LIGHTING CONTROLS EFFECTIVENESS ASSESSMENT

Final Report
on Bi-Level Lighting Study

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1. INTRODUCTION

Under a contract with Southern California Edison Company (SCE), ADM Associates, Inc. (ADM) has conducted a study to assess the effectiveness of manual lighting controls in newly constructed commercial buildings. This document is the final report on the study.

Title 24 identifies bi-level switching as a mandatory lighting design measure, and most areas in buildings must be controlled so that the connected lighting load may be reduced by at least 50 percent. Bi-level switching is a simple manual means for controlling lighting. It can be achieved by last point of control switching for lighting at either fixtures or lamps within fixtures or by the use of dimming controls. For example, in a typical 3-lamp fluorescent fixture, the outer lamps can be switched separately from the middle lamp, allowing the user to switch on one, two, or all three lamps.

There has been limited data on the degree to which building occupants use the bi-level switching capability with which they are provided. The requirements for bi-level switching were adopted into Title 24 on the basis that even limited use by occupants would cost justify installation of this relatively inexpensive control strategy. There was also the realization that bi-level switching would provide a very inexpensive mechanism for occupants to achieve voluntary peak-load reductions in their buildings; during the 2001 summer peak demand crisis in California, many retailers did just that, and voluntary demand reductions statewide far exceeded expectations. Notwithstanding this experience, there is also a great deal of anecdotal evidence that "nobody" uses bi-level switching, but rather "everybody" just turns on both switches. If this were true, then the Title 24 bi-level switching requirement would be an empty gesture.

This study was initiated to investigate these questions and to provide further information on the use of bi-level switching for lighting control. The specific objectives for the project were as follows:

- To measure actual operation of typical manual lighting controls as influenced by occupant behavior;
- To estimate demand and energy savings of manual switching;
- To identify occupant behaviors that reduce savings potential; and
- To compare actual savings to assumptions of savings from Title 24 and from utility programs.

To achieve these objectives, measured data on lighting use were collected and analyzed for several types of spaces where bi-level switching is commonly used: open offices, private offices, retail spaces, and classrooms. Samples of these spaces were selected from among office buildings, retail stores, and schools. An overview of the study methodology is provided in Chapter 2, with a full discussion of the methodology provided in Appendix A.

This report on the study of bi-level lighting is organized as follows.

- Chapter 2 provides an overview of the methodology used for the study.
- Chapter 3 presents the results of the study of bi-level switching for open office spaces.
- Chapter 4 presents the results of the study of bi-level switching for private office spaces.
- Chapter 5 presents the results of the study of bi-level switching for retail spaces.
- Chapter 6 presents the results of the study of bi-level switching for classroom spaces.
- Chapter 7 compares and discusses the savings from bi-level lighting across building types and space types.
- Chapter 8 summarizes the study findings.
- Appendix A contains a discussion of the study methodology.
- Appendix B contains copies of data collection instruments.

2. OVERVIEW OF METHODOLGY

This chapter provides an overview of the methodology used for the study of bi-level lighting. A more detailed description of the methodology is provided in Appendix A.

The specifications for the sampling design included the following:

- The sample for the data collection was to be selected from occupied nonresidential buildings that have been built since 1992.
- The types of buildings at which data were to be collected included office buildings, retail stores, and schools.
- Within a building, different types of spaces were to be monitored, including private offices, open offices, classrooms, and retail sales areas. The actual number of spaces surveyed might vary across buildings.
- On-site data collection was to be concentrated in two major regions: northern California (e.g., San Francisco Bay area, Sacramento) and southern California (e.g., Los Angeles, San Diego).

The number of buildings of different types where monitoring was actually performed and the numbers of spaces monitored within those buildings are summarized in Table 2-1. Monitoring of bi-level switching was conducted at 79 buildings, within a total of 256 spaces.

Table 2-1. Number of Sites Sampled and Spaces Monitored

Type of Building	Number of Sites Monitored	Number of Space Types Monitored			
		Classroom	Open Office	Private Office	Retail
Office	33	0	50	69	2
Retail	23	0	4	2	37
School	23	62	13	17	0
Totals	79	62	67	88	39

Some types of spaces within the selected buildings were not candidates for monitoring, based on Title 24 bi-level switching requirements. These exceptions included the following:

- Where an area had only one light source (luminaire);
- Where an area was less than 100 square feet;
- Where the lighting power density (LPD) was less than 1.0 Watt per square foot;
- Where an occupancy sensor controlled the lights within the area;
- Where the area was a corridor; or
- Where an automatic time switch control device with a timed manual override switch independently controlled each area that requires an individual switch.

For spaces within a site that were selected for monitoring, some types of space had lighting from both switches monitored, while other spaces had occupancy as well as both lighting switches monitored.

- Lighting was monitored in order to develop profiles of on/off switching and electricity use.
- Occupancy was monitored for some spaces that people may exit for significant periods of time (e.g., private offices). The occupancy data were used in analyzing whether lighting remains on when a space is not occupied. Occupancy was not monitored for some of the space types (i.e., open offices, retail sales areas, and warehouse space) because these spaces have continuous movement of people in and out of the space.

The logger data collected through the monitoring were used in data analysis to produce the following:

- Lighting and occupancy profiles;
- Manual switching characteristics; and
- Estimates of demand and energy savings (by space type) attributable to specific lighting controls, lighting switching, and other occupant behavior.

The procedure to produce these analytical results had the following major steps:

- An hourly lighting load for each circuit was developed first, using the monitored data. This load profile shows the lighting profile per actual operation of the switches.
- With bi-level switching, there are four discrete lighting levels for a space: both switches off, switch one on/switch two off, switch one off/switch two on, and both switches on. Because the wattage on circuits controlled by the bi-level switching could differ, switches were designated as either a high wattage switch or a low wattage switch.
- The measured data from the loggers for each of the monitored spaces were used to compute the percentage of time that the occupants set their lights to the different switching levels.
- Data for each circuit were aggregated to develop the lighting loads and savings for each selected area.
- Weights developed for each selected area were applied to develop the typical lighting loads and savings for each building. The building weights were also applied to extrapolate the load and savings estimates to the full population of newly constructed office, retail, or school buildings, as appropriate.

The monitoring data from the loggers also provided quantitative data pertaining to the effects of daylighting and of occupancy patterns.

- To examine the effects of daylight on the use of lighting (in spaces without photocontrols), the surveyed spaces of a given type were divided into five groups, based on how much of the space was daylit. (Data collected on-site were used to estimate the percent of a monitored space that was daylit.) Lighting use profiles were then prepared for the different daylit groups and compared to determine how the amount of daylight affects lighting use.
- The effects of occupancy were examined for private office spaces and classrooms. To examine the effects of occupancy on lighting use, data collected with the occupancy loggers were used to classify lighting data points as occurring under two states: when the space is not occupied, and when the space is occupied. Lighting use profiles were developed for these two states for private office spaces and for classrooms.

To supplement the analysis of the monitored data, information was also collected from occupants of the space regarding the effects of daylight, occupancy and other factors on their use of lighting. The responses from the interviews were tabulated to provide self-reported information regarding the operation of manual switching. For example, information from the site interview was used to determine any behavioral differences between summer and winter bi-level switch operation. That is, the occupant(s) of the space were asked in the interview whether or not they change the operation of the switches depending on the season of the year and, if so, how.

Estimates of the aggregate savings resulting from bi-level switching were calculated for each of the space types through the following procedure.

- For each monitored space, savings from using bi-level switching were defined to occur under two conditions:
  - When only the switch for the low wattage circuit is used, saving the wattage on the high wattage circuit; or
  - When only the switch for the high wattage circuit is used, saving the wattage on the low wattage circuit.
- For each space type, 24-hour profiles of Watts on per square foot and savings per square foot were calculated for each building having that type of space. Profiles were developed for weekdays and weekends.
- Data collected on-site regarding the characteristics of the monitored space were used to estimate the percentage of floor space of each building that a particular space type accounted for.
- The 24-hour profiles for Watts used per square and for Watts saved per square foot were multiplied by the space type percentage factor and the building's square footage to determine Watts used per hour and Watts saved per hour for weekdays and weekends for a particular space type in each building monitored.

- These estimates were aggregated to annual estimates of usage and savings by space type for each building. These annual usage and savings estimates were obtained by multiplying weekday values by 260 (i.e., 5 weekdays per week x 52 weeks) and weekend values by 104 (i.e., 2 days per weekend per week x 52 weeks) and summing the totals for weekdays and weekends.
- To develop aggregate estimates of savings representing the aggregate amount of square footage for new office buildings, retail stores, and schools built between 1994 and 1998, weights for the monitored buildings were taken from the Nonresidential New Construction (NRNC) database prepared by RLW Analytics.[1] The target population for the NRNC database was new construction in California in the office, retail, schools and public assembly sectors during the period 1994 through 1998. RLW defined this population using a listing of new construction projects obtained from F. W. Dodge. The database sought to list all new construction projects that were valued over $200,000. The data included renovations and expansions as well as entirely new buildings.
- As an integral part of the NRNC database, RLW prepared case weights to properly project the sample sites up to their target population. These case weights adjusted for differences between the sample and the population in terms of participation in utility programs, building type and square footage.
- Because the buildings monitored for this study were a sub-sample of the NRNC sample, their weights from the NRNC database were scaled up so that they would bring the estimates of building square footage to the NRNC population square footages when applied. These scaled-up weights were applied to the usage and savings estimates for the individual buildings monitored in order to develop the population-based estimates of usage and savings. Thus, the aggregate estimates of usage and savings presented in this study are annual estimates for the population of new buildings built between 1994 and 1998.

[1] RLW Analytics, Inc., *Nonresidential New Construction Baseline Study: Final Report*, July 1999.

3. ANALYSIS OF BI-LEVEL LIGHTING IN OPEN OFFICE SPACE

The analysis of bi-level lighting in open office spaces was based on monitored data for 67 open office spaces and on interview data from 46 occupants of those spaces. Of the 67 open office spaces monitored, 50 were in office buildings, 4 were in retail stores, and 13 were in schools. The results of that analysis are presented in this chapter.

3.1 SELF-REPORTED INFORMATION ON LIGHTING CONTROL PRACTICES FOR OPEN OFFICE SPACES

Interviews were conducted with 46 occupants of the monitored open office spaces to determine how they operated the bi-level switching for those areas. (The interview questionnaire is provided in Appendix B.)

When asked whether they turned switches on or off to adjust the lighting during the workday, 19 of the interviewees (41.3 percent) indicated that they did. The reasons provided for turning the switches on or off are shown in Table 3-1. The reason given most often was "to save energy", which was given by just over a fourth of all interviewees (who were just over two-thirds of those who reported turning lights on or off). (Because multiple responses were allowed, the responses can total more than 100 percent.)

Table 3-1. Reasons for Turning Lighting Switches On/Off in Open Office Spaces

Reason	***Number Giving As Reason***	***Percent of Those Interviewed***	***Percent of Those Turning Lights On/Off***
To save energy	13	28.3%	68.4%
To do computer work	10	21.7%	52.6%
To compensate for daylight	10	21.7%	52.6%
To create a comfortable work atmosphere	8	17.4%	42.1%
To read printed materials	5	10.9%	26.3%
Other	2	4.4%	10.5%

Just over a fourth of the interviewees (13, or 28.3 percent of those interviewed) indicated that they sometimes left the lighting off in the space during the workday. Some of the conditions under which interviewees said that they left the lighting off were as follows:

- *During lunch hour*
- *If we ever leave the office for any periods of time*
- *When I leave for long periods*
- *When unoccupied*

- *When is not occupied*
- *When alone-my office has window*
- *When sun shines into the room*

When asked whether they ever used only one switch to turn the lights on during the workday, the interviewees responded as shown in Table 3-2. Just over half of the interviewees indicated that they never use only one switch.

Table 3-2. Frequency with Which Only One Switch Is Used to Turn Lights on during Workday

Frequency in Using Only One Switch	***Number Citing***	***Percent of Those Interviewed***
Never use only one switch	24	52.2%
Sometimes use only one switch	10	21.7%
Use only one switch most of the time	3	6.5%
Always use only one switch	4	8.7%
Not answered	5	10.9%

When asked under what conditions they would use only one switch, the interviewees occupying open office spaces gave the following conditions for using just one switch:

- *Depends on daylight*
- *Weather or daylight*
- *On sunny bright summer days*
- *Daylight*
- *For more light at my desk*
- *When we have light from the outside*
- *When the sun is bright outside*
- *Only use 2 [switches] if it gets really dark*
- *To save energy*
- *When we are not doing any reading*
- *When I work with computer, and am by myself*
- *When not staying in office long*
- *Only at night or early morning*

Table 3-3 tabulates the responses from interviewees when they were asked how frequently they used both switches to turn lights on during the workday. Just under 40 percent of the interviewees said that they always use both switches.

Table 3-3. Frequency with Which Both Switches Are Used to Turn Lights on during Workday

Frequency in Using Both Switches	***Number Citing***	***Percent of Those Interviewed***
Never use both switches	10	2.17%
Sometimes use both switches	8	17.4%
Use both switches most of the time	6	13.0%
Always use both switches	18	39.1%
Not answered	4	8.7%

When asked under what conditions they used both switches, interviewees responded as follows:

- *When daylight is not sufficient*
- *Depends on how dark the room gets*
- *To be able to see my work*
- *When we need more light*
- *When I come in the morning*
- *If it gets dark*
- *Morning, to light up space*
- *When there is more than one employee*
- *Lights are turned on by the custodian in the morning*
- *During school hours*
- *When it is dark out or overcast*
- *Night or morning*

Table 3-4 shows how the interviewees were distributed when they are classified by both the frequency with which they use just one switch and the frequency with which they use both switches. By and large, the responses are consistent with expectations. In particular, three-fourths of the interviewees who reported never using just one switch also reported always using both switches. However, there are a few inconsistencies. For example, six interviewees reported that they never used just one switch but also never used both switches.

Table 3-4. Distribution of Open Office Interviewees by Frequencies of Using One Switch and Both Switches

Frequency in Using Both Switches	Frequency in Using Just One Switch					Total
	No answer	Never	Sometimes	Most of the time	Always	
No answer	3	0	0	0	1	4
Never	1	6	0	0	3	10
Sometimes	1	1	3	3	0	8
Most of the time	0	1	5	0	0	6
Always	0	16	2	0	0	18
Total	5	24	10	3	4	46

With respect to the effects of daylight, 8 of the interviewees (17.4 percent) indicated that the amount of daylight did affect how they set the light switches. When asked how the amount of daylight affected how they set the light switches, interviewees gave the following responses:

- *After sundown, both switches are used*
- *More light equals less use of light switches*
- *Do not use lights as often on summer days*
- *If outside light shines in, we don't use lights*

There were 7 of the interviewees (15.2 percent) who indicated that they used the lighting switches differently between summer and winter. Their explanations as to how the use of the lighting switches differed were as follows:

- *In summer we have more daylight, so I turn the lights off*
- *Less in summer*
- *Winter is darker, so both switches are turned on*
- *Depends on the daylight*
- *Longer days [in summer]; do not need lights on as much*
- *If it is dark outside, we turn lights on*

Just over a third of the interviewees (16, or 34.8 percent) indicated that their use of the lighting switches had changed in response to the electricity crisis in California over the past year. Their descriptions as to how their use of lighting had changed were as follows:

- *We turn lights off when nobody is in the room*
- *Turn lights off when not needed, or end of day*
- *Using just one switch, turning off lights when leaving*
- *Only turned on some of the lights.*

- *Turn lights off at end of day*
- *Use less light*
- *We only turn on one switch instead of three*
- *Don't use the lights under the overhead; turn the lights off in the bathroom.*
- *Usually put on only one switch*
- *Turn lights off when not needed*
- *Only lights that are turned on are in Health office, when students leave at the end of the day.*
- *Motion sensors reactivated*
- *Every other light was turned on*
- *Try to keep lights off in areas not being used*
- *Turn lights off if we are not in the room*

One of the hypotheses of the California Energy Commission in requiring bi-level switching has been that providing occupants with the flexibility to manage their lighting would save energy. While these data show that not all occupants take advantage of this flexibility, they do show that a significant fraction of occupants do, which supports the hypothesis.

3.2 PERCENTAGE OF TIME IN DIFFERENT CONTROL STATES

The monitored data collected for open office spaces were used to determine the percentage of time that bi-level switches were in four different states:

- Both switches off
- Only low wattage switch on
- Only high wattage switch on
- Both switches on

Figure 3-1 depicts how the percentage of time that bi-level switching is in the three "on" states varies over a weekday. During working hours, one or both of the switches are on nearly 90 percent of the time. However, Figure 3-1 shows that either the high wattage switch only or the low wattage switch only are on for some percentages of the time.

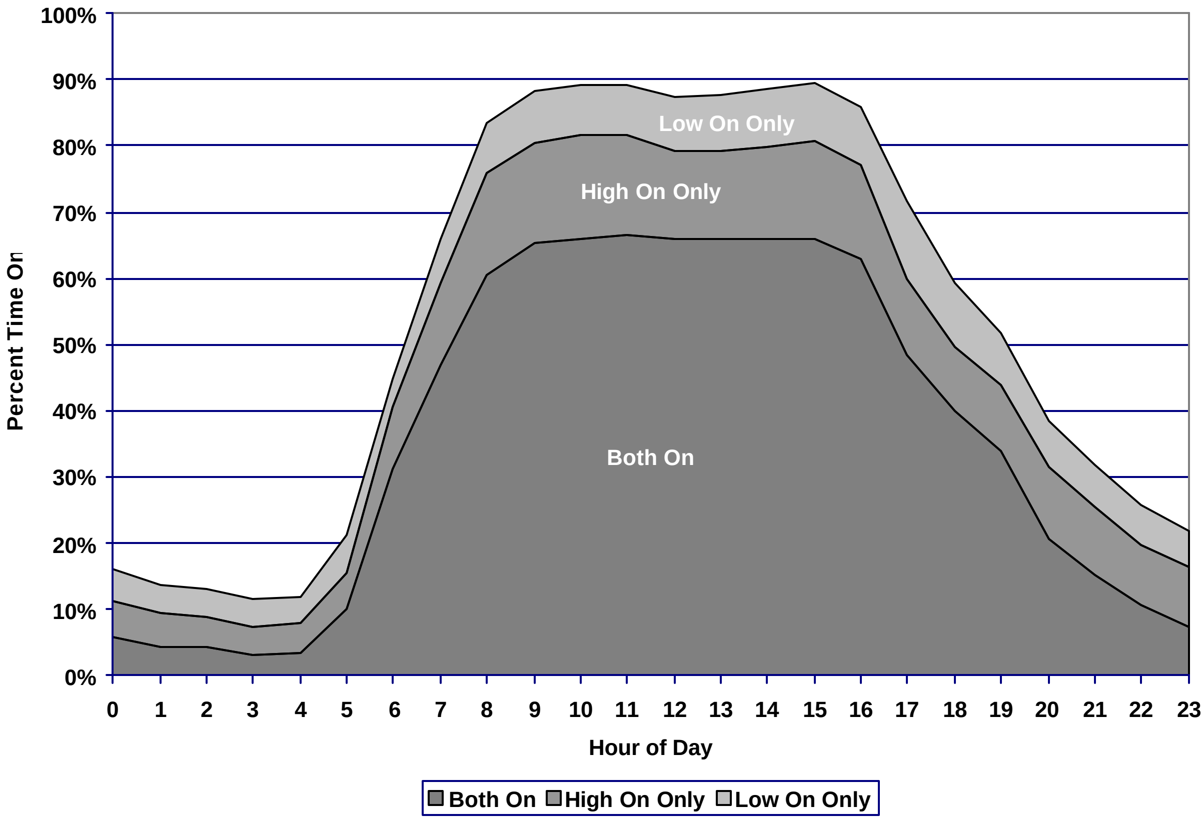

Figure 3-1. Percent of Time Bi-Level Switches in Open Office Areas Are in Different States throughout a Weekday

3.3 LIGHTING USE PROFILE FOR OPEN OFFICE SPACES

Figure 3-2 shows the use profile estimated for lighting in open office areas where there is bi-level switching. Lighting use is estimated in terms of Watts per square foot (where the square footage is for the open office space only). The average connected lighting load for open office areas is 1.105 Watts per square foot (as depicted on Figure 3-2 by the horizontal line at that level).

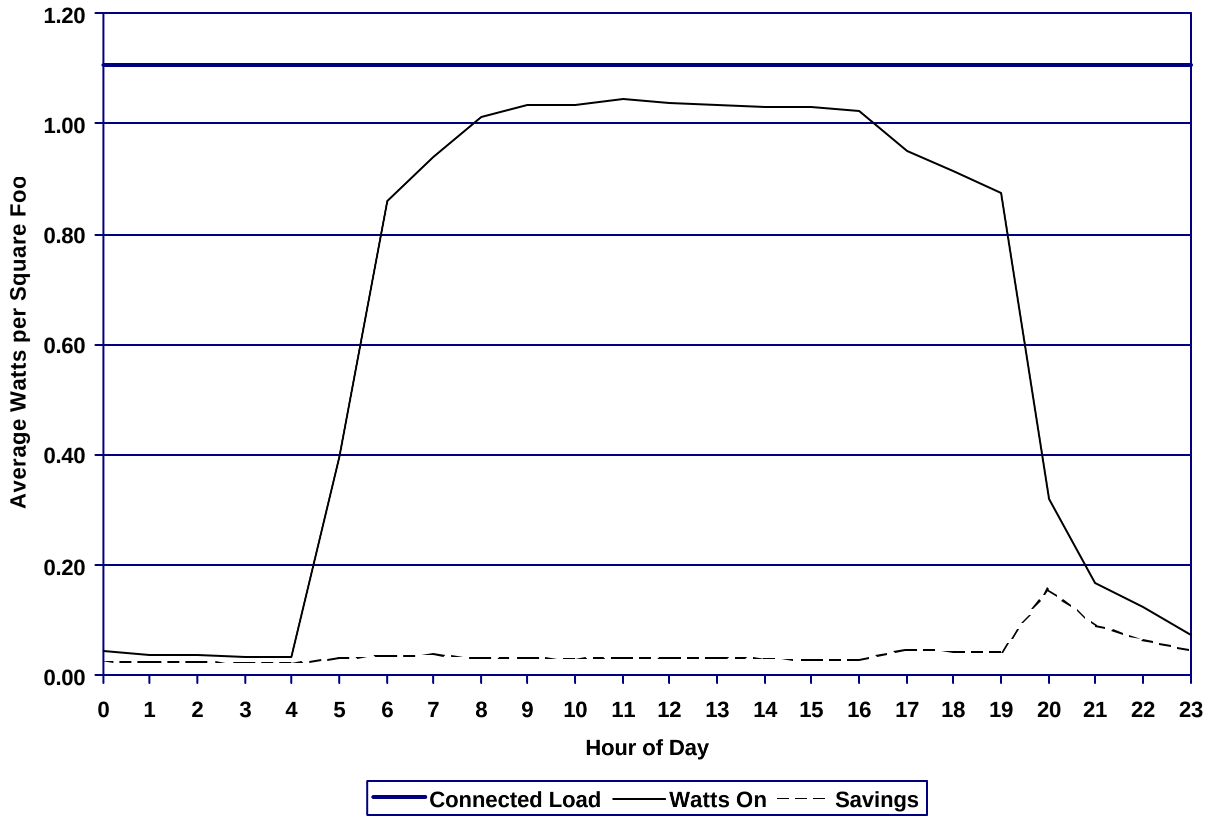

Figure 3-2. Weekday Lighting Use Profile for Open Office Areas with Bi-Level Switching

3.4 AGGREGATE SAVINGS FROM USING BI-LEVEL SWITCHING IN OPEN OFFICE SPACES

Savings from using bi-level switching in open office spaces occur under two circumstances:

- When only the switch for the low wattage circuit is used, saving the wattage on the high wattage circuit; or
- When only the switch for the high wattage circuit is used, saving the wattage on the low wattage circuit.

Figure 3-2 compares the savings from bi-level switching to the average lighting use for open office areas during workdays. Using these and similar data for weekends (and classified by building type), estimates of aggregate annual savings from use of bi-level switching in open office spaces for newly constructed buildings were developed. These estimates are reported in Table 3-5. Taking weekdays and weekends together, the savings are about 16 percent. (Savings percentages are calculated against a base of usage plus savings.)

Table 3-5. Estimated Aggregate Annual kWh Savings from Use of Bi-Level Switching in Open Office Spaces in Newly Constructed Office, Retail and School Buildings (Usage and Savings in million kWh)

Bi-Level Condition	Estimated Annual Usage	Estimated Annual Savings	Annual Usage + Annual Savings	Percent Savings
Both On	235,307	-	235,307	
High On Only	41,098	35,037	76,135	
Low On Only	15,575	20,523	36,098	
Total	291,981	55,561	347,541	16.0%

Table 3-5 shows that 80.6 percent of the estimated annual energy use for lighting in open office space occurs when both switches are on, with 14.1 percent occurring when only the high wattage switch is on and 5.3 percent when only the low wattage switch is on. With respect to savings, 63.1 percent occurs when only the high wattage switch is on and 36.9 percent occurs when only the low wattage switch is on.

3.5 EFFECTS OF DAYLIGHTING ON USE OF LIGHTING IN OPEN OFFICE SPACES

As noted in Section 3.1, about 17 percent of the occupants of open office areas reported that the amount of daylight did affect how they set the light switches. To further examine the effects of daylight on the use of lighting in open office areas, the surveyed spaces were divided into five groups, based on how much of the space was daylit. The five groups were defined as follows:

- Group 1 included spaces with no daylit areas.
- Group 2 included spaces where from 1 to 33 percent of the space was daylit.
- Group 3 included spaces where from 34 to 66 percent of the space was daylit.
- Group 4 included spaces where from 67 to 99 percent of the space was daylit.
- Group 5 included spaces where all of the space was daylit.

Figure 3-3 shows the lighting use profiles for the five groups for an average weekday. Comparison of these profiles shows that the amount of daylight does affect lighting use. There is a monotonic ranking, with areas with more and more daylight using less electricity for lighting.

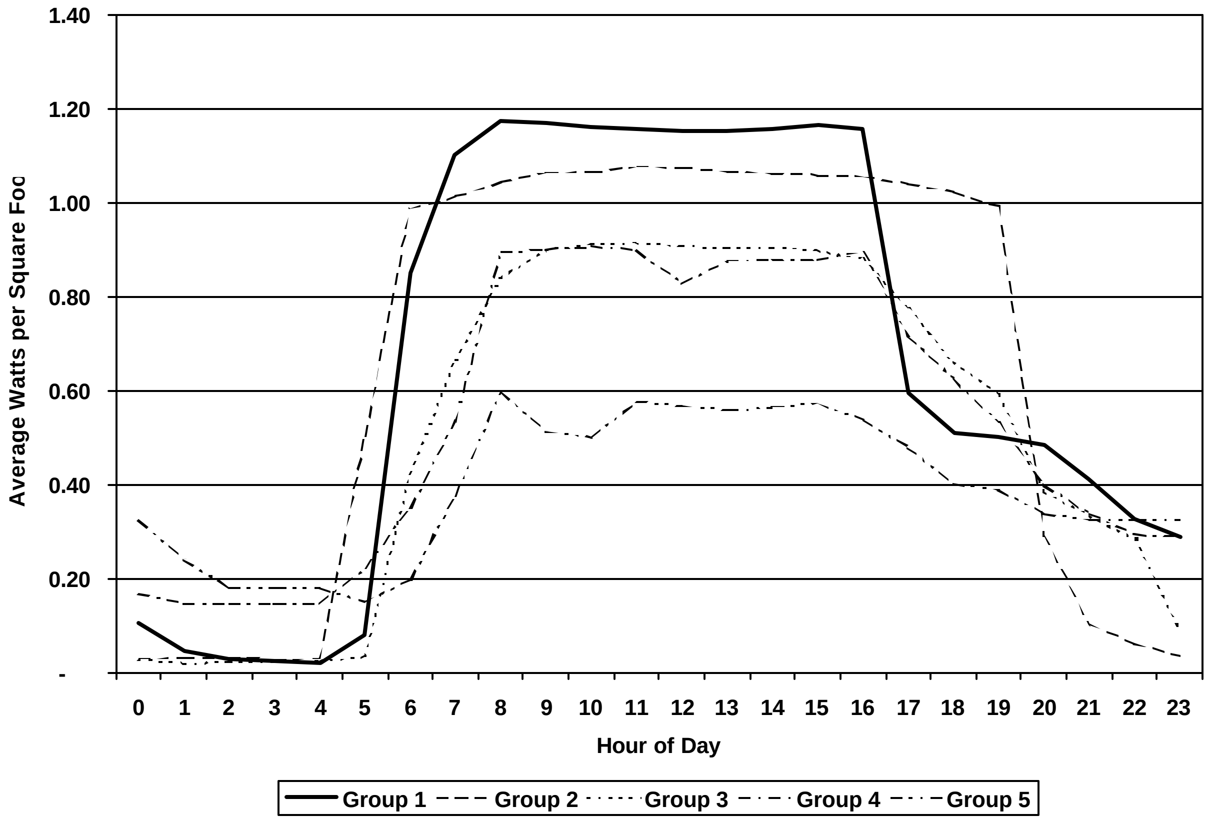

Figure 3-3. Comparison of Weekday Lighting Use Profiles for Open Office Spaces with Different Amounts of Daylight

4. ANALYSIS OF BI-LEVEL LIGHTING IN PRIVATE OFFICE SPACE

The analysis of bi-level lighting in private office spaces was based on monitored data for 88 private office spaces and on interview data from 75 occupants of those private office spaces. Of the 88 private office spaces monitored, 69 were in office buildings, 2 were in retail stores, and 17 were in schools. The results of that analysis are presented in this chapter.

4.1 SELF-REPORTED INFORMATION ON LIGHTING CONTROL PRACTICES FOR PRIVATE OFFICE SPACES

Interviews were conducted with 75 occupants of the monitored private office spaces to determine how they operated the bi-level switching for those areas. (The interview questionnaire is provided in Appendix B.)

When asked whether they turned switches on or off to adjust the lighting during the workday, 43 of the interviewees (57.3 percent of those interviewed) indicated that they did. The reasons provided for turning the switches on or off are shown in Table 4-1. Just under 40 percent of those interviewed (or just over 67 percent of those turning lights on or off) reported that the reason they turned lighting switches on or off was to save energy. (Because multiple responses were allowed, the responses can total more than 100 percent.)

Table 4-1. Reasons for Turning Lighting Switches On/Off in Private Office Spaces

Reason	***Number Giving As Reason***	***As Percent of Those Interviewed***	***As Percent of Those Turning Lights On/Off***
To save energy	29	38.7%	67.4%
To compensate for daylight	23	30.7%	53.5%
To create a comfortable work atmosphere	23	30.7%	53.5%
To do computer work	21	28.0%	48.8%
To read printed materials	16	21.3%	37.2%
Other	1	1.3%	2.3%

Just over 60 percent of the interviewees (46, or 61.3 percent of those interviewed) indicated that they sometimes left the lighting off in private office space during the workday. The conditions under which lighting was left off were identified by interviewees as follows:

- *Out for lunch or meeting and at end of day*
- *For lunch and at end of day*
- *When I go on sales, calls or deliveries*

- *During lunch, or when at a meeting*
- *When I am out for lunch or outside office for meeting*
- *For lunch, or if called to the reference desk*
- *When I am away from desk for lunch, meetings, etc.*
- *When I go home*
- *When there is sunlight outside*
- *Depends on sunlight*
- *When I am out of office*
- *When I am out of the office for long periods of time*
- *To see monitors better; turn off in a room that doesn't need light.*
- *Just when I leave at the end of the day*
- *Out of the office for most of the day*
- *When I am out of the office*
- *If I am out of the office for a few hours or if looking at the computer a lot*
- *Save energy and too bright*
- *When I am not here*
- *Depends on sunlight*
- *Late in day when few people come by*
- *Whenever I leave the office for the day mid-day or evening*
- *Lunch or out of office*
- *During afternoon, when sun is high*
- *On bright sunny days, there is often enough light in the afternoon*
- *After business hours, or when out for lunch*
- *When I am out of office*
- *If daylight is bright*
- *If not returning for the day*
- *Only if I am not in the office that day*
- *At end of day when manager leaves*
- *When I am not going to be in the office*
- *When I leave office for lunch or meeting*
- *When I am in classes*
- *When I am out of office for a long period of time (3 minutes or more)*
- *When I am at a district meeting*
- *When I am not in office*

As this list shows, occupants of private offices often turn off lights when they will not by occupying the space for some period of time (e.g., for lunch or during meetings).

When asked whether they ever used only one switch to turn the lights on during the workday, the interviewees responded as shown in Table 4-2. About 44 percent of the interviewees indicated that they never use only one switch.

Table 4-2. Frequency with Which Only One Switch Is Used to Turn Lights on in Private Office Spaces during Weekdays

Frequency in Using Only One Switch	***Number Citing***	***Percent of Those Interviewed***
Never use only one switch	33	44.0%
Sometimes use only one switch	22	29.3%
Use only one switch most of the time	8	10.7%
Always use only one switch	9	12.0%
Not answered	3	4.0%

When asked about the conditions under which they would use just one switch, interviewees identified the conditions as follows:

- *On sunny, bright days (2)*
- *Depends on daylight*
- *When working on computer (2)*
- *Low light condition*
- *When alone (2)*
- *To control the amount of light and to save energy.*
- *When there is a skeleton crew, or late in day*
- *When want less light*
- *Every day*
- *Daily*
- *When it has been turned on before my arrival*
- *First-thing in the morning, before everyone comes to work*
- *When working at desk*
- *All the time; too bright with both on*

Table 4-3 tabulates the responses from interviewees for private office spaces when they were asked how frequently they used both switches to turn lights on during the workday. Just over a third of the interviewees indicated that they always use both switches.

Table 4-3. Frequency with Which Both Switches Are Used to Turn Lights on in Private Office Spaces during Weekdays

Frequency in Using Both Switches	***Number Citing***	***Percent of Those Interviewed***
Never use both switches	14	18.7%
Sometimes use both switches	15	20.0%
Use both switches most of the time	19	25.3%
Always use both switches	26	34.7%
Not answered	1	1.3%

When asked under what conditions they used both switches, interviewees responded as follows:

- *On cloudy day*
- *When in the office working*
- *Depends on sunlight*
- *When meeting a client (2)*
- *When writing or reading (2)*
- *Evening work*
- *If working at night, might turn both lights on.*
- *On a regular work day*
- *Whenever doing paperwork with computer work*
- *Regular work (2)*
- *Most of the time when in room*
- *When doing paperwork*
- *When outside light not enough (usually early morning)*
- *When there is little sunlight*
- *When it is extremely dark outside*
- *When reading blueprints*

Table 4-4 shows how the private office interviewees were distributed when they are classified by both the frequency with which they use just one switch and the frequency with which they use both switches. By and large, the responses are consistent with expectations. In particular, three-fourths of the interviewees who reported never using just one switch also reported always using both switches. However, there are a few inconsistencies. For example, four interviewees reported that they never used just one switch but that also never used both switches.

Table 4-4. Distribution of Private Office Interviewees by Frequencies of Using One Switch and Both Switches

Frequency in Using Both Switches	Frequency in Using Just One Switch					Total
	No answer	Never	Sometimes	Most of the time	Always	
No answer	1	0	0	0	0	1
Never	2	4	1	1	5	14
Sometimes	0	0	8	5	2	15
Most of the time	0	4	13	2	0	19
Always	0	25	0	0	1	26
Total	3	33	22	8	9	75

With respect to the effects of daylight, 25 of the interviewees (33.3 percent) indicated that the amount of daylight did affect how they set the light switches. When asked how the amount of daylight affected how they set the light switches, interviewees gave the following responses:

- *Use both switches after sun goes down*
- *My office gets a lot of sunlight*
- *On sunny days I turn lights off*
- *More daylight; less fluorescents*
- *On dark cloudy days, we occasionally use both switches*
- *It is always too bright with both switches on*
- *Upstairs depending on sunlight*
- *On bright sunny days, there is often enough light in the afternoon*
- *The more daylight, the less need of overhead*
- *Brightness in afternoon*

There were 20 of the interviewees (26.7% percent) who indicated that they used the lighting switches differently between summer and winter. Their explanations as to how the use of the lighting switches differed were as follows:

- *Generally, more sunlight in summer*
- *It gets dark early [in winter]*
- *Winter days are short and dark*
- *Depends on sunlight*
- *More daylight; less fluorescents*
- *Less in summer (Brighter days, longer light here). Conversely, winter days are darker*
- *Depending on sunlight*

- *The extra light is needed more in winter for just computer work.*
- *More in winter, less in summer*
- *In winter more likely to always use at least 1 switch*
- *Daylight savings*
- *Use both more often in winter*
- *On more during the winter*
- *Afternoons are longer [in summer]*
- *Winter - early morning or late afternoon use 2 lights*
- *More during the winter time*

Just over half of the interviewees (40, or 53.3 percent) indicated that their use of the lighting switches had changed in response to the electricity crisis in California over the past year. Their descriptions as to how their use of lighting had changed were as follows:

- *I try to conserve when I do not need the light on*
- *By turning off lights when not needed*
- *I have made myself aware to turn off the switch if I will be gone for more than 15 minutes.*
- *Be more conscious of turning off lights when not needed.*
- *More conservation minded*
- *Now I am more conservation-minded*
- *I turn lights off when I don't need them*
- *I turn off lights every night before leaving*
- *Try to turn off lights more*
- *Use only 2 of 3 light panels available*
- *We are definitely more conscious of our power usage.*
- *University asked its employees to be conscious of conserving energy. When I've found both switches on (staff might have opened my office) I notice immediately and turn one switch off.*
- *Turn off lights not needed.*
- *I sometimes leave all lights off to save energy and just use the window lights*
- *The lights are turned off when I leave, rather than letting the timer turn off the lights.*
- *More aware of conservation. I turn off lights when I leave*
- *Used to use both switches automatically*
- *I only use one switch; make sure everything is off when I leave for the day.*

- *I make sure that the lights are off at the end of work, or if I am not in the office for a long period of time*
- *Using half of the lighting*
- *Use natural light more*
- *Turn off lights that are not in use; turning lights out at the end of business day*
- *When go home*
- *More often than not, I use only one set of lights*
- *Turn off lights when I will be out of my office for 3 minutes or more*
- *Use lights less*
- *Have cut use dramatically*
- *Turn lights off when not in office*

4.2 PERCENTAGE OF TIME IN DIFFERENT CONTROL STATES

The monitored data collected for private office spaces were used to determine the percentage of time that bi-level switches were in four different states:

- Both switches off
- Only low wattage switch on
- Only high wattage switch on
- Both switches on

Figure 4-1 depicts how the percentage of time that bi-level switching is in the three "on" states varies over a weekday for private office spaces. During working hours, one or both of the switches are on just over 70 percent of the time. Moreover, Figure 4-1 shows that either the high wattage switch only or the low wattage switch only are on for some percentages of the time.

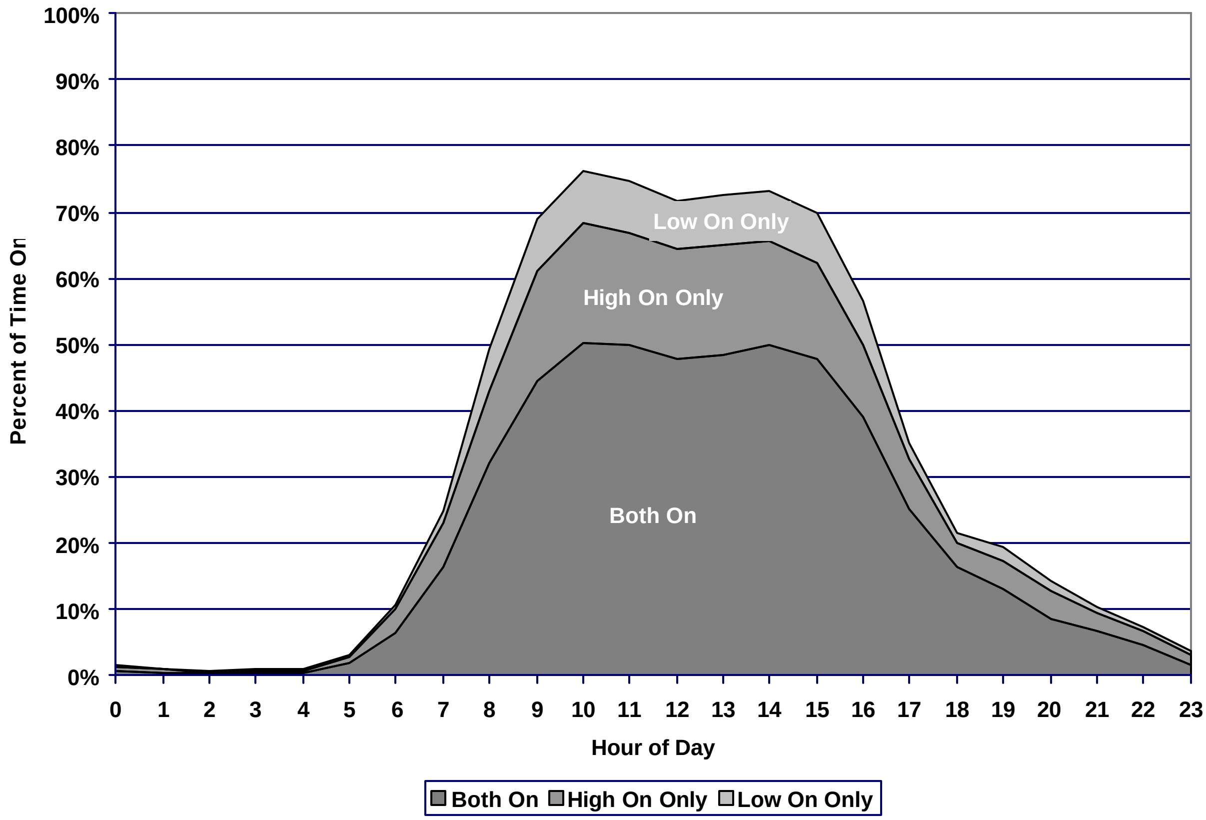

Figure 4-1. Percent of Time Bi-Level Switches in Private Office Spaces Are in Different States throughout a Weekday

4.3 LIGHTING USE PROFILE FOR PRIVATE OFFICE SPACES

Figure 4-2 shows the use profile estimated for weekday lighting in private office areas where there is bi-level switching. Lighting use is estimated in terms of Watts per square foot (where the square footage is for the private office space only). The average connected lighting load for private office areas is 1.452 Watts per square foot (as depicted on Figure 4-2 by the horizontal line at that level).

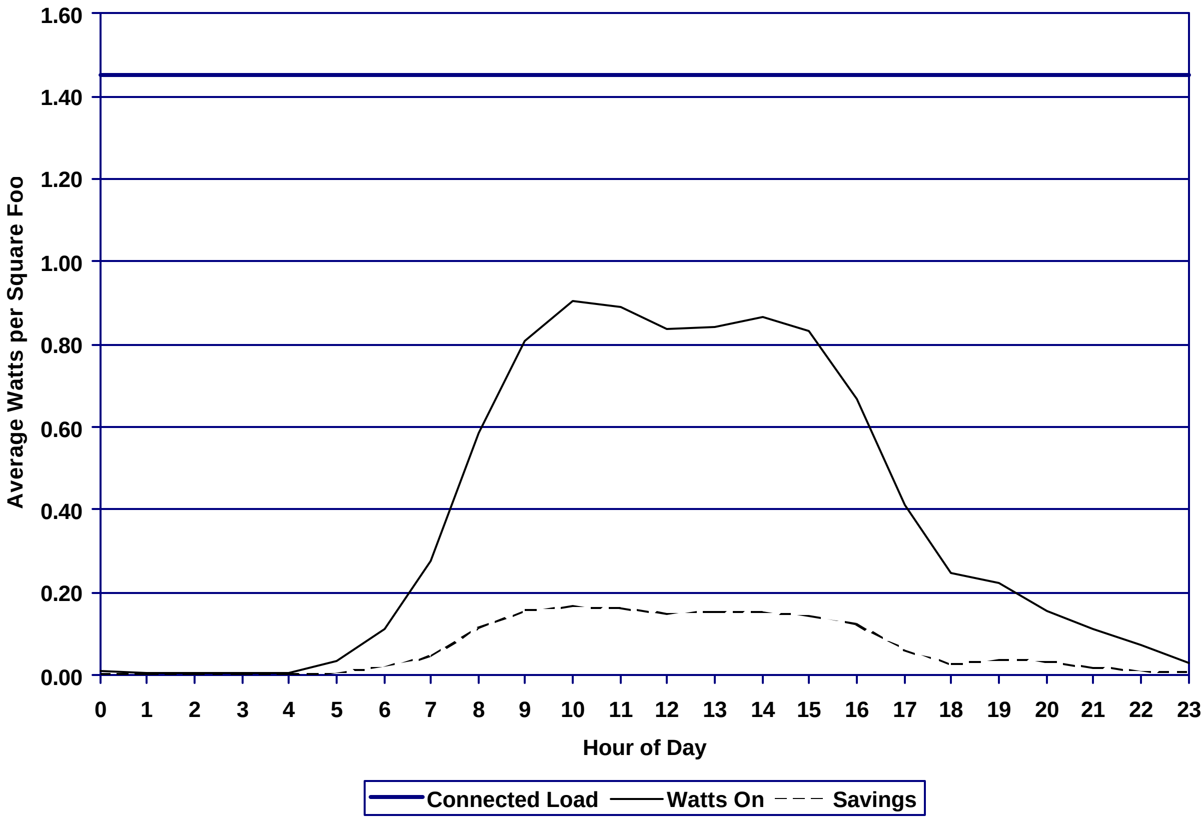

Figure 4-2. Weekday Lighting Use Profile for Private Office Areas with Bi-Level Switching

4.4 AGGREGATE SAVINGS FROM USING BI-LEVEL SWITCHING IN PRIVATE OFFICE SPACES

Savings from using bi-level switching in private office spaces occur under two circumstances:

- When only the switch for the low wattage circuit is used, saving the wattage on the high wattage circuit; or
- When only the switch for the high wattage circuit is used, saving the wattage on the low wattage circuit.

Figure 4-2 compares the savings from bi-level switching to the average lighting use for private office areas during workdays. Using these and similar data for weekends (and classified by building type), estimates of aggregate annual savings from use of bi-level switching in private office spaces for newly constructed buildings were developed. These estimates are reported in Table 4-5. Taking weekdays and weekends together, the savings are about 24 percent. (Savings percentages are calculated against a base of usage plus savings.)

Table 4-5. Estimated Aggregate Annual kWh Savings from Use of Bi-Level Switching in Private Office Spaces in Newly Constructed Office, Retail and School Buildings (Usage and Savings in million kWh)

Bi-Level Condition	Estimated Annual Usage	Estimated Annual Savings	Annual Usage + Annual Savings	Percent Savings
Both On	66,297	-	66,297	
High On Only	22,012	14,083	36,095	
Low On Only	9,178	12,734	21,911	
Total	97,486	26,817	124,303	21.6%

Table 4-5 shows that 68.0 percent of the estimated annual energy use for lighting in private office space occurs when both switches are on, with 22.6 percent occurring when only the high wattage switch is on and 9.4 percent when only the low wattage switch is on. With respect to savings, 52.5 percent occurs when only the high wattage switch is on and 47.5 percent occurs when only the low wattage switch is on.

4.5 EFFECTS OF DAYLIGHTING ON USE OF LIGHTING IN PRIVATE OFFICE SPACES

As noted in Section 4.2, a third of the occupants of private office areas reported that the amount of daylight did affect how they set the light switches. To further examine the effects of daylight on the use of lighting in private office areas, the surveyed spaces were divided into five groups, based on how much of the space was daylit. The five groups were defined as follows:

- Group 1 included spaces with no daylit areas.
- Group 2 included spaces where from 1 to 33 percent of the space was daylit.
- Group 3 included spaces where from 34 to 66 percent of the space was daylit.
- Group 4 included spaces where from 67 to 99 percent of the space was daylit.
- Group 5 included spaces where all of the space was daylit.

Figure 4-3 shows the lighting use profiles for the five groups for an average weekday. Comparison of these profiles shows that the amount of daylight does not necessarily affect lighting use in private offices. The profiles for Groups 1, 2, and 3 (those with the lowest amount of daylight) are close together and lower than the profiles for Groups 4 and 5 (those with the highest amount of daylight).

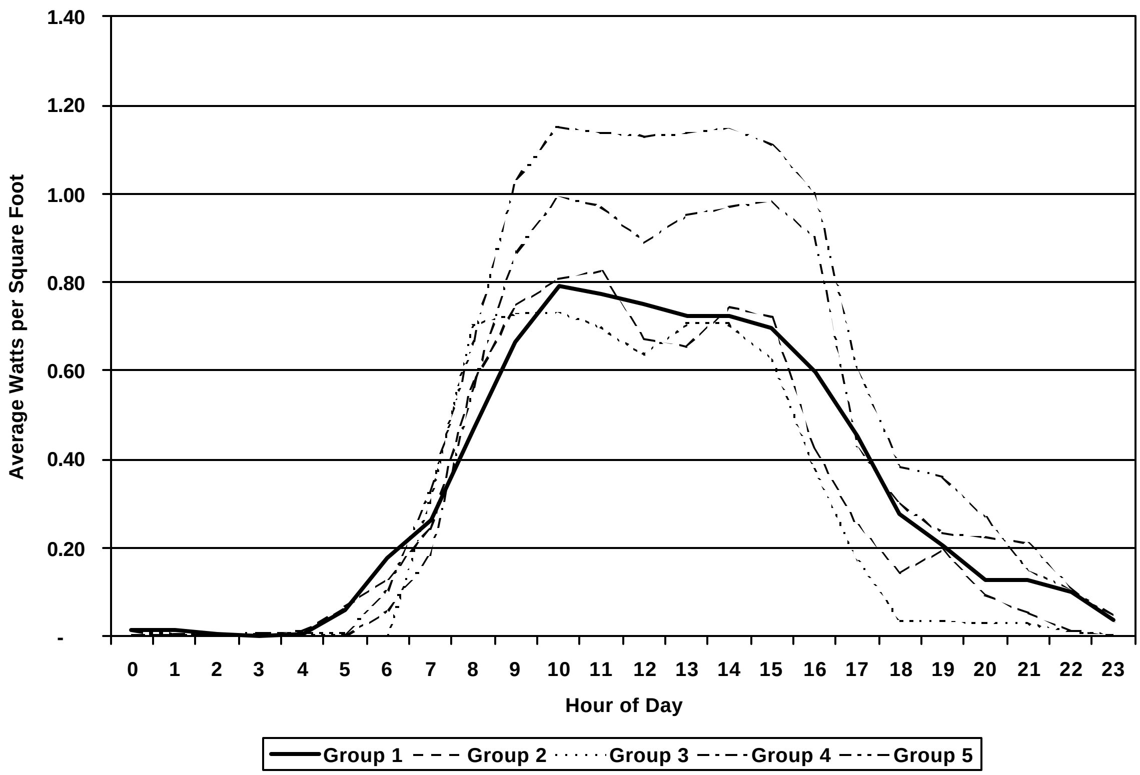

Figure 4-3. Comparison of Weekday Lighting Use Profiles for Private Office Spaces with Different Amounts of Daylight

4.6 OCCUPANCY PATTERNS AND LIGHTING USE IN PRIVATE OFFICE SPACES

To examine the effects of occupancy on lighting use for private office spaces, data collected with the occupancy loggers were used to classify lighting data points as occurring under two states:

- When the space is not occupied; and
- When the space is occupied.

Analysis of lighting use for the different states of occupancy is useful to identify "wasted" lighting energy, which can be characterized as energy used for lighting when a space is not occupied.[2]

Lighting use profiles for private office spaces that were developed for the two occupancy states are shown in Figure 4-4. The figure shows the average Watts of electricity used for lighting per square foot on a weekday when the space is occupied

[2] See, for example, Von Neida, B., Maniccia, D., and Tweed, A., "An Analysis of the Energy and Cost Savings Potential of Occupancy Sensors for Commercial Lighting Systems", IES Paper No. 43, August 2000.

and when the space is not occupied. As can be seen, electricity is used for lighting even when the space is not occupied; this represents electricity that might be saved. Based on these profiles and on estimates calculated for the percentages of time that space is occupied and not occupied, the lighting that is used when the space is not occupied represents about a fourth of the average daily use of electricity for lighting private office space during a weekday.

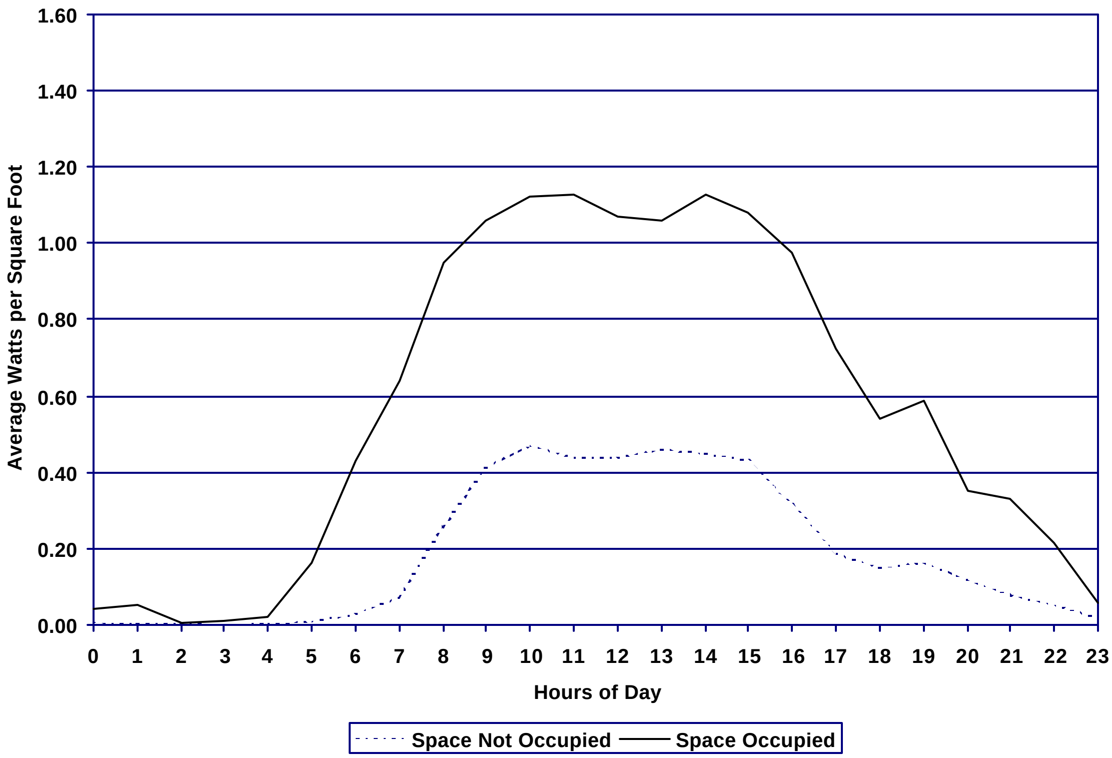

Figure 4-4. Lighting Use Profiles for Private Office Spaces
When Space Is Occupied and When Space Is Not Occupied during a Weekday

5. ANALYSIS OF BI-LEVEL LIGHTING IN RETAIL SPACE

The analysis of bi-level lighting in retail spaces was based on monitored data for 39 retail spaces and on interview data from 23 occupants of these retail space. The results of that analysis are presented in this chapter.

5.1 SELF-REPORTED INFORMATION ON LIGHTING CONTROL PRACTICES FOR RETAIL SPACES

Interviews were conducted with 23 occupants of the monitored retail spaces to determine how they operated the bi-level switching for those areas. (The interview questionnaire is provided in Appendix B.)

When asked whether they turned switches on or off to adjust the lighting during the workday, only one of the interviewees (4.4 percent) indicated that he/she did. The reason provided for turning the switches on or off was to save energy.

Only two of the interviewees (8.7 percent of those interviewed) indicated that they sometimes left the lighting off in retail space during the workday. The conditions under which the lighting would be left off were identified by the interviewees as follows:

- *Partial lighting to control energy*
- *At night, we leave some lights on for the custodian. The rest of the lights are off.*

When asked whether they ever used only one switch to turn the lights on during the workday, only one interviewee indicated that he/she did, always.

Table 5-1 tabulates the responses from interviewees for retail spaces when they were asked how frequently they used both switches to turn lights on during the workday. Just under 40 percent reported always using both switches. (Because multiple responses were allowed, the responses can total more than 100 percent.)

Table 5-1. Frequency with Which Both Switches Are Used to Turn Lights on in Retail Spaces during Workdays

Frequency in Using Both Switches	***Number Citing***	***Percent of Those Interviewed***
Never use both switches	3	13.0%
Sometimes use both switches	0	0.0%
Use both switches most of the time	0	0.0%
Always use both switches	9	39.1%
Not answered	11	47.8%

With respect to the effects of daylight, two of the interviewees (8.7 percent) indicated that the amount of daylight did affect how they set the light switches.

There was one of the interviewees (4.4 percent) who indicated that they used the lighting switches differently between summer and winter.

Of the 23 interviewees, four (17.4 percent) indicated that their use of the lighting switches had changed in response to the electricity crisis in California over the past year. Explanations for how lighting use had changed included the following:

- *We were able to conserve some energy (10%-15%) last summer, 2001.*
- *We turned dome lights off.*
- *Turned off valance and neon lighting.*

5.2 PERCENTAGE OF TIME IN DIFFERENT CONTROL STATES FOR RETAIL SPACES

The monitored data collected for retail spaces were used to determine the percentage of time that bi-level switches were in four different states:

- Both switches off
- Only low wattage switch on
- Only high wattage switch on
- Both switches on

Figure 5-1 depicts how the percentage of time that bi-level switching is in the three "on" states varies over a weekday for retail spaces. During working hours, one or both of the switches are on over 90 percent of the time. Moreover, Figure 5-1 shows that either the high wattage switch only or the low wattage switch only are on for some percentages of the time.

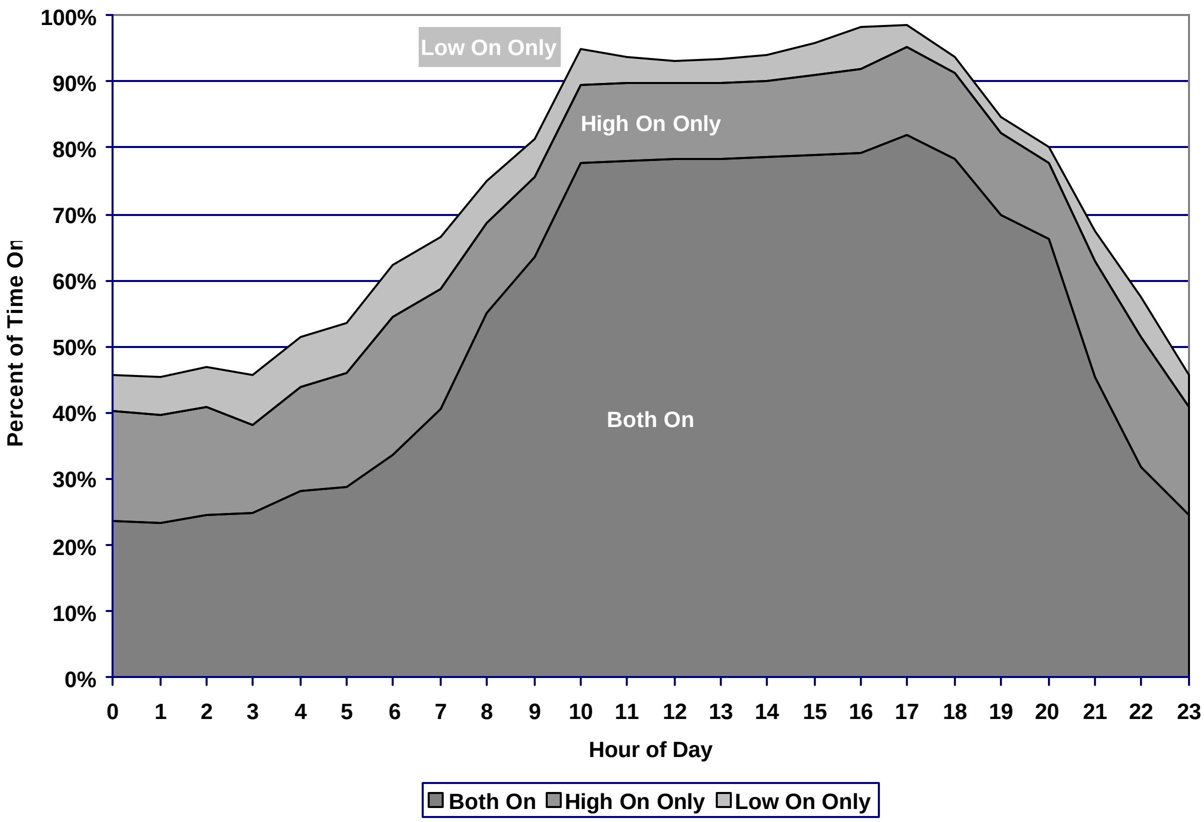

Figure 5-1. Percent of Time Bi-Level Switches in Retail Spaces Are in Different States throughout a Weekday

5.3 LIGHTING USE PROFILE FOR RETAIL SPACES

Figure 5-2 shows the use profile estimated for weekday lighting in retail areas where there is bi-level switching. Lighting use is estimated in terms of Watts per square foot (where the square footage is for the retail space only). The average connected lighting load for retail areas is 1.146 Watts per square foot (as depicted on Figure 5-2 by the horizontal line at that level).

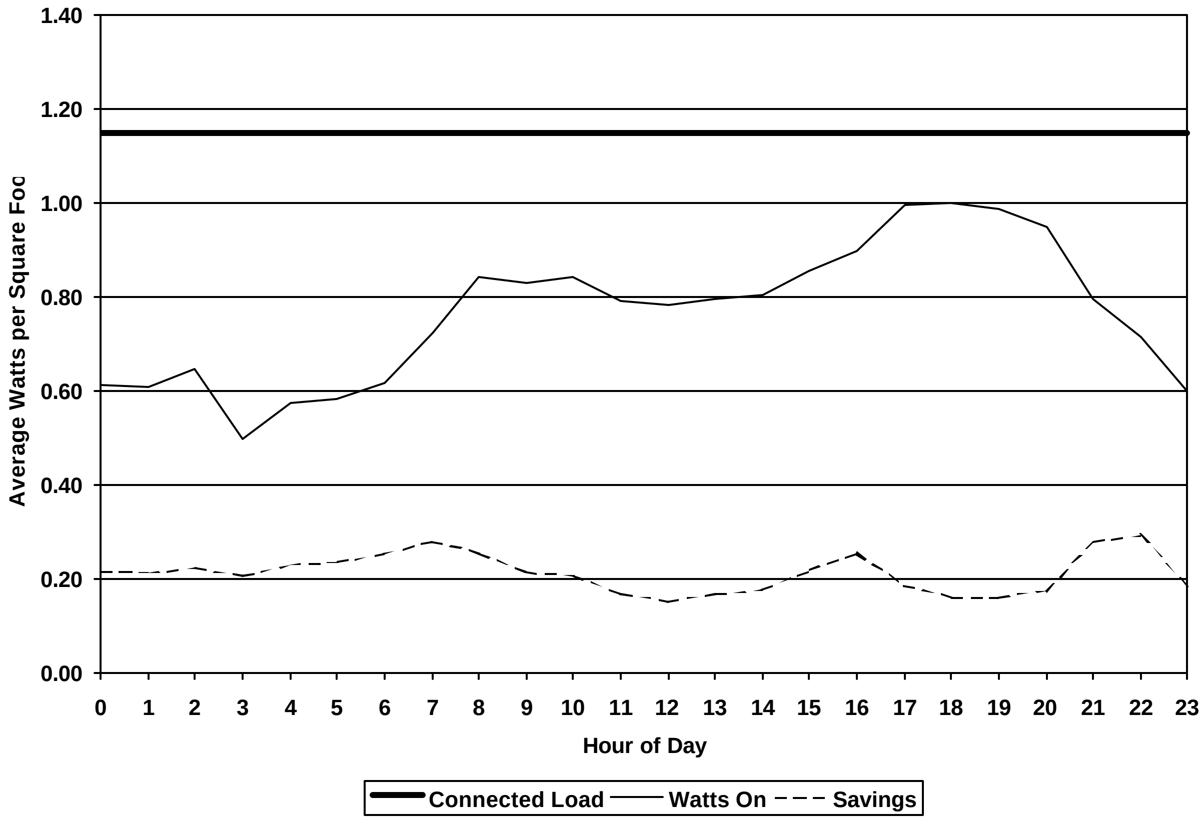

Figure 5-2. Weekday Lighting Use Profile for Retail Areas with Bi-Level Switching

5.4 AGGREGATE SAVINGS FROM USING BI-LEVEL SWITCHING IN RETAIL SPACES

Savings from using bi-level switching in retail spaces occur under two circumstances:

- When only the switch for the low wattage circuit is used, saving the wattage on the high wattage circuit; or
- When only the switch for the high wattage circuit is used, saving the wattage on the low wattage circuit.

Figure 5-2 compares the savings from bi-level switching to the average lighting use for retail spaces during weekdays. Using these and similar data for weekends (and classified by building type), estimates of aggregate annual savings from use of bi-level switching in retail spaces for newly constructed buildings were developed. These estimates are reported in Table 5-2. Taking weekdays and weekends together, the savings are just under 15 percent. (Savings percentages are calculated against a base of usage plus savings.)

Table 5-2. Estimated Aggregate Annual kWh Savings from Use of Bi-Level Switching in Retail Spaces

in Newly Constructed Office and Retail Buildings
(Usage and Savings in million kWh)

Bi-Level Condition	***Estimated Annual Usage***	***Estimated Annual Savings***	***Annual Usage + Annual Savings***	***Percent Savings***
Both On	656,796	-	656,796	
High On Only	128,043	91,479	219,522	
Low On Only	54,558	54,568	109,126	
Total	839,398	146,047	985,445	14.8%

Table 5-2 shows that 78.2 percent of the estimated annual energy use for lighting in retail space occurs when both switches are on, with 15.3 percent occurring when only the high wattage switch is on and 6.5 percent when only the low wattage switch is on. With respect to savings, 62.6 percent occurs when only the high wattage switch is on and 37.4 percent occurs when only the low wattage switch is on.

5.5 EFFECTS OF DAYLIGHTING ON USE OF LIGHTING IN RETAIL SPACES

As noted in Section 5.2, only two of the occupants of retail areas reported that the amount of daylight did affect how they set the light switches. To further examine the effects of daylight on the use of lighting in areas, the surveyed spaces were divided into five groups, based on how much of the space was daylit. The five groups were defined as follows:

- Group 1 included spaces with no daylit areas.
- Group 2 included spaces where from 1 to 33 percent of the space was daylit.
- Group 3 included spaces where from 34 to 66 percent of the space was daylit.
- Group 4 included spaces where from 67 to 99 percent of the space was daylit.
- Group 5 included spaces where all of the space was daylit.

Figure 5-3 shows the lighting use profiles for the five groups for an average weekday. Comparison of these profiles shows that the amount of daylight does affect lighting use in retail spaces. Most noticeable, the retail spaces with 100 percent daylight use electric lighting relatively less during the daytime hours than do the spaces with lower amounts of daylight.

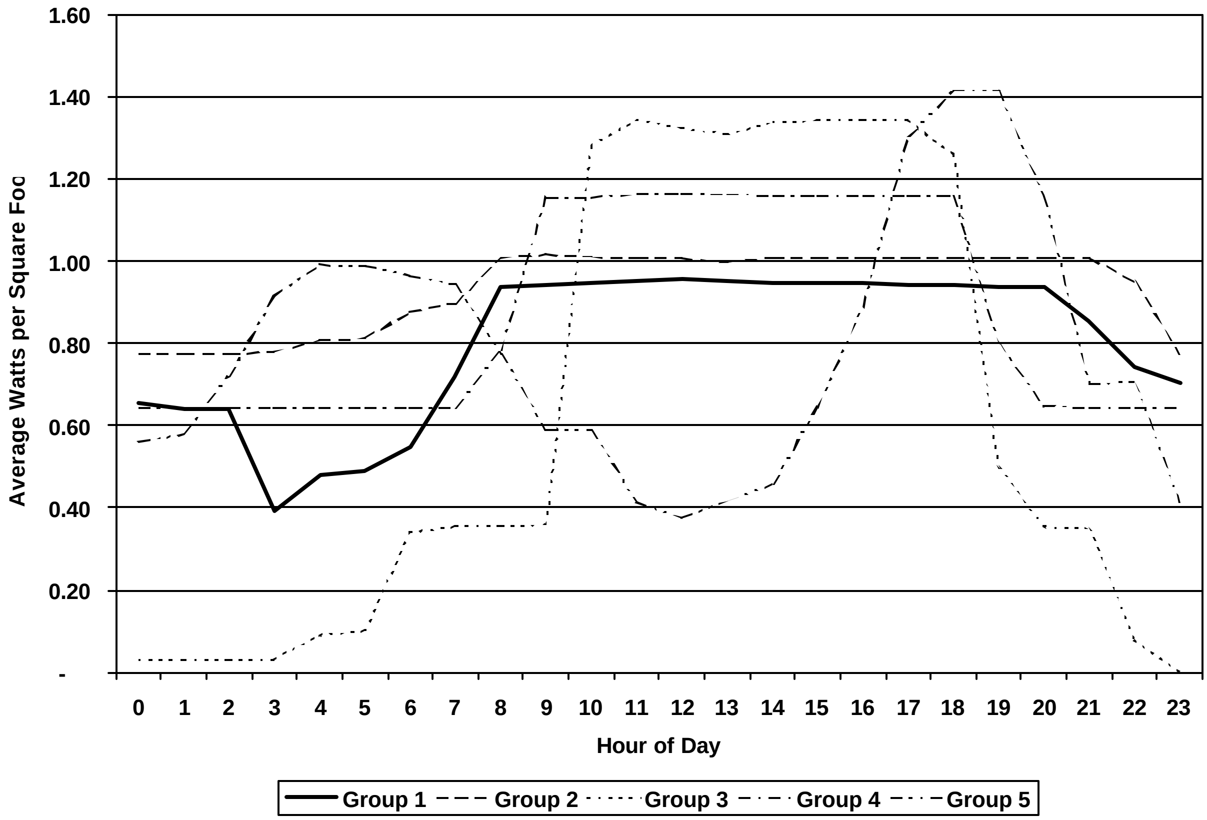

Figure 5-3. Comparison of Weekday Lighting Use Profiles for Retail Spaces with Different Amounts of Daylight

6. ANALYSIS OF BI-LEVEL LIGHTING IN CLASSROOM SPACE

The analysis of bi-level lighting in classroom space was based on monitored data for 62 classroom spaces (all of which were in schools) and on interview data from 56 teachers whose classrooms were monitored. The results of that analysis are presented in this chapter.

6.1 SELF-REPORTED INFORMATION ON LIGHTING CONTROL PRACTICES FOR CLASSROOM SPACES

Interviews were conducted with 56 teachers whose classrooms were monitored to determine how they operated the bi-level switching for those areas. (The interview questionnaire is provided in Appendix B.)

When asked whether they turned switches on or off to adjust the lighting in classrooms during the workday, 49 of the teachers interviewed (87.5 percent) indicated that they did. The reasons provided for turning the switches on or off are shown in Table 6-1. About 54 percent reported turning lighting switches on or off to save energy. (Because multiple responses were allowed, the responses can total more than 100 percent.)

*Table 6-1. Reasons for Turning Lighting Switches On/Off in Classroom Spaces**

Reason	***Number Giving As Reason***	***Percent of Those Interviewed***
To save energy	30	53.6%
To compensate for daylight	20	35.7%
To create a comfortable work atmosphere	20	35.7%
To read printed materials	14	25.0%
To do computer work	6	10.7%
Other	21	37.5%

Just over three-fourths of the teachers interviewed (44, or 78.6 percent of those interviewed) indicated that they sometimes left the lighting off in classroom spaces during the workday. The interviewed teachers identified a number of conditions under which lighting was left off. Such conditions included the following:

- *To save energy, or when using overhead projector*
- *Recess and lunch, and of course at the end of day*
- *During recess and lunchtime*
- *When we leave for lunch or a day*
- *For only a few minutes*
- *For recess and lunch*

- *When the room is vacant*
- *Go to lunch*
- *When I use the overhead projector*
- *During breaks, prep period, lunch*
- *Lunchtime*
- *During recess, when left for meeting, or when using visual aid*
- *If leave room at lunchtime, or sometimes to watch video*
- *When leaving for extended periods*
- *When I leave the room with my class to go to another room, or to lunch or out to P.E.*
- *Lunch and P.E.*
- *When we go to lunch*
- *Depends on weather conditions*
- *To watch TV*
- *When class leaves the room*
- *Whenever the class is not in the room*
- *At lunch and recess*
- *Watching videos, or when I leave the classroom*
- *Only when we're out of the room or using projector*
- *When I leave, play videos, or if students request*
- *When using video material*
- *When room is vacant or when showing video*
- *When I'm not in the room for over an hour*
- *Lunch, etc or when kids are not in room*
- *When we are out of the room*
- *If I'm only going to be there for a few minutes, or if we are having quiet time*
- *When I am in the room alone, using the computer*
- *When I am not in room*
- *When empty, alone*
- *During lunch*
- *During prep period only. Off at end of day.*
- *Whenever I leave - lunch and preparation (2 hours)*
- *Plenty of natural light--fluorescent lights TOO bright; my eyes are especially sensitive*
- *When we go out of the room for recess, lunch or PE*

- *When room not in use*
- *When we're out of class*

When asked whether they ever used only one switch to turn the lights on during the school day, the interviewed teachers responded as shown in Table 5-2. About 36 percent reported never using only one switch, while under 4 percent reported always using just one switch.

Table 6-2. Frequency with Which Only One Switch Is Used to Turn Lights on in Classroom Spaces during Weekdays

Frequency in Using Only One Switch	***Number Citing***	***Percent of Those Interviewed***
Never use only one switch	20	35.7%
Sometimes use only one switch	25	44.6%
Use only one switch most of the time	6	10.7%
Always use only one switch	2	3.6%
Not answered	3	5.4%

When asked about the conditions under which they would use just one switch, interviewees identified the conditions as follows:

- *When using overhead projector*
- *To view the overhead projector copies in the mornings*
- *To watch TV or visual aid*
- *When students are looking at the overhead*
- *Very bright days*
- *Very rarely - when playing a video*
- *To watch TV*
- *Depends on sunlight*
- *If lesson calls for listening only - cuts down on distractions*
- *When the overhead is being used*
- *To use overhead or to view a video*
- *If it is bright outside*
- *When I am by myself*
- *When I don't need all the lights on*
- *One is all that is required when the sun is out*
- *99.9% of the time*
- *Dark days; both switches on -- Bright days; one switch on*
- *Rarely, but during certain presentation*

- *When I am the only one in the room*
- *When I don't need as much light*
- *One switch when I use the computer; Two switches most of the rest of the day*
- *Quiet time - TV watching*
- *Overhead projector; conserve energy*
- *For viewing art films*
- *When room partially being used, or to view projection material*
- *When it's warm in the class, or we're doing something that doesn't require much light*

Table 6-3 tabulates the responses from interviewees for classrooms when they were asked how frequently they used both switches to turn lights on during the day. About 38 percent indicated that they always use both switches, while about 7 percent indicated that they never use both switches.

Table 6-3. Frequency with Which Both Switches Are Used to Turn Lights on in Classroom Spaces during Weekdays

Frequency in Using Both Switches	Number Citing	Percent of Those Interviewed
Never use both switches	4	7.1%
Sometimes use both switches	8	14.3%
Use both switches most of the time	23	41.1%
Always use both switches	21	37.5%

When asked under what conditions they used both switches, interviewees provided the following responses:

- *Reading*
- *To read*
- *Always; the room is too dark with just one*
- *Depends on the class activity*
- *For regular use*
- *Reading*
- *About 5 1/2 hrs. per day*
- *When class is in the room (2)*
- *When we are reading or writing*
- *When it is cloudy out*
- *Normal classroom activities*
- *For everyday work*

- *When teaching*
- *Open house or night type meetings*
- *For daily academics*
- *For reading, writing*
- *During class time*
- *When working on art projects*
- *When someone complains about the dimness*
- *Only if dark when I arrive*
- *For full classroom use*

Table 6-4 shows how the classroom interviewees were distributed when they are classified by both the frequency with which they use just one switch and the frequency with which they use both switches. By and large, the responses are consistent with expectations. In particular, 70 percent (14 of 20) of the interviewees who reported never using just one switch also reported always using both switches. However, there are a few inconsistencies. For example, one interviewee reported that he/she never used just one switch but also never used both switches.

Table 6-4. Distribution of Classroom Interviewees by Frequencies of Using One Switch and Both Switches

Frequency in Using Both Switches	***Frequency in Using Just One Switch***					***Total***
	No answer	***Never***	***Sometimes***	***Most of the time***	***Always***	
No answer	0	0	0	0	0	0
Never	2	1	0	0	1	4
Sometimes	1	1	3	3	0	8
Most of the time	0	4	16	3	0	23
Always	0	14	6	0	1	21
Total	3	20	25	6	2	56

With respect to the effects of daylight, 20 of the interviewees (35.7 percent) indicated that the amount of daylight did affect how they set the light switches. When asked how the amount of daylight affected how they set the light switches, interviewees gave the following responses:

- *If dark outside, then we need more light*
- *The windows are tinted - daylight makes very little difference*
- *By turning off lights by window*
- *Depends on outside weather*
- *On sunny days, I turn on only one light switch*
- *I don't get much daylight*

- *Really bright days, depending on activity*
- *Dark days; both switches on -- Bright days; one switch on*
- *Both used at night, or any cloudy dark day*
- *This is a Special Ed. Class- they are greatly affected by lighting*
- *On rainy days there is more need for light switch*
- *When it is cloudy or raining outside, I'll make sure that we have enough light*
- *Don't use during the day*

There were 12 of the interviewees (21.4 percent) who indicated that they used the lighting switches differently between summer and winter. Their explanations as to how the use of the lighting switches differed were as follows:

- *During the summer, we may use light switch in the afternoon sometimes*
- *Sometimes on bright days*
- *Depends on amount of daylight*
- *In winter we have more cloudy days*
- *More lights on during winter - less in spring/fall*
- *Dark days, both switches on. Bright days, one switch on*
- *No class in this room in summer - winter yes, we're here*
- *Not here in summer*
- *On rainy days there is more need for light switch*
- *Very little - keep lights off*

Just over a third of the interviewees (21, or 37.5 percent) indicated that their use of the lighting switches had changed in response to the electricity crisis in California over the past year. Their descriptions as to how their use of lighting had changed were as follows:

- *We save energy more*
- *I try to be more careful when the room is empty.*
- *Turn lights off when leave room*
- *I try to turn off lights when not in the room*
- *More aware of it [energy use]*
- *We turn the lights off when leaving the room for extended periods.*
- *I always turn off my light switches when I exit my room*
- *We turn lights off at end of day*
- *I always turn them off after class*
- *I use only one switch when weather permits.*
- *We make sure to turn them off when no one is in the room*

- *I always conserve as a way of life*
- *I try to use less lighting when possible*
- *Turning them off more often*
- *Turn them off when I leave the room (which is not too often)*
- *I make sure the lights are off when I leave the room*
- *Sometimes we use only one switch*
- *Occasionally one light*
- *Turning off the lights during lunch is something that I started doing to help out with the crisis*
- *Started using half lighting since the crisis*
- *We turn them off when we are not in the classroom*

6.2 PERCENTAGE OF TIME IN DIFFERENT CONTROL STATES FOR CLASSROOM SPACES

Monitoring of bi-level lighting use was conducted for 62 classroom spaces. The monitored data collected for classroom spaces were used to determine the percentage of time that bi-level switches were in four different states:

- Both switches off
- Only low wattage switch on
- Only high wattage switch on
- Both switches on

Figure 6-1 depicts how the percentage of time that bi-level switching is in the three "on" states for classroom space varies over a weekday. During the school hours, one or both of the switches are on between 65 to 75 percent of the time. Moreover, Figure 6-1 shows that either the high wattage switch only or the low wattage switch only are on for some percentages of the time. The low wattage switch is usually on for higher percentages of time than the high wattage switch.

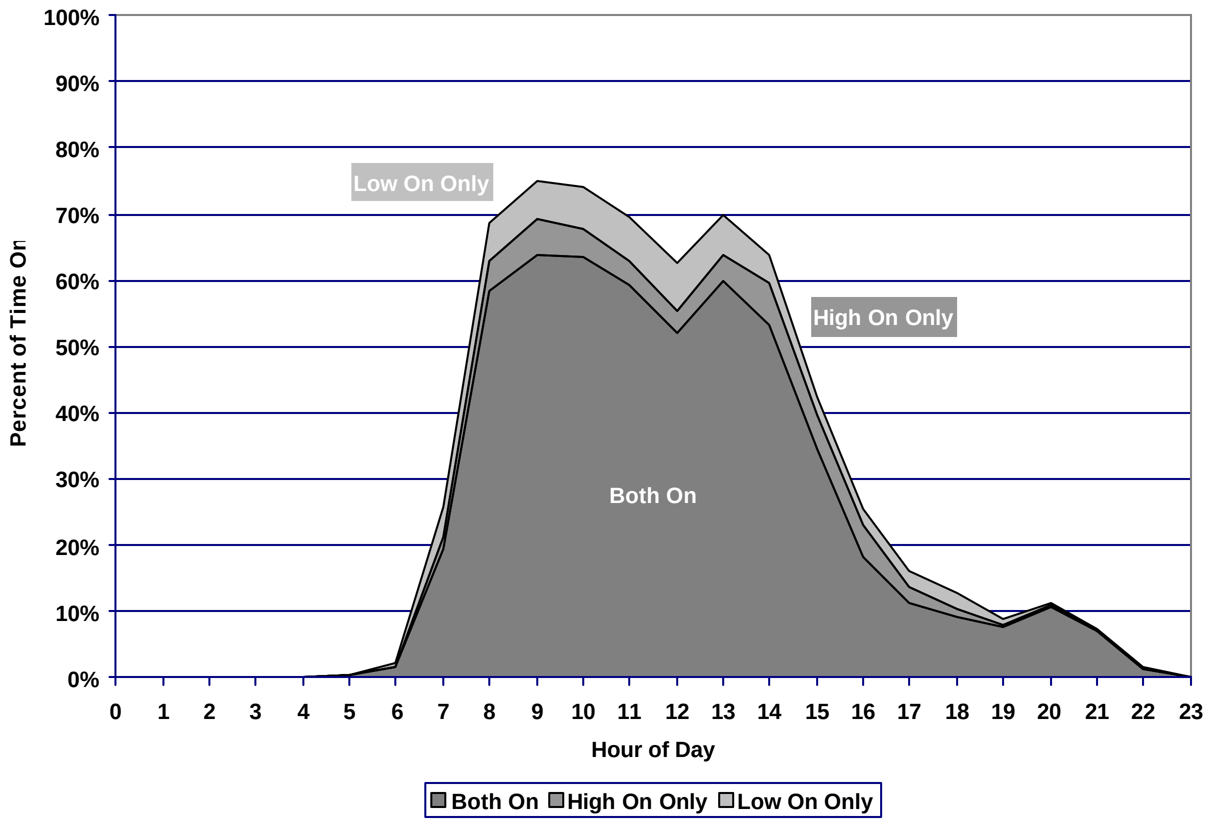

Figure 6-1. Percent of Time Bi-Level Switches in Classroom Spaces Are in Different States throughout a Weekday

6.3 LIGHTING USE PROFILE FOR CLASSROOM SPACES

Figure 6-2 shows the use profile estimated for weekday lighting in classrooms where there is bi-level switching. Lighting use is estimated in terms of Watts per square foot (where the square footage is for the classroom space only). The average connected lighting load for classroom space as estimated from the monitored data is 1.50 Watts per square foot (as depicted on Figure 6-2 by the horizontal line at that level).

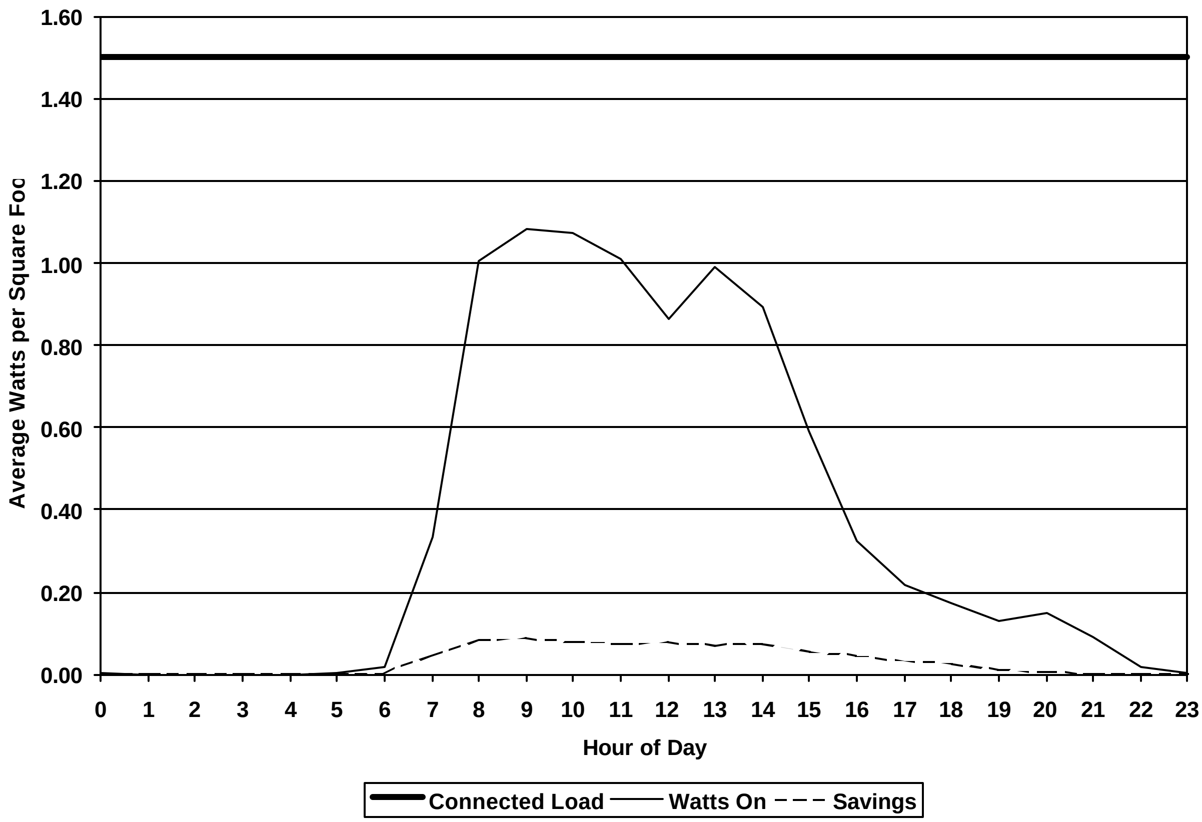

Figure 6-2. Weekday Lighting Use Profile for Classroom Areas with Bi-Level Switching

6.4 AGGREGATE SAVINGS FROM USING BI-LEVEL SWITCHING IN CLASSROOM SPACES

Savings from using bi-level switching in classrooms occur under two circumstances:

- When only the switch for the low wattage circuit is used, saving the wattage on the high wattage circuit; or
- When only the switch for the high wattage circuit is used, saving the wattage on the low wattage circuit.

Figure 6-2 compares the savings from bi-level switching to the average lighting use for classroom spaces during weekdays. Using these and similar data for weekends, estimates of aggregate annual savings from use of bi-level switching in classroom spaces for newly constructed school buildings were developed. These estimates are reported in Table 6-5. Taking weekdays and weekends together, the savings are about 9 percent. (Savings percentages are calculated against a base of usage plus savings.)

Table 6-5. Estimated Aggregate Annual kWh Savings from Use of Bi-Level Switching in Classroom Spaces

in Newly Constructed School Buildings
(Usage and Savings in million kWh)

Bi-Level Condition	***Estimated Annual Usage***	***Estimated Annual Savings***	***Annual Usage + Annual Savings***	***Percent Savings***
Both On	68,161	-	68,161	
High On Only	3,636	3,129	6,764	
Low On Only	3,500	3,708	7,208	
Total	75,297	6,837	82,134	8.3%

Table 6-5 shows that 90.5 percent of the estimated annual energy use for lighting in classroom areas occurs when both switches are on, with 4.8 percent occurring when only the high wattage switch is on and 4.6 percent when only the low wattage switch is on. With respect to savings, 45.8 percent occurs when only the high wattage switch is on and 54.2 percent occurs when only the low wattage switch is on.

6.5 EFFECTS OF DAYLIGHTING ON USE OF LIGHTING IN CLASSROOM AREAS

As noted in Section 6.1, about 36 percent of the occupants of classroom areas reported that the amount of daylight did affect how they set the light switches. To further examine the effects of daylight on the use of lighting in classroom areas, the surveyed spaces were divided into four groups, based on how much of the space was daylit. The four groups were defined as follows:

- Group 1 included spaces with no daylit areas.
- Group 2 included spaces where from 1 to 33 percent of the space was daylit.
- Group 3 included spaces where from 34 to 66 percent of the space was daylit.
- Group 4 included spaces where from 67 to 99 percent of the space was daylit.

There were no classroom spaces where all of the space was daylit.

Figure 6-3 shows the lighting use profiles for the four groups for an average weekday. Comparison of these profiles shows that the amount of daylight does affect lighting use in classrooms. However, the pattern differs from expectations. Most noticeable, Group 1, which has the lowest amount of daylight, has the lowest level of lighting use.

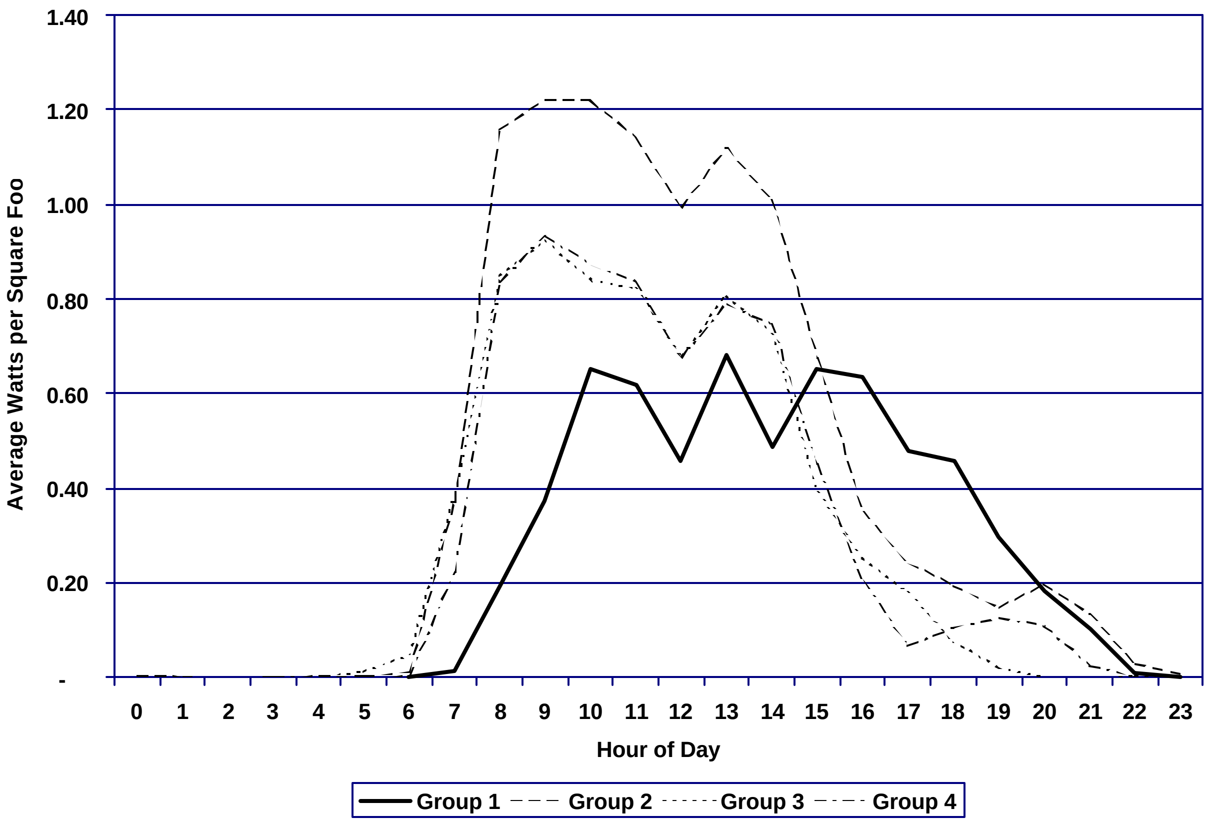

Figure 6-3. Comparison of Weekday Lighting Use Profiles for Classroom Spaces with Different Amounts of Daylight

6.6 OCCUPANCY PATTERNS AND LIGHTING USE IN CLASSROOM SPACES

To examine the effects of occupancy on lighting use for classroom spaces, data collected with the occupancy loggers were used to classify lighting data points as occurring under two states:

- When the space is not occupied; and
- When the space is occupied.

Lighting use profiles for classroom spaces that were developed for these two states are shown in Figure 6-4.

Lighting use profiles for classroom areas that were developed for the two occupancy states are shown in Figure 4-4. The figure shows the average Watts of electricity used for lighting per square foot on a weekday when the space is occupied and when the space is not occupied. As can be seen, electricity is used for lighting even when the space is not occupied; this represents electricity that might be saved. Based on these profiles and on estimates calculated for the percentages of time that space is occupied and not occupied, the lighting that is used when the space is not occupied represents about a fifth of the average daily use of electricity for lighting classroom space during a weekday.

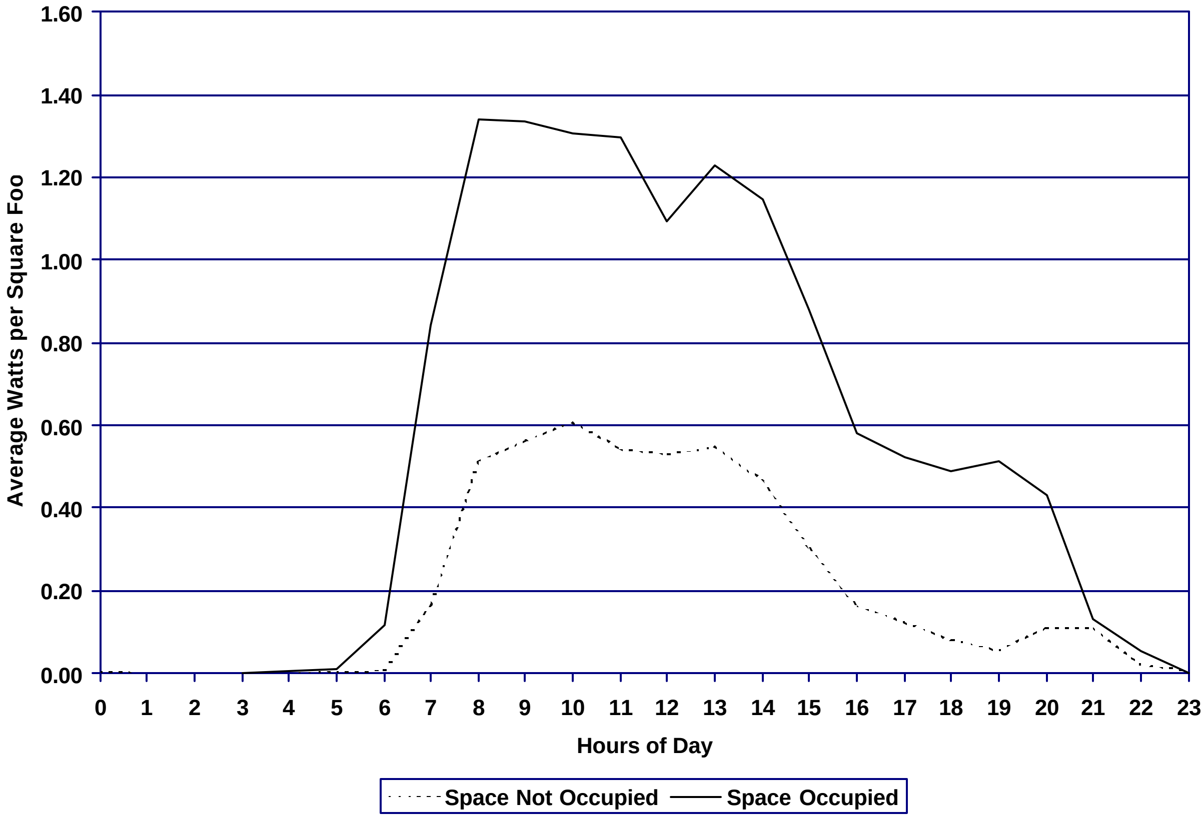

Figure 6-4. Lighting Use Profiles for Classroom Spaces When Space Is Occupied and When Space Is Not Occupied

7. COMPARISON OF SAVINGS FROM BI-LEVEL LIGHTING ACROSS TYPES OF SPACE AND TYPES OF BUILDINGS

One of the objectives of this study was to compare actual savings from bi-level switching to the assumptions of savings from other studies (e.g, for Title 24 and for utility programs). This chapter provides this comparison. The estimates of savings from bi-level lighting are compared across types of spaces (i.e., open office, private office, retail, and classroom) and across types of buildings (i.e., office buildings, retail buildings, schools). The savings from bi-level lighting estimated in this study are then compared to savings estimates developed in other studies.

7.1 COMPARISON OF SAVINGS FROM BI-LEVEL LIGHTING ACROSS TYPES OF SPACE

Table 7-1 brings together the estimates of aggregate savings from bi-level lighting for different types of spaces within buildings. The percentage savings range from 8.3 percent for classrooms to 21.6 percent for private office space. Open offices show savings from bi-level lighting of about 16 percent, while retail space shows savings of about 14.8 percent.

Table 7-1. Estimated Aggregate Annual Electric Savings from Use of Bi-Level Switching in Different Types of Spaces in Newly Constructed Buildings (Usage and Savings in million kWh)

Type of Space	***Estimated Annual Usage***	***Estimated Annual Savings***	***Annual Usage + Annual Savings***	***Percent Savings***
Open office	291,981	55,561	347,541	16.0%
Private office	97,486	26,817	124,303	21.6%
Retail	839,398	146,047	985,445	14.8%
Classroom	75,297	6,837	82,134	8.3%

7.2 COMPARISON OF SAVINGS FROM BI-LEVEL LIGHTING ACROSS TYPES OF BUILDINGS

Table 7-2 shows the estimates of aggregate savings from bi-level lighting according to type of building. These savings estimates essentially represent weighted averages of savings across the types of spaces that might be present in a given type of building.

- For office buildings, the types of spaces include open offices, private offices, and some retail.
- For retail stores, the types of spaces include retail space, open offices, and private offices.

- For schools, the types of space include classrooms, open offices, and private offices.

Table 7-2. Estimated Aggregate Annual kWh Savings from Use of Bi-Level Switching in Different Types of Newly Constructed Buildings (Usage and Savings in million kWh)

Type of Building	***Estimated Annual Usage***	***Estimated Annual Savings***	***Annual Usage + Annual Savings***	***Percent Savings***
Office	356,645	77,508	434,154	17.9%
Retail	856,135	149,777	1,005,911	14.9%
School	91,381	7,976	99,357	8.0%

As can be seen, the savings from bi-level lighting range from 8.0 percent for schools to just under 18 percent for office buildings, with retail stores showing savings of just under 15 percent.

7.3 SAVINGS FROM BI-LEVEL LIGHTING ESTIMATED IN OTHER STUDIES

There is limited research reported in the literature regarding the savings that can be realized from bi-level lighting. There are two studies that examined the effects of manual switching in office buildings.

One study that considered the effects of manual lighting was conducted by the Lighting Research Center (LRC).[3] In this study, LRC conducted a study of lighting controls at the Foothills Laboratory campus of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. The goal of the study was to evaluate the effectiveness and occupant acceptance of several lighting control technologies. The study began in December 1996 and spanned nine months. During the data collection period (December 1996 through March 1997), occupant tasks and window blind usage were observed and recorded hourly. A building automation system was used to record motion and current data for every five minutes. From a starting sample of 60 perimeter offices and 21 interior offices, LRC obtained data usable for analysis for 43 perimeter offices and 15 interior offices.

Using the data they collected, LRC analyzed the effects of different lighting controls on energy use. With respect to manual switching, LRC estimated that the use of such switching by office occupants reduced energy use by 9 percent (where the base energy use is for full-on lighting use for a ten-hour business day). This estimate is somewhat

[3] Morrow, W. et al., “High Performance Lighting Controls in Private Offices: A Field Study of User Behavior and Preference”, Paper prepared by Lighting Research Center for World Workplace, October 1998.

lower than the estimates developed in this study (i.e., 16.0 percent for open offices and 21.6 percent for private offices). However, the LRC study was directed at examining the effects of a variety of lighting controls (e.g., automatic dimming) other than manual switching. The behavior of office occupants with respect to manual lighting could have been affected by their exposure to other types of lighting control.

A second study that examined the effects of manual switching was conducted by Lawrence Berkeley National Laboratory (LBNL).[4] In their study, LBNL collected and analyzed data on the wall switch usage patterns for 30 private offices at the San Francisco Federal Building. All of the offices were perimeter offices with daylight available. Other than two manual wall switches, there were no other lighting controls in the offices. The occupants were not instructed in the use of the switches.

The purpose of LBNL's research was to determine whether the occupants of the offices used their bi-level wall switches effectively. LBNL collected ceiling lighting power data for each office at 15-min intervals. Data collected over seven months (June 1998 - December 1998) were analyzed to determine occupant behavior with respect to manual switching. Using the data collected, LBNL estimated that there were 6.9 hours per day of "full-equivalent" lighting because lighting for a significant fraction of the total lighting hours was at reduced levels. Compared to a mean of 9.1 hours per day for lighting hours, this represented energy savings of 24 percent. This is similar to the savings estimated in this study for office spaces (i.e., 16.0 percent for open offices and 21.6 percent for private offices).

Although the literature on the effects of manual switching on lighting use is sparse, the two studies cited provide estimates of energy savings for manual switching in offices that bracket the estimates developed in this study. There are no similar studies that provide estimates of the effects of manual switching on energy use in retail or classroom space. However, the *Advanced Lighting Guidelines: 2001 Edition*[5] provides an estimate of 15 percent as the savings from multilevel switching in classrooms and of 10 percent as the savings in "big box" retail. The AGL estimate for classrooms is higher than the estimate developed in this study (i.e., 15 percent from ALG *versus* 8.3 percent from this study). For retail, the AGL estimate is lower (i.e., 10 percent from ALG *versus* 15 percent from this study).

[4] Lawrence Berkeley National Laboratory, "The Usefulness of Bi-Level Switching," LBNL Technical Note LBNL-44281, August 1999.

[5] New Buildings Institure, *Advanced Lighting Guidelines: 2001 Edition*, 2001, p. 8-12.

8. FINDINGS AND CONCLUSIONS

The study reported here has been one of the few field studies to collect and analyze data on how bi-level switching is used in different types of spaces and on how that use affects lighting energy consumption. The specific objectives for the project were as follows:

- To measure actual operation of typical manual lighting controls as influenced by occupant behavior;
- To estimate demand and energy savings of manual switching;
- To identify occupant behaviors that reduce savings potential; and
- To compare actual savings to assumptions of savings from Title 24 and from utility programs.

To achieve these objectives, measured data on lighting use were collected and analyzed for several types of spaces where bi-level switching is commonly used: open offices, private offices, retail spaces, and classrooms. Samples of these spaces were selected from among office buildings, retail stores, and classrooms. Major findings from the analysis of the data collected are summarized here.

For the four types of spaces studied (i.e., open offices, private offices, retail spaces, and classrooms), bi-level switching in which only one or the other switch was on occurred for some percentage of the time. The percentage on time depended on type of space and hour of day. For example, Table 8-1 shows the percentage of the time that one or the other bi-level switch was on for different types of spaces at 3:00 p.m. on weekdays.

Table 8-1. Percentage Breakdown across Bi-Level Switching Conditions for Different Space Types at 3 PM on Weekdays (Rows total to 100% except for rounding)

Type of Space	Both Switches Off	Both Switches On	High Wattage Switch Only On	Low Wattage Switch Only On
Open office	10.4%	65.8%	14.9%	8.9%
Private office	30.3%	47.9%	14.5%	7.3%
Retail	4.1%	78.9%	12.0%	5.0%
Classroom	57.6%	34.4%	5.3%	2.8%

The monitoring data were used to develop profiles showing average use of lighting at different hours of the day for the different types of spaces. Average energy (kWh) savings at each hour were also calculated and used in preparing estimates of annual energy savings from bi-level switching, aggregated across hours in the year and buildings for a given type of space. Savings from using bi-level switching were defined to occur under two conditions:

- When only the switch for the low wattage circuit is used, saving the wattage on the high wattage circuit; or
- When only the switch for the high wattage circuit is used, saving the wattage on the low wattage circuit.

Figure 8-1 summarizes the percentage energy savings estimated for different types of space.[6] The highest savings (in percentage terms) are for private office space, followed in order by open offices, retail space, and classrooms.

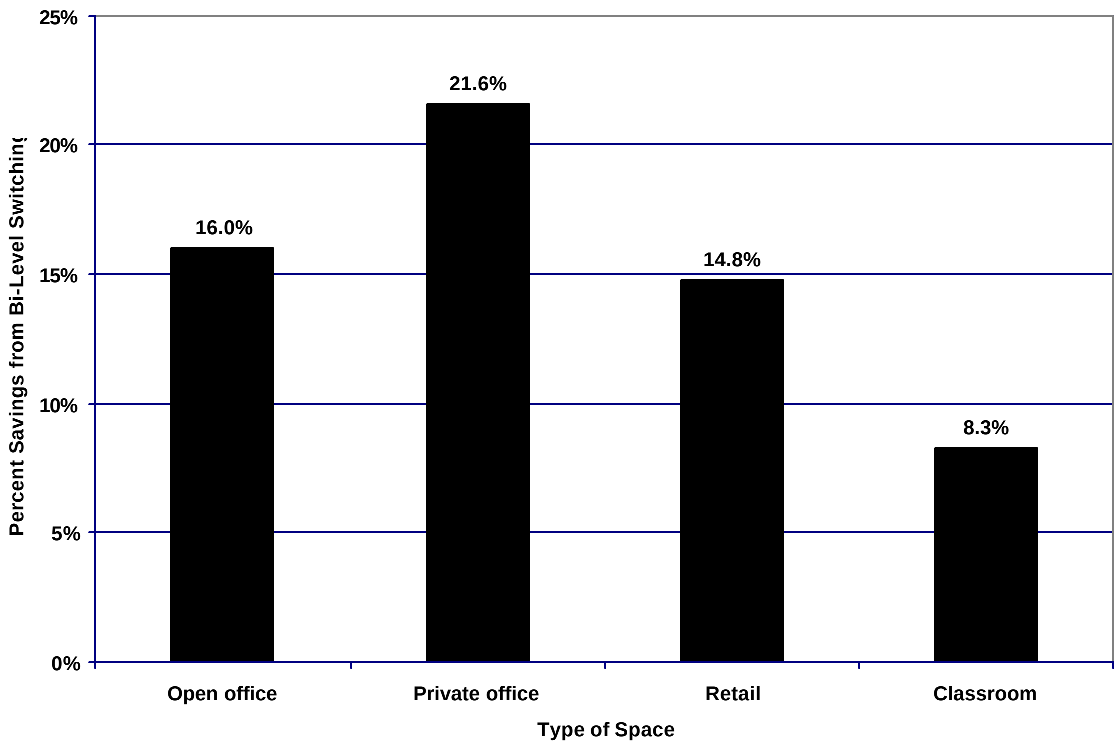

Figure 8-1. Percentage Energy (kWh) Savings from Bi-Level Switching for Different Types of Space

The effects that different amounts of daylight have on lighting use in spaces with manual bi-level switching was also examined. The results differed across space types.

- For open office spaces, the analysis showed that the amount of daylight does affect lighting use. Open office areas with more daylight use less electricity for lighting.

[6] Percentage savings are calculated as savings/(use + savings) for a given type space. See Table 7-1.

- For private offices, the analysis did not show that higher amounts of daylight affects lighting use in such spaces. Private office areas with less daylight showed less lighting use than did private office areas with more daylight.
- For retail spaces, the analysis showed that the amount of daylight does affect lighting use. Most noticeable, the retail spaces with 100 percent daylight use lighting relatively less during the daytime hours than do the retail spaces with lower amounts of daylight.
- For classrooms, the analysis showed that the amount of daylight does affect lighting. However, the results of the analysis differed from expectations. Most noticeable, classrooms with the lowest amount of daylight also had the lowest level of lighting use.

The unexpected correlation between more electric lighting use and more daylight may be accounted for by the need, in one-sided daylighting applications, to balance light levels across the space, resulting in higher electric lighting on the side away from the bright daylit area.

The effects of occupant behavior on the potential for savings from bi-level switching were examined in two areas.

A first area was with respect to the effects of occupancy on lighting use in areas with bi-level switching. These effects were examined for private office spaces and for classrooms, the types of spaces where occupancy is more variable throughout a day. For both types of spaces, the analysis showed that lighting use was considerably lower for any hour of the day if the space were not occupied. However, because electricity was still being used for lighting when the space was not occupied, there is some potential for reducing this use. Electricity used for lighting space that is not occupied represented about a quarter of the electricity used to light private office space during a weekday. For classroom areas, electricity used for lighting space that is not occupied represented about a fifth of the electricity used for lighting during a weekday. Thus, that space is still lighted when unoccupied is one example of occupant behavior that affects savings potential.

Another example is the difference across space types with respect to the percentage of electricity use for lighting that occurs when both switches are on *versus* the percentage that occurs when only the high wattage switch or the low wattage switch is on. Figure 8-2 compares the different space types with respect to the percentage breakdown of annual electricity use for lighting across bi-level switching conditions. As can be seen, there are differences across space types in the degree to which bi-level switching is used. In particular, about 32 percent of the electricity used for lighting for private offices occurs when only one switch (either high wattage or low wattage) is on. By contrast, only 9.4 percent of the electricity use for classrooms occurs when only one switch is on. This would suggest that there may be factors for classrooms that constrain the use of bi-level switching.

Finally, other studies of the effects of manual switching on lighting use against which the results of this study could be compared are small in number. There were two other studies that provided estimates of energy savings for manual switching in offices; those estimates bracketed the estimates developed in this study. The estimates of the savings from manual switching in retail or classroom space developed in this study are somewhat different than those set out in *Advanced Lighting Guidelines: 2001 Edition*. In particular, this study's estimate of savings is higher for retail than the ALG's, but is lower for classrooms.

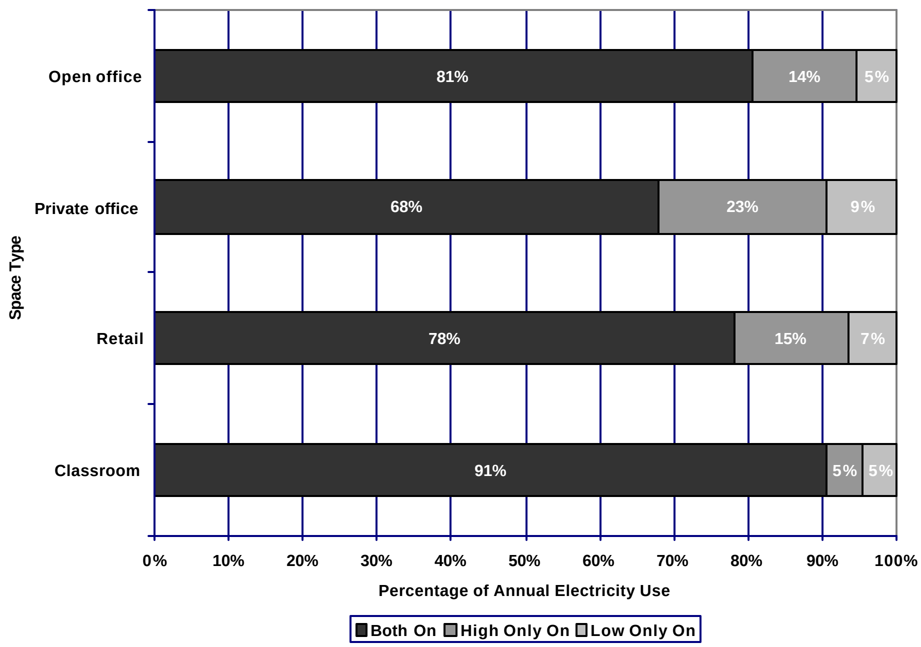

Figure 8-2. Percentage Distribution of Annual Electricity Use for Lighting by Bi-Level Switching Condition for Different Space Types

This study demonstrates that the manual bi-level switching control strategy has indeed resulted in energy savings. Although there are limitations to the use of only one switch, the availability of bi-level switching provides an inexpensive mechanism for occupants to achieve voluntary peak-load reductions in their buildings. From this study, we conclude that the Title 24 bi-level switching requirement is justified. There is the potential for greater energy savings, if building occupants could be better educated about the benefits and savings from bi-level switch operation.

APPENDIX A: METHODOLOGY

This appendix describes the methodology used to conduct the study of bi-level lighting.

A.1 SAMPLE DESIGN

Initial specifications for the sampling design included the following:

- The total sample for the data collection was to be 75 occupied nonresidential buildings that have been built since 1992.
- The types of buildings at which data were to be collected include office buildings, schools, public assembly, and retail.
- Within a building, different types of spaces were to be monitored, including private offices, open offices, conference rooms, classrooms, retail sales areas, and storage/stock rooms. The actual number of spaces surveyed might vary across buildings.
- On-site data collection was to be concentrated in two major regions: northern California (e.g., San Francisco Bay area, Sacramento) and southern California (e.g., Los Angeles, San Diego).

Subsequent discussion during the kick-off meeting modified or added to these specifications.

- Because monitoring of task lighting is now included in the project, the sampling plan was expanded to include the monitoring of task lighting at 30 sites. However, these sites could overlap with the sites monitored for bi-level switching.
- The types of buildings for which data were to be collected was narrowed to include office buildings, retail stores, and schools.

A.1.1. Sampling Frame

Developing the sampling plan required a sampling frame that contained information on the nonresidential facilities that were candidates for the monitoring. The amount of information that was available in the database that was used to develop the frame determined the degree to which stratification and other sampling features could be incorporated into the sampling design.

Several existing databases that contain information on new and/or remodeled nonresidential buildings were reviewed as to their potential as sampling frames for this study.

- The California Statewide NRNC database is a collection of buildings statistically selected to represent the majority of statewide NRNC activity. Most of the data in this database come from on-site surveys conducted by RLW Analytics during impact evaluation studies of the SCE and PG&E 1994 and 1996 NRNC energy efficiency programs. These data were supplemented with thirty audits from the impact evaluation of the 1995 SDG&E NRNC program and some additional on-site surveys. Participants in utility energy-efficiency programs are included, but are weighted according to their general representation in the population. The population was defined using a listing of new construction projects obtained from F. W. Dodge. The data include renovations and expansions as well as entirely new buildings. There are 990 sites in the complete database.

- As part of the Nonresidential Remodeling and Renovation study conducted for the CEC, ADM had developed a database of information for a sample of 300 nonresidential buildings that underwent remodeling or renovation during 2000.

Together, these two databases provided a list of new or remodeled nonresidential buildings that could be used to prepare the sampling frame from which to develop the sampling design for this study. There were several advantages to using these databases as the sampling frames.

- First, the databases represent samples already drawn from the overall population of new and recently remodeled/renovated nonresidential buildings. Accordingly, there were pre-existing weights whereby information developed for buildings sampled for this study could be expanded back to represent the population of new and/or remodeled nonresidential buildings.
- Second, as noted above, the databases contain information identifying the space types within each building.

Upon inspection of the two data bases, it was determined that the level of detail available in the NRNC database considerably exceeded that in the remodeling/renovation database. Merging the two databases to create one sampling frame would create considerable disparity between sites in the frame. Accordingly, the NRNC database was chosen as the main vehicle for preparing the sampling frame. It had more sites for the building types of interest and more detailed information regarding those sites.

Because space type was to be used as the basis for the analysis in this study, it was desirable to represent each major space type in the sample for the data collection. It was thought that having functional areas identified for the buildings in the NRNC database that was used as the sampling frame would allow development of a sampling design that explicitly took functional areas into account in determining the number of buildings to monitor. As part of the NRNC data collection, information was collected on building functional areas (i.e., space types**.** Functional areas were defined on the basis of operating schedules, with information on occupancy, lighting, and equipment schedules collected for each defined functional area.

However, review of the NRNC data showed the following breakdowns for functional areas within given building types:

- Within office buildings, 86 percent of the functional space was shown as being office space.
- With retail stores, 80 percent of the functional space was shown as being retail space.
- With schools, 68 percent of the functional space was shown as being classrooms.

Thus, relatively few functional areas accounted for most of the space in the types of buildings that are of interest for this study. Stratifying by functional space type within a given type of building would not add much information.

In summary, the NRNC database was chosen as the main vehicle for preparing the sampling frame because it had more sites for the building types of interest and more detailed information regarding those sites. However, the information on functional space types in the NRNC database indicated that stratifying by functional space type within building types was not necessary.

A.1.2 Sample Size and Allocation

For the study of bi-level switching, the total sample size was determined initially to be 75 sites to allow for examination of manual switching. With the added study of task lighting, monitoring of task lighting was expected to be conducted at 30 sites, but with 20 of these sites being sites where bi-level switching was also being studied. Based on this, an additional 10 sites needed to be added to the overall study to be able to meet the desired ends. Thus, for sampling design purposes a total sample of 85 sites was used.

Given the total sample size of 85, the next question to be resolved was how to allocate these sample points across the three building types (i.e., offices, retail stores, schools) that were to be studied. From sampling theory, it is known that sample points should be allocated according to (1) the size of each building type's population and (2) the variability of the factor that is to be measured within each population. Allocating in proportion to size is important so that building types or areas that have relatively little importance in determining overall electricity use for lighting do not have larger sample sizes than areas that are much more important (e.g., office space type).

Table A-1, which is reproduced from the final report on the NRNC Baseline Study, shows the relative importance of different building types in new construction during the period of the 1990's covered by the baseline study. On the three different measures (i.e., number, floor space, and electricity use), offices are relatively most important, followed by retail and then schools.

Table A-1. Characteristics of Population of Newly Constructed Nonresidential Buildings per NRNC Baseline Study

	Office	**Public Assembly**	**Retail**	**School**	**Total**
Number in Population	6,259	1,567	3,690	2,179	13,697
Percentage of Total Population	46%	11%	27%	16%	
Total Floor Area (SF, in thousands)	184,192	27,422	132,543	54,889	399,046
Percentage of Total Floor Area	46%	7%	33%	14%	
Total Energy (mWh)	2,847,697	401,301	2,562,884	483,131	6,259,012
Percentage of Total Energy	45%	6%	41%	8%	

As noted above, another consideration in allocating sample points was the variability of the factor of interest within each population. A population that shows relatively more variability should be allocated relatively more sample points.

ADM had collected data on hours of lighting use by space type as part of the measurement and verification work we have performed for several participants in PG&E's PowerSaving Partners Program. These data, which are summarized in Table A-2, showed that the variability for hours of lighting use differs among usage areas. Using the coefficient of variation as the measure of variability, it can be seen that classrooms show relatively more variability than office space or retail space.

Table A-2. Lighting Hours-On Percentages for Different Usage Areas (Based on Data for Peak Hours from 2 PM to 6 PM for Specific Circuits)

Space Type	**Number of Buildings**	**Average % On Time during Peak Hours**	**Standard Deviation**	**Coefficient of Variation**
Break Room	23	73.6%	24.1%	0.327
Classroom	5	46.5%	27.3%	0.587
Computer	10	72.4%	20.8%	0.287
Conference	20	60.2%	23.5%	0.390
Office	38	54.6%	26.2%	0.479
Restroom	30	61.7%	28.4%	0.461
Retail	8	82.5%	29.8%	0.361
Sales Floor	8	100.0%	0.0%	-
Storage	40	43.3%	23.6%	0.544
Wait HOSP	6	87.5%	11.9%	0.136
Wait MOB	15	88.3%	16.6%	0.188
Warehouse	12	88.0%	21.7%	0.247

Based on this review of the two factors affecting sample allocations, it was determined to allocate the total sample of 85 sites to building types as follows:

- Office buildings 40 sites (30 for bi-level and 10 for task)
- Retail stores 20 sites
- Schools 25 sites

A.1.3 Proposed Sample of Sites

Based on the preceding considerations, a proposed sample of sites for the monitoring was selected using the data from the NRNC database. The proposed sample was selected through the following steps.

Buildings were first stratified by type, using the Title 24 building type variable in the NRNC database. Because some sites in the NRNC database had also been selected for a subsequent lighting quality survey, these sites were eliminated as candidates for the monitoring of manual lighting so as not to overburden them. The resulting numbers of buildings for the three building types of interest are shown in Table A-3.

Table A-3. Determining Number of Candidate Sites by Building Type

Building Type	***In NRNC Database***	***In Lighting Quality Survey***	***Candidates for Manual Lighting Monitoring***
Office buildings	220	18	202
Retail stores	162	17	145
Schools	169	17	152

The candidate sets of sites (i.e., Column 4 of Table A-3) were screened to identify those falling into two main regions: Northern California and Southern California. These regions were defined by CEC climate zones as follows:

- Northern California: climate zones 3, 4, 11, and 12
- Southern California: climate zones 6, 7. 8, 9, and 10

This produced the distribution of candidate sites by region for each building type as shown in Table A-4. These sites formed the pool from which the sample of sites to monitor was selected.

Table A-4. Distribution of Candidate Sites by Building Type and Region

Regions	***Building Types***		
	Office Buildings	***Retail Stores***	***Schools***
Northern California	71	41	27
Southern California	66	44	37
Totals	137	85	64

For each building in the sample pool, information in the NRNC database on floor area and window area was used to calculate the ratio of window area to floor area. This variable was used to proxy for the possible effects of daylight on control patterns for bi-level light switching. Within each building type, buildings were sorted by region and by the value of the window area/floor area ratio. A sample of sites was then selected through systematic random sampling. With this sampling, the resulting sample for each building type was spread over the range of values for the window area/floor area ratio.

Summary statistics are presented in Table A-5 that compare the selected sites to the overall set of sites for each building type for several variables.

Table A-5. Summary Statistics for Sites Selected for Sample

Region/Sample Status	***Number of Sites***	***Average Floor Area (Square Feet)***	***Average Ratio of Window Area to Floor Area***	***Average Lighting Power Density***
Office Buildings				
SF Bay area candidate sites	57	61,659	0.0949	1.1313
SF Bay area sample sites	17	102,955	0.0824	1.0644
Sacramento Valley candidate sites	14	30,026	0.1137	1.0711
Sacramento Valley sample sites	4	76,431	0.0838	1.1617
Greater LA candidate sites	48	52,371	0.1252	1.3850
Greater LA sample sites	14	55,344	0.0897	1.1388
San Diego candidate sites	18	61,916		
San Diego sample sites	5	74,972		
Retail Stores				
SF Bay area candidate sites	28	59,718	0.1089	1.7122
SF Bay area sample sites	7	49,790	0.0534	1.7400
Sacramento Valley candidate sites	13	56,301	0.0445	1.5235
Sacramento Valley sample sites	3	30,514	0.0401	1.3808
Greater LA candidate sites	31	88,967	0.0228	1.5369
Greater LA sample sites	7	104,292	0.0080	1.4332
San Diego candidate sites	13	38,159		
San Diego sample sites	3	50,051		
Schools				
SF Bay area candidate sites	14	25,145	0.0543	1.2571
SF Bay area sample sites	5	19,709	0.0325	0.9597
Sacramento Valley candidate sites	13	21,680	0.0692	1.3474
Sacramento Valley sample sites	5	29,017	0.0444	0.9761
Greater LA candidate sites	30	45,962	0.0836	1.2955
Greater LA sample sites	12	33,149	0.0674	1.3651
San Diego candidate sites	13	38,159		
San Diego sample sites	3	50,051		

A.1.4 Realized Set of Sites

The number of buildings of different types where monitoring was performed and the numbers of spaces monitored within those buildings are summarized in Table A-6. Monitoring of bi-level switching was conducted at 79 buildings, within a total of 256 spaces being monitored.

Table A-6. Number of Sites Sampled and Spaces Monitored

Type of Building	Number of Sites Monitored	Number of Space Types Monitored			
		Classroom	Open Office	Private Office	Retail
Office	33	0	50	69	2
Retail	23	0	4	2	37
School	23	62	13	17	0
Totals	79	62	67	88	39

A.2 PROTOCOL FOR RECRUITING SITES

A protocol for recruiting buildings to participate in the study. A copy of this recruitment protocol is provided in Appendix B.

The recruitment protocol had several components. To begin with, the sample sites were screened to identify those with occupancy sensors and possible task lighting. Because the sample sites had been selected from the NRNC database, fairly detailed information was available on the types of lighting in different areas of the selected sites. These data were reviewed to determine the prevalence and location of occupancy sensors, dimming controls, and other lighting controls at the sample sites.

The NRNC database also includes the name of a contact person for each site. An introductory letter was sent to the contact person for each facility selected for the sample. This letter explained the purpose of the study and indicated that they would be contacted by telephone to arrange their participation in the study.

After the letters had been sent, telephone calls were begun to the contact persons to recruit their buildings to participate in the survey. Recruitment and scheduling of visits was handled by an ADM staff member who has considerable experience in this area. These customer contacts were handled according to a screening and recruitment script that we prepare. An example of this recruiting script is provided in Appendix B.

- The first part of the script was used to confirm that the buildings contacted are suitable for the study. That is, because of the detailed information on lighting that is contained in the NRNC database for each building, there was good information as to whether the building has had various types of lighting controls installed. The screening was used mainly to confirm the information on the type and location of the building in the NRNC database and to determine whether daylighting controls, occupancy sensors, or task lighting beyond that specified in the NRNC database had been added to the building.
  - For buildings that passed the screening questions, the recruiter proceeded in recruiting the building for the study. He/she explained the purposes of the study, indicated the types of data that would be collected, and described the amount of time for the on-site visits during which the monitoring equipment would be

installed and then removed. This script also provided the scheduler with appropriate responses to questions that customers might ask.

As an inducement for building owners/operators to participate in the study, they were offered a report that characterizes how lighting is being used in the spaces in their building that were monitored. This report provides summary profiles for lighting for the monitored spaces.

If a building owner/operator agreed to participate in the study, our scheduler arranged a mutually acceptable time for installing the monitoring equipment, based on the convenience of the owner/operator and on the travel schedule of the field staff. As the dates for installations were scheduled, they were entered into a timetable. Particulars were also entered into a tracking database, including the names of the buildings to be surveyed and their locations, the contact persons at the buildings and their telephone numbers, and the dates and times planned for the visits. This information was used to administer and manage the data collection effort. Complete and accurate records of all attempts to contact a building's owner/operator and of the final disposition of the attempts to schedule a visit were kept in a status file on this tracking and reporting system.

A.3 APPROACH TO MONITORING BI-LEVEL LIGHTING

Title 24 identifies bi-level switching as a mandatory lighting design measure and most areas in buildings must be controlled so that the connected lighting load may be reduced by at least 50 percent. Bi-level switching may be achieved by last point of control switching for lighting at either fixtures or lamps within fixtures or by the use of dimming controls.

There are some exceptions to the mandatory bi-level switching controls for the buildings that were to be studied:

- Where an area has only one light source (luminaire);
- Where an area is less than 100 square feet;
- Where the lighting power density (LPD) is less than 1.0 Watt per square foot;
- Where an occupancy sensor controls the areas;
- Where the area is a corridor; or
- Where an automatic time switch control device with a timed manual override switch independently controls each area that requires an individual switch.

Upon arrival at a site, the first step in the monitoring procedure was to determine how many areas that meet the Title 24 requirements for bi-level switching for a given space type were in the building. Areas <u>excluded</u> from selection were areas with:

- Occupancy sensors,

- Photocell controls,
- Dimming controls,
- Task lighting, or
- Unoccupied areas.

Spaces identified as falling under these exceptions were excluded from consideration for monitoring of bi-level switching.

Within each site selected for the monitoring, some types of space had lighting from both switches monitored, while other spaces had both lighting and occupancy monitored.

- Lighting was monitored in order to develop profiles of on/off switching and electricity use.
- Occupancy was monitored for some spaces that people may exit for significant periods of time (e.g., private offices). The occupancy data were to be used in analyzing whether lighting remains on when a space is not occupied. Occupancy was not monitored for some of the space types (i.e., open offices, retail sales areas, and warehouse space) because these spaces have continuous movement of people in and out of the space.

A.3.1 Selecting Spaces to be Monitored within a Site

The types of monitoring that were used for different types of space are shown in Table A-7.

Table A-7. Monitoring by Space Type for Various Building Types

Space Type	Building Type		
	Office	Schools	Retail
Private Office	Lighting & Occupancy	Lighting & Occupancy	Lighting & Occupancy
Open Office, daylit area	Lighting Only		
Open Office, non-daylit area	Lighting Only		
Classrooms		Lighting & Occupancy	
Retail Sales Area			Lighting Only
Warehouse			Lighting Only

After the space types for a building selected for the sample had been identified, there could be more than one room or area within that space type. Accordingly, the room or area within each space type to be surveyed was selected randomly using the information on functional areas. Different rooms within a building were assigned to one of the designated space types. A random drawing was then made from the listed areas of a given space type to select the one to be monitored for that space type for that building. Probabilities-proportional-to-size (PPS) sampling was used for this sampling, with floor area or connected lighting load used as the measure of size. The PPS sampling gave larger areas within a space type for a building higher probabilities of selection.

A random selection of the remaining areas within the building was made while on site. Up to four areas in each building were be selected and identified by the field staff for monitoring.

- Spaces were selected that could considered to be operating under business-as-usual conditions. That is, spaces were selected that did not have any special conditions that would make them non-representative (e.g., vacant offices, spaces affected by remodeling or renovation activities).
- Consideration was given to physical monitoring constraints or occupant objections in making the final selection.

A.3.2 Inspection of Lighting System

Because the sample sites had been selected from sites in the NRNC database, there was already information available for the sites regarding installed lighting throughout the building. However, while on-site the field staff collected data needed to characterize the lighting for the spaces being monitored. These data were collected through (1) interviews with facility staff, (2) review of building plans, and (3) field staff inspection. The field staff used the data collection/interview forms provided in Appendix B for this purpose.

A knowledgeable contact person was interviewed to obtain information about the control strategies and operating practices for the lighting systems being monitored. The interview was also used to uncover any operational difficulties that the facility may be experiencing with the lighting system. The field personnel recorded both quantitative information (e.g., operating schedules) and qualitative information (e.g., occupant tasks that influence the choice of lighting control strategies) from the interview.

The field staff also performed an inspection of the lighting system. During this inspection, the field staff fill out an inventory sheet for each area being monitored. Recorded on the inventory sheets were the following:

- Original lighting conditions and floor space of each area being monitored;
- quantity and condition of each type of fixture;
- total number of bulbs and ballasts, by type, for each circuit;
- connected load for each circuit, including ballasts and bulbs;
- control or wiring strategy; and
- current condition of the fixtures, such as the percentage of burned-out or disabled lamps.

The data collected during the pre-installation lighting survey were entered into a computerized database, using an *Access*™ data entry program. After the data had been entered into the database, they were verified using both automated and manual checks. These checks were applied to insure good data quality and to minimize the errors attributable to mis-coding, mis-judgments, or incorrect responses. Exception reports were generated at each stage of the error-checking process.

A.3.3 Equipment for Monitoring Bi-Level Lighting

For the monitoring of bi-level lighting controls, two types of monitoring equipment were used.

- Lighting status was monitored using Pacific Science & Technology TOU-L loggers.
- Occupancy was monitored using a combination of IntellTimer Pro Loggers (models IT-100 and IT-200) and Radio Shack Personal Alarms modified for use with Onset Computer's Hobo External loggers.

Table A-8 shows the sources for the different types of equipment that were used for the monitoring of bi-level switching.

Table A-8. Types and Sources of Equipment for Monitoring Bi-level Switching

Equipment	***Quantity***	***Source***
PST TOU-L	96	SCE
PST TOU-L	104	ADM
IT-100	5	PEC
IT-200	5	PEC
RS PA	10	PEC

RS PA	50	ADM

All equipment was tested prior to initial deployment, and batteries were replaced as necessary.

A.4 QUESTIONNAIRES ON LIGHTING EQUIPMENT AND OPERATION

On-site survey instruments were developed that could be used by the field staff in collecting data on lighting system characteristics and operation (with special attention paid to circuit switching).

The on-site survey instrument for monitoring of bi-level switching had two major parts.

- A first part provided a form for entering information about the characteristics of the lighting equipment/system found in the spaces to be monitored.
- A second part pertained to the interview of occupants to collect information regarding who primarily controls the operation of lighting in each space type and how they manually operate the lighting system using bi-level switches.

Draft versions of the data collection instruments are provided in Appendix B.

A.5 PREPARATION OF STUDY DATABASE

All of the data collected or developed during the study were entered into computerized databases. These data included the building and lighting equipment characteristics data collected during the site visits and the results of the building-specific data logging.

To ensure that the data are accessible and transferable, full and complete documentation on the data base was prepared, including its contents and formats. This documentation includes the following:

- Sample disposition report;
- Copies of all sample contact logs, indicating the results of each attempt to collect data;
- Original hard copies of survey instruments;
- *Access* database;
- Codebook for database; and
- Data dictionary listing all variables contained in the database. The dictionary will provide a clear description of every database and variable and show a clear correspondence between the variable and any instruments.

A.6 DATA ANALYSIS PROCEDURES

There were four objectives for the data analysis:

- To measure actual operation of typical lighting controls as influenced by occupant behavior;
- To estimate demand and energy savings of manual switching;
- To identify occupant behavior that reduce savings potential; and
- To compare actual savings to assumptions of savings from Title 24 and from utility programs.

A.6.1 Verify Data

Before beginning the analysis of the monitored data, a number of checks of the data were made. This verification effort included automated as well as manual checks. These checks were applied to ensure good data quality and to minimize the errors attributable to mis-coding, mis-judgments, or incorrect responses.

Additional checks were made of the logger data.

- Logger data were checked for evidence of "flickering". If the lamps in a fixture on a circuit being monitored flickered during the monitoring period, there might be a large number of cycles with very short duration in the logger data. Any transition less than 5 minutes was taken as an indicator that the lamps were flickering and that such episodes could be ignored in the analysis.
- There might also be episodes in the logger data that reflect "box time", which refers to the time a logger spends in a box as opposed to monitoring a fixture. There are two kinds of "box time": before a logger starts logging and after the logger is removed. The first type is the period between logger initialization and logger installation. Once a logger is initialized, it records "Light Off" until the sensor is properly installed. The second type is the period between logger removal and data downloading. The logger records "Off" when the logger is waiting for data to be downloaded.

A.6.2 Prepare Weights for Sampled Buildings/Spaces

Weights were prepared for the sampled buildings and spaces to be able to develop statistical estimates representing the population of newly constructed buildings. For each space type monitored in a building, a weight was calculated that is comprised of three components

The first component of the weight for a space was the weight assigned to the building in which the space is located. Most of the buildings chosen for the monitoring were selected from the NRNC Baseline database; these buildings have already been assigned this component of the weight. However, some buildings represented substitutions (i.e., another building at the same site that had the required types of lighting was substituted for an originally selected building that was discovered to not have the required types of lighting). For such buildings, an appropriate weight was calculated based on the site probability of selection.

The second component of the weight was based on the percentage of total floor space in the building that was accounted for by the particular space type, while the third component was based on the percentage of floor space for the space type that is accounted for by the floor space of that type that has been monitored. The data for these two components were obtained during the installation of the monitoring equipment.

The building/space weights can be used to extrapolate savings estimates for the monitored space types to represent the savings achieved for the population of newly constructed buildings.

A.6.3 Analyze Data for Bi-Level Switching

After the logger data had been verified, they were used in the data analysis to produce the following:

- Lighting and occupancy profiles;
- Manual switching characteristics; and
- Estimates of demand and energy savings (by space type) attributable to specific lighting controls, lighting switching, and other occupant behavior.

The procedure to produce these analytical results had the following major steps:

- An hourly lighting load for each circuit was developed first, using the monitored data. This load profile shows the lighting profile per actual operation of the switches.
- With bi-level switching, there are four discrete lighting levels for a space: both switches off, switch one on/switch two off, switch one off/switch two on, and both switches on. The measured data from the loggers for each of the monitored spaces was used to compute the percentage of time that the occupants set their lights to these different levels.
- Data for each circuit were aggregated to develop the lighting loads and savings for each selected area.
- Weights developed for each selected area were applied to develop the typical lighting loads and savings for each building. The building weights were also applied to extrapolate the load and savings estimates to the full population of newly constructed office, retail, or school buildings, as appropriate.

Information from the site interview were used to determine any behavioral differences between summer and winter bi-level switch operation. That is, the occupant(s) of the space were asked in the interview whether or not they change the operation of the switches depending on the season of the year and, if so, how. Adjustments did not need to be made for those occupants indicating no differences between seasons in their operation of the switches. For those who did indicate changing switch operation, the information they provided in the interview was used to determine whether the hours of operation for the switching needed to be adjusted.

The monitoring data from the loggers also provided quantitative data pertaining to the effects of daylight and of occupancy patterns. To supplement the analysis of these data, information was also collected for occupants of the space regarding these and other factors that affect their use of the lighting. The responses from the interviews were tabulated to provide self-reported information regarding the operation of manual switching.

Estimates of the aggregate savings resulting from bi-level switching were calculated for each of the space types through the following procedure.

- For each monitored space, savings from using bi-level switching were defined to occur under two conditions:
  - When only the switch for the low wattage circuit is used, saving the wattage on the high wattage circuit; or
  - When only the switch for the high wattage circuit is used, saving the wattage on the low wattage circuit.
- For each space type, 24-hour profiles of Watts on per square foot and savings per square foot were calculated for each building having that type of space. Profiles were developed for weekdays and weekends.
- Data collected on-site regarding the characteristics of the monitored space were used to estimate the percentage of floor space of each building that a particular space type accounted for.
- The 24-hour profiles for Watts used per square and for Watts saved per square foot were multiplied by the space type percentage factor and the building's square footage to determine Watts used per hour and Watts saved per hour for weekdays and weekends for a particular space type in each building monitored.
- These estimates were aggregated to annual estimates of usage and savings by space type for each building. These annual usage and savings estimates were obtained by multiplying weekday values by 260 (i.e., 5 weekdays per week x 52 weeks) and weekend values by 104 (i.e., 2 days per weekend per week x 52 weeks) and summing the totals for weekdays and weekends.

To develop aggregate estimates of savings representing the aggregate amount of square footage for new office buildings, retail stores, and schools built between 1994 and 1998, weights for the monitored buildings were taken from the Nonresidential New Construction Database prepared by RLW Analytics. Because the buildings monitored were a sub-sample of the NRNC sample, their weights were scaled up so that they would bring the estimates of building square footage to the population square footages when applied. These scaled-up weights were applied to the usage and savings estimates for the individual buildings monitored in order to develop the population-based estimates of usage and savings.

APPENDIX B: DATA COLLECTION FORMS

Forms for recruitment and to document lighting characteristics and logger installation are provided in this appendix.

RECRUITMENT SCRIPT

Hello, I am [_______________]. I'm calling from ADM Associates, on behalf of [SCE / PG&E / SDG&E].

We recently sent you a letter describing a study that [SCE / PG&E / SDG&E] are conducting to determine how customers are using the manual lighting switches in buildings constructed during the last 10 years. The purpose of the study is to evaluate the actual operation of the type of light switches that have been required by building standards since 1990. This evaluation will provide customers like you and [SCE / PG&E / SDG&E] with the energy savings associated with these new switches. This study will identify ways to reduce your energy consumption.

First, can you confirm that your electricity is supplied by {SCE/PG&E/SDG&E]?

No Who supplies your electricity? __________________________

Yes

Our records showed that your building was built within the last 10 years and is therefore a good candidate for participating in the study. However, we do need to check whether the lighting in your building is of the type that we are studying. In particular:

Does your building have automatic occupancy sensors to control lighting?

No

Yes What percent of the building's lighting is controlled by automatic occupancy sensors? _________%

Does your building have non-ceiling lighting that is provided as a standard part of your work area to provide task lighting (such as workstation lighting installed as part of cubicle furniture/partitions, but not an individual's self-supplied desk lamp)?

No

Yes Where is this task lighting installed?

Private offices

Open offices

[If percent of lighting controlled by occupancy sensors is less than 25 percent and task lighting has been installed, continue recruitment. Otherwise, thank customer and end call.]

Continue recruitment:

In order to conduct this study, we need to install lighting monitors in a few selected areas in your building. This installation will take less than an hour. We will remove the equipment in two weeks.

[*If customer agrees to participate*] [________________] will be the person installing the equipment. He will have a badge identifying himself as an ADM employee.

[*If customer does not agrees to participate* – ***thank the customer and end the call.***]

If you have questions about this study, you may call the program manager.

(*at SCE*) His name is Richard Pulliam, and his phone number is (626) 302-8289.
(*at PG&E*) His name is Patrick Eilert, and his phone number is (530) 757-5261.

If you need to re-schedule the visit, please call ADM at (800) 556-2123.

Thank you for your cooperation.

INTERVIEW QUESTIONS: BI-LEVEL SWITCHING

Site ID _____________ Date ___________

Bi-Level Switch Monitoring Location ________________________________ Logger SN ___________

1. Do you control the lighting switches for this space?
   - ❑ No Who controls the lighting switches? ______________________________
   - ❑ Yes Go to Question 2.
2. During the normal workday, do you turn switches on or off to adjust lighting?
   - ❑ No ❑ Yes Why do you turn switches on or off?
     - ❑ (A) To do computer work
     - ❑ (B) To compensate for daylight
     - ❑ (C) To read printed materials
     - ❑ (D) To create a comfortable work atmosphere
     - ❑ (E) To save energy
     - ❑ (F) Other (describe) ______________________________
3. Do you ever leave the lighting off in this space during the workday?
   - ❑ No ❑ Yes Under what conditions do you leave the lighting off?

   ____
4. Do you ever use just one switch to turn the lights on during the workday?
   - ❑ No ❑ Yes How frequently do you use just one switch?
     - ❑ Never ❑ Sometimes ❑ Most of the time ❑ Always

   Under what conditions do you use just one switch?

   ____
5. How frequently do you use both switches to turn lights on during the workday?
   - ❑ Never ❑ Sometimes ❑ Most of the time ❑ Always

   Under what conditions do you use both switches?

   ____
6. Does the amount of daylight affect how you set the light switches?
   - ❑ No ❑ Yes How does the amount of daylight affect how you set the light switches?

   ____
7. Do you use the lighting switches different between summer and winter?
   - ❑ No ❑ Yes How does your use of the lighting switches differ between summer and winter?

   ____
8. Has your use of the lighting switches changed any in response to the electricity crisis of the past year?
   - ❑ No ❑ Yes How has your use of the lighting switches changed?

   ____

Other Comments: ____

____