not include active oversight of laboratories, nor a level of oversight of manufacturers' claims equivalent to NFRC's[1]. AAMA also does not have a procedure equivalent to the NFRC's simulations for extrapolating test results on a couple products to the entire product line. This potentially makes the AAMA procedures more costly for the manufacturer as well as the Commission if the Commission were to challenge any performance claims.

Adoption of NFRC's rating and certification procedures for site-built products will create continuity with the existing reference to NFRC 100 within the Commission's standards. In addition, recognition of NFRC 100-SB by the Commission will help bring about the same sort of fairness and regularity within the curtain wall and commercial sloped glazing industries as is now apparent in the residential fenestration products industry. It will also help to keep California's building standards in harmony with national standards since the recently adopted ASHRAE 90.1 1999 references NFRC 100-SB.

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[1] *AAMA's thermal certification program was the subject of a FTC investigation and suit*

3. Implications

It is unlikely that adoption by the Energy Commission of NFRC 100-SB will render any products obsolete or give any one manufacturer's products a tremendous boost up. Of all the things that developers and designers consider when choosing a curtain wall system, a few points in the second decimal place of the product's U-factor (even as much as a whole number in the first decimal place) is probably not in the top ten. With other changes to Title 24 that are contemplated, the SHGC becomes more important than in the past. It is likely that building developers and curtain wall manufacturers will no longer find the Commission's default SHGC values to be an acceptable alternative to "real" performance numbers.

However, other products' U-factors and SHGC ratings are likely to be higher (worse) than what is currently being reported, or what would be reported if the default numbers were to be used. In that case, building energy features that could be "traded away" using falsely "high-performance" numbers, might remain in the design using more accurate fenestration performance numbers. Measures that should today be included to compensate for poor fenestration performance, but aren't today, will be if the curtain wall systems chosen are properly rated.

When mechanical engineers use inaccurate fenestration U-factors and SHGC values, equipment can end up being improperly sized for the loads of the space. Referencing NFRC 100-SB, by providing greater certainty of fenestration performance, will result in better HVAC sizing and selection. This will not only make the affected spaces more energy efficient, but more comfortable and productive as well.

NFRC does not allow manufacturers to label product for NFRC SHGC values without first including the NFRC U-factor. AAMA does not have a SHGC rating protocol. Therefore, if the Commission is interested in having both accurate U-factors and accurate SHGC values, and having them labeled, the NFRC procedures meet the goals where other options do not. Further, the cost of using AAMA 1503 could be prohibitive compared to NFRC. AAMA 1503 is a test based rating method with no provision for obtaining U-factors for related products, short of also testing each of them. The NFRC procedures include the means for extrapolating to similar products.

4. Cost Effectiveness

To calculate the cost effectiveness of a change in the Building Energy Efficiency Standards to reference NFRC 100-SB is not as simple as it would be for analyzing the cost effectiveness of one efficiency level in fenestration products versus another. The scale and uncertainty in the assumptions that would have to be made renders any specificity in the results almost meaningless. However, we can, with those same assumptions, provide a qualitative analysis of cost effectiveness. Let's first examine what the issues are that lead us to an assessment of savings versus cost.

There are three general categories of costs and benefits associated with this proposal: energy costs and savings, manufacturer's costs and benefits, and enforcement costs and benefits.

4.1 *Energy Costs and Benefits*

In order to calculate a numeric energy and cost savings we would first need to have a reliable estimate of the current real performance levels (U-factor and SHGC) of products being installed in nonresidential buildings, their claimed performance levels (without NFRC's certification program), and expected performance levels of the products that would be used once all products are rated and certified under the NFRC program. The latter is perhaps the easiest to estimate. We can assume that the real performance levels would be the minimum levels set by the standards. However, since U-factor and SHGC levels for the nonresidential standards are both under consideration for the AB970 round of standards revisions, even those numbers are not certain.

We could obtain the nominal performance values for products currently being used in new nonresidential construction in California, but to know the <u>real</u> performance values, the products would have to be rated and certified through the NFRC program. Since they generally are not, we cannot currently do a comparison of real versus claimed performance.

As was stated above, there is a myriad of methods for obtaining a U-factor for a product. Since there is no "standard" method required in California, and they have a choice, we can assume that manufacturers are reporting the "better" of many possible U-factors and SHGC values. Therefore, it is also safe to assume that the real values, once obtained through the NFRC program, will be higher ("worse") than those currently being used in both compliance documentation and building load calculations[2]. In some cases, the real performance value could be lower than what is being used for sizing calculations because the mechanical engineer has assumed a value from the conservative CEC default tables. Generally though, it is likely that bringing a uniform rating and certification requirement to the curtain wall and sloped glazing industry, will (a) raise the reported values of current product (compared to what is currently being assumed) and (b) incrementally move the market toward products with better real performance values. Although we cannot quantify this effect, it is clearly in the direction of energy efficiency and energy cost savings.

4.2 *Manufacturers' Costs and Benefits*

There are potentially viable arguments on both sides of the issue of whether referencing NFRC 100-SB versus either of the other two choices (do nothing, or reference AAMA 1503) would save manufacturers money, or cost them more. We do not pretend to answer this argument here, but present the case for both sides. It is worth noting however, that the costs, even if they outweigh the benefits to manufacturers, have been estimated to be on the order of pennies per opening (compared to estimated but not verified installed curtain wall costs of roughly $10/sf).

The costs that would be faced by manufacturers who are not currently testing at all, would include simulation costs, testing costs and certification costs. NFRC performed a study a few years ago on the total costs for compliance with their voluntary certification program. The results are highly dependent upon how many products manufacturers choose to label, but the overall cost was less than $0.75 per product for manufactured fenestration products. In some cases it was as little as $0.07 per product. These costs included simulations, testing, certification procedures and labels.[3] Since the new Label Certificate program allows manufacturers to now obtain certified U-factors and SHGCs for curtain wall designs created specifically for one building, the costs will vary from the standard labeling program. It is cheaper to get one certificate than tens of thousands of labels, but the smaller the commercial building is the higher the per-opening costs will be. For a very large office building, the manufacturer's costs could be less than they would be for a "standard" window line that is not the manufacturer's best seller. For a small building with less product over which to spread the costs, the label certificate program might cost the manufacturer a little more per-opening. The scale however would remain pennies per opening. Even so, we recommend exempting the smaller buildings (under 100,000 square feet) for this revision to the standards.

A potential set of benefits for manufacturers is the raft of benefits that comes from a uniform rating and certification system. Producers of better product would no longer be at an unfair competitive disadvantage. Manufacturers might be able to realize an economy of scale by getting their energy performance ratings through one system. The cost of operating the system, and therefore cost passed through to the manufacturers, should come down as it is more widely used.

The potential additional cost to manufacturers could include getting structural certification through one entity, AAMA, and energy performance ratings and certification through another, NFRC. This is likely not going to be much, if any, additional cost, since (a) AAMA is accredited to use NFRC's procedures and provide their member with certification under NFRC's accreditation program; so, there could still be one stop certification, and (b) many of the labs who provide air/water/structural certification under AAMA's program are also accredited in NFRC's energy performance program. For those manufacturers who get air/water/structural certification, but don't provide certified energy performance ratings at all, there is clearly an additional cost.

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[2] *Section 3.3.1B of the Nonresidential Manual provides help to the plan checker regarding what can be used as a source for U-factors and SHGC values. On page 3-35, under "Fenestration Surfaces," the Manual says to use either "manufacturer's data or the Energy Commission's default U-values (see Table 3-10)," and "manufacturer's data or the Energy Com-mission's default SHGC values (see Table 3-11)." While "manufacturer's data" could be interpreted as U-factors obtained using NFRC 100 and SHGCs obtained using NFRC-200, it could also mean manufacturer's published data with values from any method they choose.*

[3] *NFRC is currently in the process of updating this information and including site-built product costs in the spreadsheet. These cost estimates should be ready before the Commission completes its public hearings on the AB970 standards revision.*

4.3 Enforcement Costs and Benefits

Currently, unless a project team only submits default performance values, a plan checker or building inspector has to compare the performance data provided on the plans with manufacturer's data, either on cut sheets or from a catalogue. If the Commission adopted a standards change to reference NFRC 100-SB for site built product ratings and certification, the plan checker or building inspector would compare the values on the plans with the Label Certificate from NFRC. (A copy of the certificate is included at the end of this report.) This creates no extra effort for either the plan checker or the inspector, and may relieve them of some effort in cases where they would otherwise have to search for the manufacturer's data.

Conceivably, if the Energy Commission received a complaint about a manufacturer providing misleading performance values, and the Commission desired to provide consumer protection, it might have to expend significant time and expense to obtain the product, have it simulated and tested, and pursue having the manufacturer change its performance claims. In fact the Commission had a draft of such an enforcement plan to be adopted in 1990 to help address this same issue in the residential fenestration product arena. It was the opportunity to work with manufacturers, other states, industry associations (including AAMA), and other interested parties in crafting a national, consensus certification and accreditation program, with a built-in enforcement element, that dissuaded the Commission from pursuing a California specific program. The national organization that the Commission helped to start at that time has developed, with the help of AAMA and AAMA members, a rating and certification program for site built fenestration, including the requisite enforcement elements. The Commission need only refer complaints it receives to NFRC for action, saving the state an unquantifiable, but not insignificant amount of time, effort and money.

5. Questions for Stakeholders

There are a number of questions that have been raised by CEC staff and others about the implications of this proposal. We will be seeking the advice and feedback from stakeholders and other commenters in answering these questions.

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

1. *Is the infrastructure for obtaining NFRC U-factor and SHGC ratings for site built commercial curtain walls and overhead glazing systems sufficient to allow contractors to comply without major "bottlenecks?"?*

   The process of obtaining NFRC certified U-factors and SHGCs for site built products is the same at the front end as the process for obtaining manufactured product U-factors and SHGCs. For U-factor, the manufacturer has the product line simulated and then tests a subset of the product line. For SHGC, the manufacturer simply has the product simulated by an NFRC accredited simulator. There are plenty of simulators and no reason to believe that the simulators would experience a backlog if California suddenly required ratings on commercial (site-built) fenestration for all new commercial buildings in California. However, it is conceivable that the test labs could get backed up. There is only one in California (Fresno) and two on the West Coast (Fresno and Everett, WA). Commenters suggested minimizing the potential for over-taxing the NFRC system by limiting the requirement to a minimum size building. They suggested a cut-off of 100,000 square feet. Others, while not totally rejecting the idea of a cut-off for this round of standards, felt that 100,000 sf was too large. They recommended 30,000 sf instead. Either of these numbers are somewhat arbitrary.

   Obtaining accurate information on how much new construction would be affected if the limit were set at 30,000 or 100,000 square feet was not a simple matter. Using Commercial End Use Survey (CEUS) data collected by PG&E[4] we could conclude that approximately 1% of all commercial new construction in California would be subject to the new requirement at the 100,000 sf limit. However, using data collected for the Non-Residential New Construction (NRNC) Baseline study[5] we could conclude that it would be 9% of the new construction. The CEUS data did not have a break point for building size at 30,000 sf, but at 25,000 sf, 5% of new

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4 *1999 Commercial Building Survey Report, PG&E, 1999.*

5 *Based on a conversation with Stacia Okura of RLW Analytics, Oct. 31, 2000.*

construction would be captured[6]. According to the NRNC Baseline study, approximately 35% of commercial new construction projects are over 30,000 sf.

A third commenter recommended that a sizeable portion of the potential backlog could be eliminated by simply exempting all first floor (store front type) glazing.

What we have done in this proposal is to recommend both setting the minimum building size for the requirement at 100,000 and exempting all first floor site built glazing. This is because we cannot confidently predict that the NFRC system would not be overwhelmed if there were no exemptions, and the progress of the Standards builds on successes. That is to say, even if the number of buildings to which this new requirement would apply is fairly small, the success of the program within that small number will allow the Commission to consider extending the requirement to the rest of commercial construction during the next round of Standards. If, on the other hand, the scope of the requirement were larger this round than the NFRC rating system could accommodate, it would be difficult to justify even maintaining the requirement next round.

2. *It is no more difficult or time consuming to obtain NFRC ratings for manufactured fenestration products for commercial construction than it is for manufactured products for residential construction. Would the exemption for smaller commercial buildings extend to manufactured products rather than just to site built products?*

   The products this commenter is referring to are windows and skylights produced in a factory rather than assembled from parts on the job site. Typically, they are used in two ways:

   - ♦ commercial construction that resembles residential construction, such as single story small office buildings, or
   - ♦ "punched openings" in larger commercial buildings.

   Either way, the production of these products is no different from the production of residential fenestration products which have been covered by the Standards since 1992. Our proposal does not provide an exemption for these products.

3. *Who is going to have to take responsibility for obtaining the NFRC Certification Label Certificate?*

   The NFRC wrestled with the same question literally for years, trying to establish one clear point of responsibility that would be the same in all cases. There are so many different business models that assigning the task to the fabricator, the extruder, the glazier, the architect, or the building contractor always left cases where the requirement wouldn't work. After a long analysis and discussion period, the industry decided to allow any of the above participants to take the responsibility; but someone has to. The Commission does not have to decide who it should be either. The NFRC has a uniform set of procedures in place to allow any of the parties to obtain the necessary ratings and certification approvals.

[6] *"1999 Commercial Building Report" and "1997 commercial Building Report" agree on the 1% figure for buildings over 100,000 s.f., but the 1997 report indicates that 7% of new commercial buildings are over 25,000 s.f.*

4. *Isn't this new site-built rating/certification system untested? How do we know it will function as it should?*

   First, except for the "label certificate," the system for obtaining site built fenestration ratings and certification is the same as for obtaining manufactured product ratings and certification. That system has worked for nearly eight years.

   Secondly, the site built certification system has been in place for over two years in Washington State. Seattle Department of Construction and Land Use, the largest building jurisdiction in the state, reports that there have been no problems either with parties obtaining ratings and certification, or with the department obtaining compliance.

   But perhaps the best answer to this question is that there needs to be a significant amount of training provided to architects, curtain wall manufacturers and installers, building contractors and building officials. This is outside the code adoption process, but a commitment to train made by the Commission and the state's utilities would go a long way toward allaying the fears of the soon-to-be-regulated embodied in the question above.