PROJECT REPORT

BI-LEVEL SWITCHING IN OFFICE SPACES

CALIFORNIA LIGHTING TECHNOLOGY CENTER

FEBRUARY 1, 2010

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ABOUT CLTC

California Lighting Technology Center's mission is to stimulate the development and application of energy-efficient lighting by conducting technology development and demonstrations, outreach and educational activities, in partnership with lighting manufacturers, lighting professionals, the electric utility community, and governmental agencies. CLTC was established as a collaborative effort between the California Energy Commission and UC Davis, with support by the U.S. Department of Energy and the National Electrical Manufacturers Association (NEMA).

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1.0 BACKGROUND AND OBJECTIVE

Incorporating bi-level switching into office spaces allows occupants to select the desired level of lighting in the space (off, on-low, and on-high). This switching method is theorized to save energy because occupants may choose to work with less electric lighting. Occupants may make this decision based on personal preference and the availability of daylight. Requirements for bi-level switching vary by state depending on the energy code adopted (Figure 1) and specific state amendments.

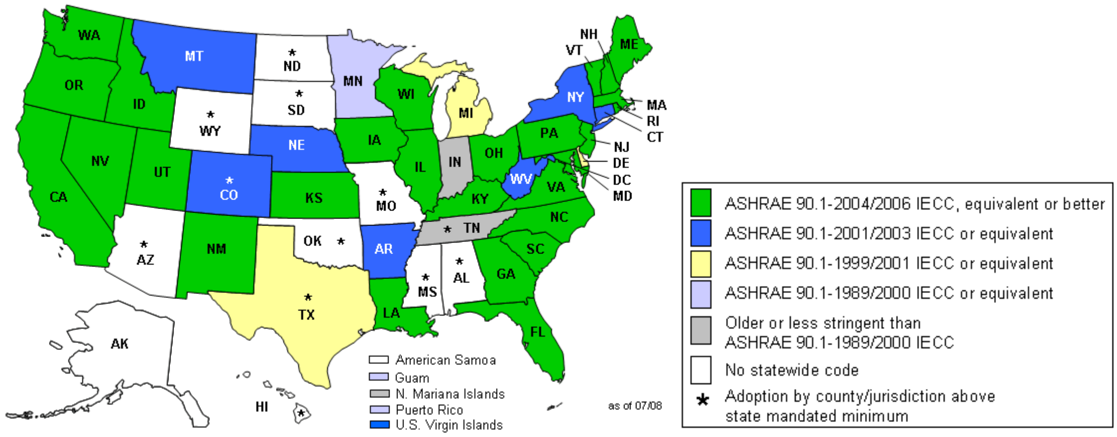

Figure 1 - Bi-level switching requirements vary by state implemented energy codes[1]

State energy codes may rely on standards published by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and/or the International Energy Conservation Code (IECC). ASHRAE Standard 90.1 (2007), which provides the minimum requirements for the energy-efficient design of buildings, does not require bi-level switching or for the occupants to have manual control of their lighting[2]. International Energy Conservation Code (IECC) 2006 requires occupants to have manual control of their lighting. IECC 2006 also requires bi-level switching, but excludes those spaces controlled by occupancy sensors[3]. Therefore, it is easy to circumvent the bi-level switching requirement by incorporating an occupancy sensor. Some states adopt state specific standards that may exceed ASHRAE or IECC codes. For example, California's Title 24-2008 code requires bi-level switching with manual control by the occupant[4].

The primary objective of this study is to quantify the energy use in private offices that are equipped with bi-level switching and occupant controls. The baseline comparison is made to a theoretical case where the occupant has no control over their lighting and it is switched on and off solely by an occupancy sensor. In addition, this study looks closely at the possibilities for combining automatic and manual control to achieve the greatest energy savings and user satisfaction.

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[1] Status of Commercial Energy Codes, Department of Energy, http://www.energycodes.gov/implement/state_codes/
[2] ANSI/ASHRAE/IESNA Standard 90.1-2007 Section 9.4.1.2
[3] IECC 2006 Section 505.2.1-505.2.2
[4] California Title 24 – 2008 Section 131(b)

2.0 EXPERIMENTAL DESIGN AND METHODOLOGY

California Lighting Technology Center conducted this study in eight private offices (Figure 2 below) that featured bi-level switching controlled by the Watt Stopper WA-300 (Figure 3, following page, right image). The offices are located at the University of California, Davis at the Office of Research. The office sizes are between 90 ft^2 and 140 ft^2 with a ceiling height of 9 ft. Five offices face the south-east direction while three offices face the north-east direction. All offices have windows with manually adjustable vertical blinds. The offices are equipped with pendant direct/indirect fixtures with four T8 lamps (Figure 3, following page, left image). Each switch controls two lamps (Figure 3, following page, middle image), with 48 watts required for 50% light output and 96 watts required for 100% light output.

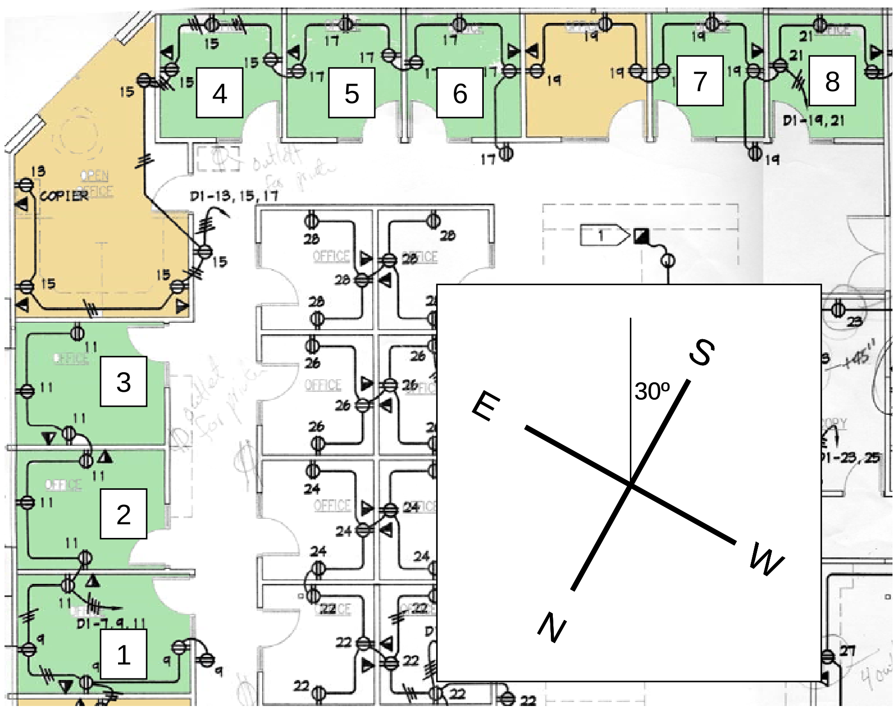

Figure 2 - Office layout for bi-level switching study

The lighting in each private office is controlled by the Watt Stopper WA-300, which is a bi-level wall switch that turns lighting on and off automatically based on occupancy (detected by a passive infrared occupancy sensor). The automatic on and off functions can always be manually overridden by the user. The two relays can be configured independently to provide the following scenarios when the occupant first enters the office:

1. <u>50% Automatic On</u>*:* With this setting the WA-300, upon sensing an occupant, turns on one relay, thereby generating 50% light output.
2. <u>Manual On</u>: With this setting the WA-300, upon sensing an occupant, does not turn on any lighting.
3. <u>100% Automatic On</u>*:* With this setting the WA-300, upon sensing an occupant, turns on both relays, thereby generating 100% light output.

All three scenarios are combined with an automatic shut-off for when the office is unoccupied. The time delay for the automatic shut-off is adjustable between 5-30 minutes.

This study measured energy use for all three switch configurations: 50% automatic on, manual on, and 100% automatic on. Each phase lasted three weeks, with the first beginning in March 2008. In each phase occupants were informed about the manner in which the electric lights would behave and also that they were participating in a lighting-controls study. However, the occupants were specifically not told that the purpose of the study was to measure the impact of their behavior on energy consumption.

Figure 3 - Example office (left), light fixture (center), Watt Stopper WA-300 Bi-level Switch (right)

In order to measure energy use, the following items were monitored:

1. The on/off states of both switches, recorded by two Watt Stopper IT-200 data acquisition light on/off sensors placed next to the lamps (Figure 4 following page, left image). State changes were recorded with an accuracy of 1 minute.
2. The occupancy state of the office, recorded by a Watt Stopper IT-200 data acquisition occupancy sensor mounted to the ceiling (Figure 4 below, middle image). State changes were recorded with an accuracy of 1 minute.
3. The use of task lighting, recorded in 5 minute intervals by Brand Electronics power meters.
4. The relative measure of available daylight in the office, recorded by a Hobo UA-002 Light Data Logger mounted to the end of the light fixture oriented toward the window (Figure 4 below, right image). This sensor records relative light levels in lux with sensitivity over the wavelength range of 200-1200 nm. The sensor does not have photopic correction.

Figure 4 - Watt Stopper IT-200 data acquisition sensors recording status of both switches (left) and occupancy status (middle) and Hobo Light Sensor recording relative daylight available in the office (right)

At the end of each three-week phase the data was collected and analyzed using Microsoft Excel to correlate, in one-minute intervals, occupancy, the status of the overhead lighting, the relative daylight available, and the task light status. Since the number of hours of occupancy varied between offices and between phases, the data was normalized for occupied times only.

To further understand light levels in the offices, average work plane illuminance measurements were recorded with a Minolta T-10 meter on a sunny summer day during the time frame of 12 p.m. - 1 p.m. The measurements were taken with the blinds in the position normally used by the occupants. The foot-candle contribution was recorded for daylight, 50% of electric light, the other 50% of electric light, and task lighting (only for occupants that used task lighting).

After the study, an in-person survey gathered the preferences and feedback of the occupants. Occupants were asked to state a preference for either the 50% automatic on operation or the manual on operation.

3.0 RESULTS

For the 50% automatic on phase, the occupants worked, on average, with 100% of lights on 13% of occupied time, 50% of lights on 70% of occupied time, and no lights on 17% of occupied time (Figure 5, Appendix page 9). For the calculated average yearly occupancy of 1550 hours, this equates to 72 kwh per office per year (Figure 9, Appendix page 11). Individual occupant behavior varied, with 5 occupants working with 50% light level almost all of the time, 2 occupants occasionally increasing their light level to 100%, and 1 occupant faithfully turning off all lighting (Figure 5, Appendix Page 9).

For the manual on phase, the occupants worked, on average, with 100% of lights on 38% of occupied time, 50% of lights on 32% of occupied time, and no lights on 30% of occupied time (Figure 6, Appendix page 9). For the calculated average yearly occupancy of 1550 hours, this equates to 81 kwh per office per year (Figure 9, Appendix page 11). Individual occupant behavior varied, with 2 occupants working with 50% light level most of the time, 4 occupants working with 100% light level most of the time, and 2 occupants working without electric lighting (Figure 6, Appendix page 9). These findings show that the manual on phase actually increased energy use by 12% over the 50% automatic on phase. This reason for this result may be that the occupant, when entering a dark office, hits both switches without considering whether the 50% light level is adequate. Conversely, when entering an office with a 50% light level, the occupant may not consider turning on the additional lighting.

For the 100% automatic on phase, the occupants worked, on average, with 100% of lights on 50% of occupied time, 50% of lights on 31% of occupied time, and no lights on 19% of occupied time (Figure 7, Appendix page 10). A problem occurred with the control device for office 2 in this phase and the corresponding results are excluded. For the calculated average yearly occupancy of 1550 hours, the average use equates to 99 kwh per office per year (Figure 9, Appendix page 11). Individual occupant behavior varied, with 2 occupants working with 50% light level most of the time, 4 occupants working with 100% light level most of the time, and 1 occupant faithfully turning off all lighting (Figure 7, Appendix page 10). This phase used the most energy compared to the previous phases. This result is intuitive as it is reasonable to assume that most occupants would not think to turn off lights that come on automatically, even if they would be satisfied with lower light levels.

The energy use of three control scenarios is significantly less than the baseline case where 100% of the lights are on and no manual controls are present (Figure 9, Appendix page 11). Energy savings for adding manual, bi-level controls are between 34-52%, depending on the automatic or manual on configuration. The average maximum energy savings of 52% is achieved with setting the controls to the 50% automatic on scenario.

Task light on/off status was monitored throughout the duration of the study to observe if occupants' use of task lighting was affected by the control scheme for the overhead lighting. Seven out of eight occupants did not use any task lighting for the duration of the study. The occupant of office 8 consistently used task lighting throughout the study. This occupant used under-cabinet task lights consuming 51 Watts approximately 80% of the time. The percent on-time was consistent for all three phases. Therefore, the use of task lighting can be discarded as a variable when comparing the three phases.

In general, results did not show a strong correlation between the measured daylight index and electric lighting use (Figure 10, Appendix page 11). A weak correlation does indicate occupants that use less electric lighting do use more daylight. The occupant in office 5 who rarely used electric lighting used more daylight than the rest of the occupants. In general, changing between phases did not appear to affect the occupants' use of daylight. The exception is the occupant in office 2, who changed behavior with the manual on phase by opting for less electric lighting and increasing the use of daylight.

Daylight contributions in the offices were generally small in comparison to the electric lighting (Figure 11, Appendix page 12). 50% of the electric lighting provided between 12-21 Foot-candles on the desk while 100% of the electric lighting brought the lighting levels up to 22-47 Foot-candles. In comparison daylight contributed 3-29 Foot-candles. Daylight contribution varied greatly because the measurements were taken with the blinds in the position that the occupants normally use them, which varied from completely closed to completely open.

When interviewing the occupants about their preference, it was observed that half of them favored the scenario where 50% of the lights turn on as they enter the office. The rest of the occupants preferred to have complete manual control over the system since they can adjust it as per their individual needs. The occupants commented that

- "I have got enough light through the window in my office. If both of the lights are on, it will be a waste of energy. I prefer to use the natural light. But I like one light to come on when I walk into the office. " – *Occupant that prefers 50% automatic on*
- "I have got used to it. It is nice that the lights are on when you walk in." – *Occupant that prefers 50% automatic on*
- "I don't trust the automatic system. It should be used for the places that people can't control, like the parking lot. But in my office, I would like to get full control and achieve energy efficiency." – *Occupant that prefers manual on*
- "In the morning, I have got enough lights from the window. If the lights are automatically on, I turned them off in the morning and in the afternoon; I will turn on one light by hand." – *Occupant that prefers manual on*

4.0 CONCLUSION

Providing occupants with manually controlled bi-level switching in daylit private offices is a powerful energy-saving tool. This study demonstrates that occupants, when given the choice, will often choose to work with less than the designed electric lighting level. Bi-level manual control with automatic off saves 46% energy use compared to a system control where lighting is only controlled by an occupancy sensor. Adding the automatic on to 50% feature garnered additional savings for a total of 52% compared to the baseline. The reason for this result may be that the occupant, when entering a dark office, hits both switches without considering whether the 50% light level is adequate. Conversely, when entering an office with a 50% light level, the occupant may not consider turning on the additional lighting. The automatic on to 100% phase still saved 34% compared to the baseline but is the least preferred setting for energy savings.

The survey carried out during the study revealed that occupants pay attention to daylight and were comfortable working when the system was set to 50% auto on because this setting provided them with an adequate mix of daylight and electric light during most of the day. Occupants also preferred and were happy to have manual controls since they could adjust the lighting according to their needs. Optimum energy savings and user satisfaction can be achieved by offering occupants a choice between manual on and automatic on to a low level. Considering the tremendous benefits provided by the use of bi-level switching, building codes should be modified to have a minimum requirement for bi-level controls with an option for automatic on to a low level.

5.0 APPENDIX: STUDY RESULTS GRAPHS

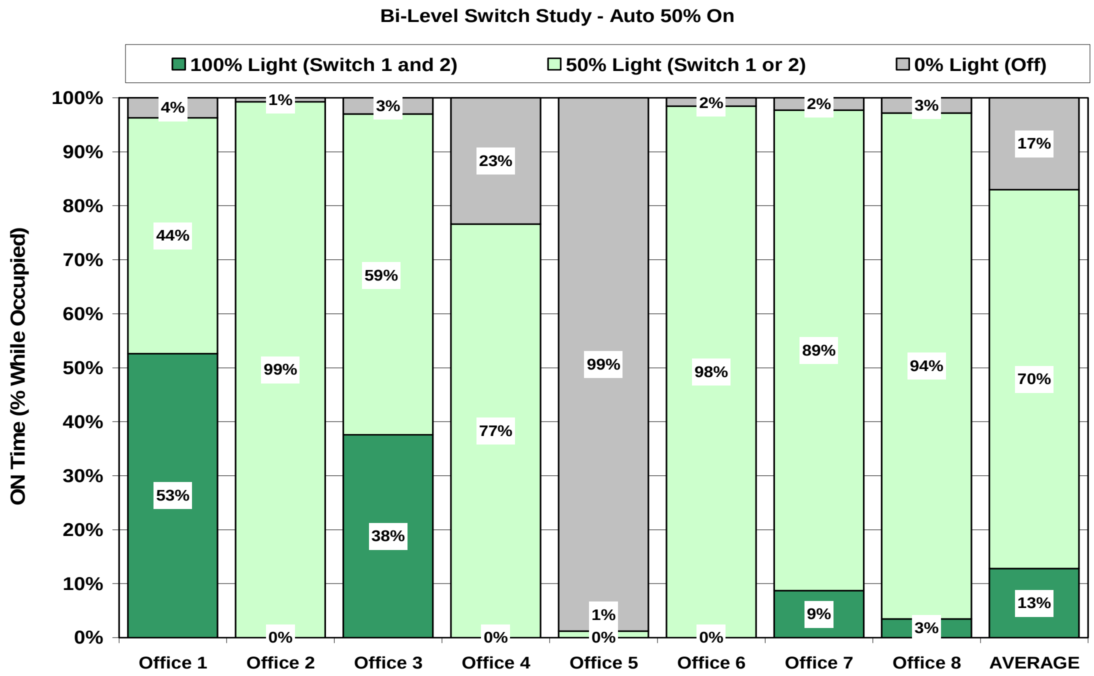

Figure 5 – Results for the 50% automatic on phase show that the majority of occupants worked with 50% light levels during most of the phase.

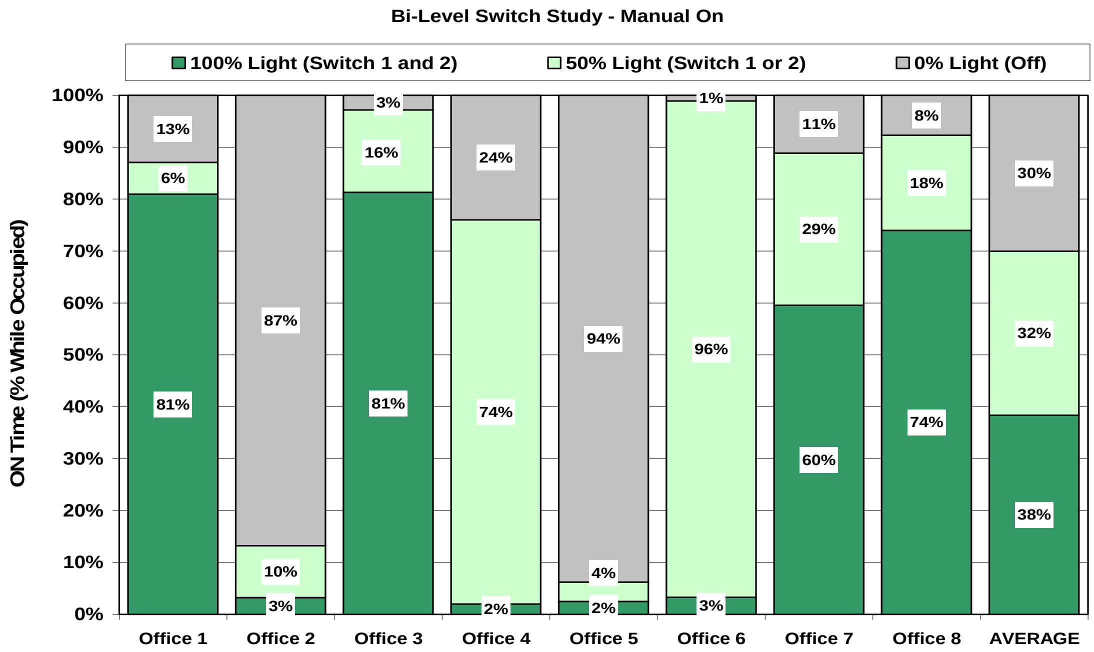

Figure 6 – Results for the manual on phase show widely varying occupant behavior with an average increased energy use compared to the 50% automatic on case.

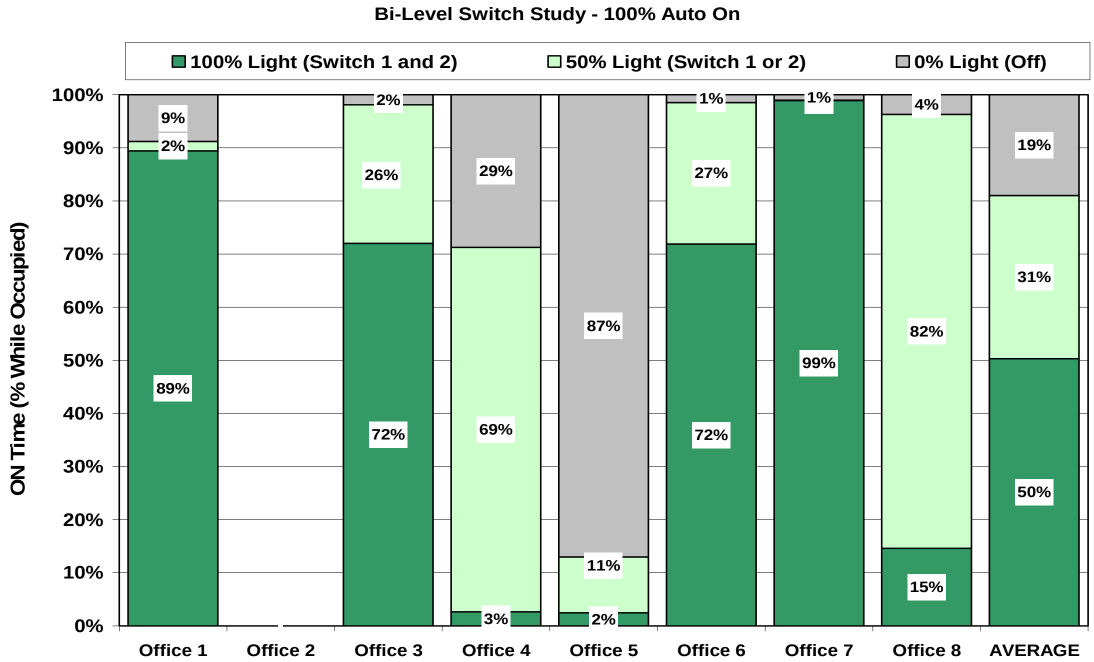

Figure 7 – Results for the 100% automatic on phase show increased energy use compared to other phases and widely varying occupant behavior. Office 2 is excluded from the results.

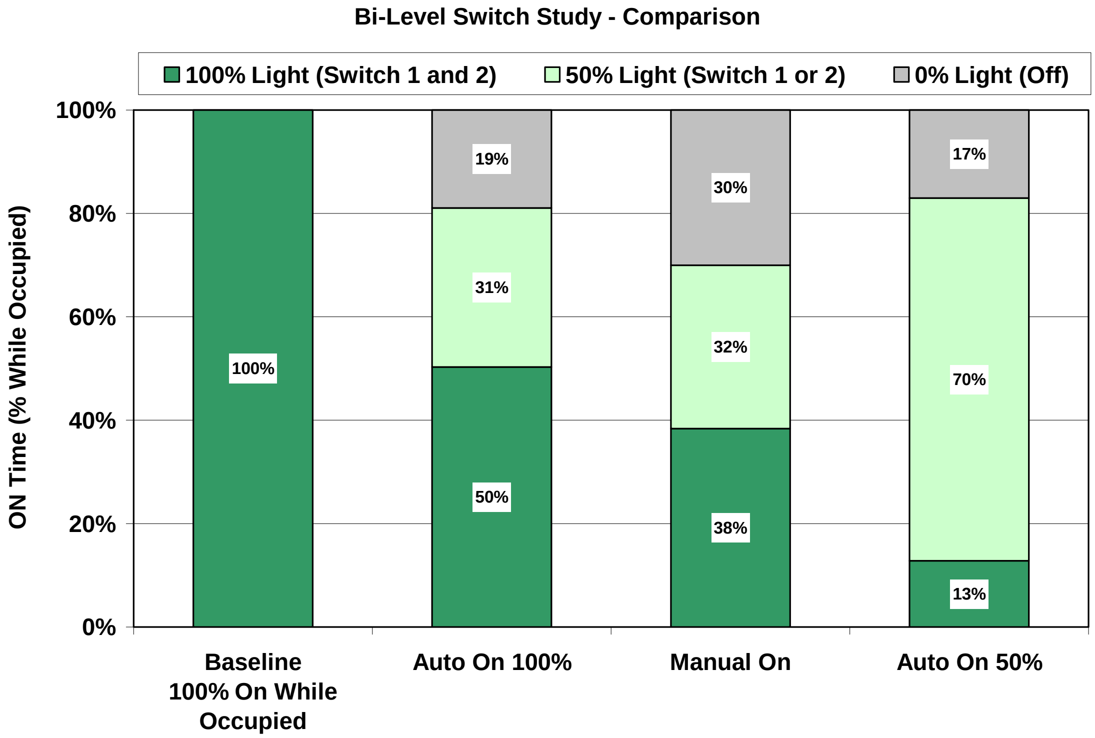

Figure 8 – The average use of electric lighting for all three phases compared to a baseline scenario where 100% of the lighting is on while occupied and manual, bi-level controls are not available.

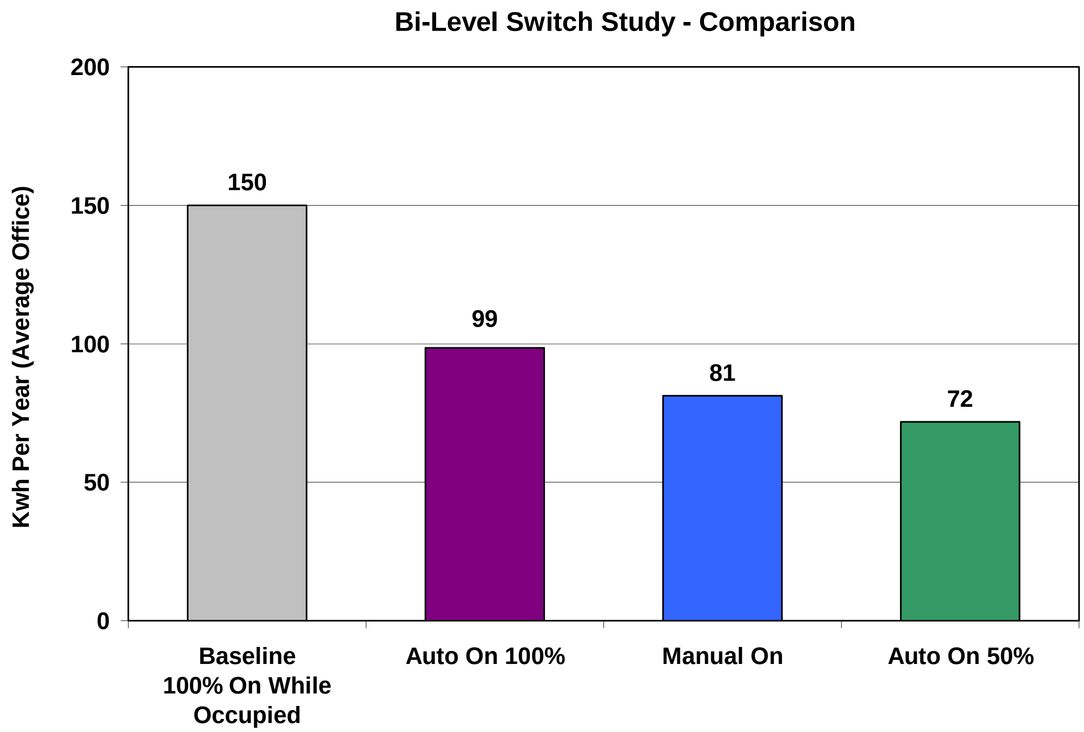

Figure 9 – Average annual energy consumption per office for all three phases compared to a baseline scenario where 100% of the lighting is on while occupied, and manual, bi-level controls are not available.

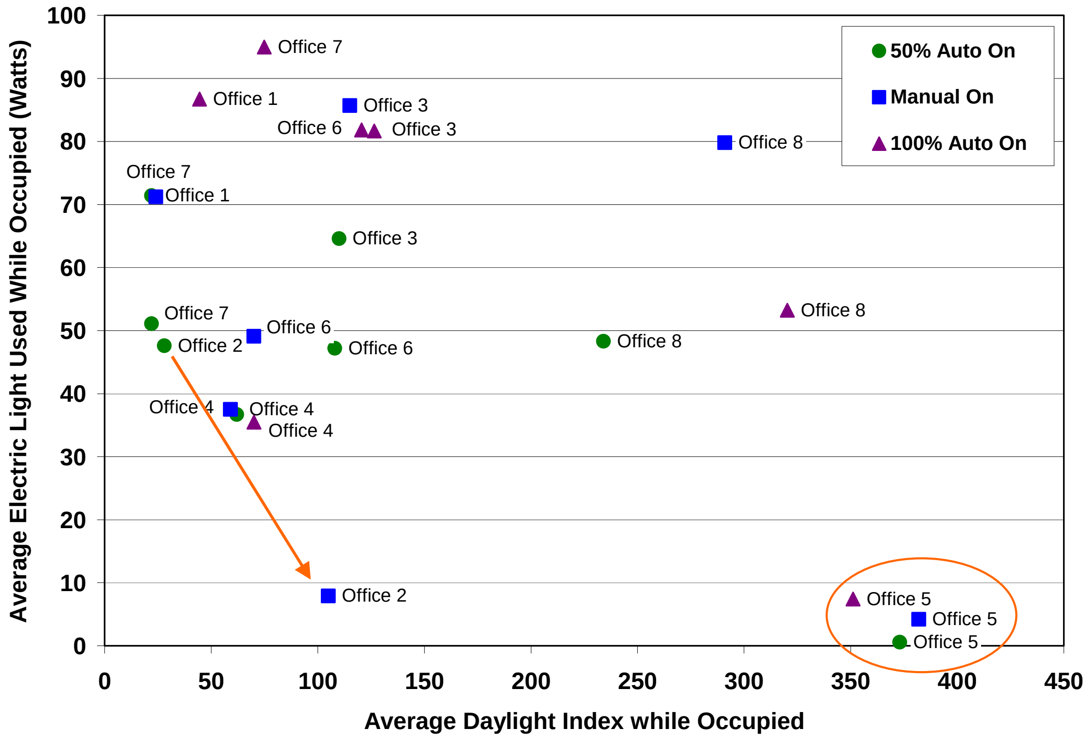

Figure 10 – In general, results did not show a strong correlation between the daylight index and electric lighting use. However, the occupant in office 5 that rarely used electric lighting did use more daylight than average. The occupant in office 2 changed behavior

with the manual on phase by opting for less electric lighting and increasing the use of daylight.

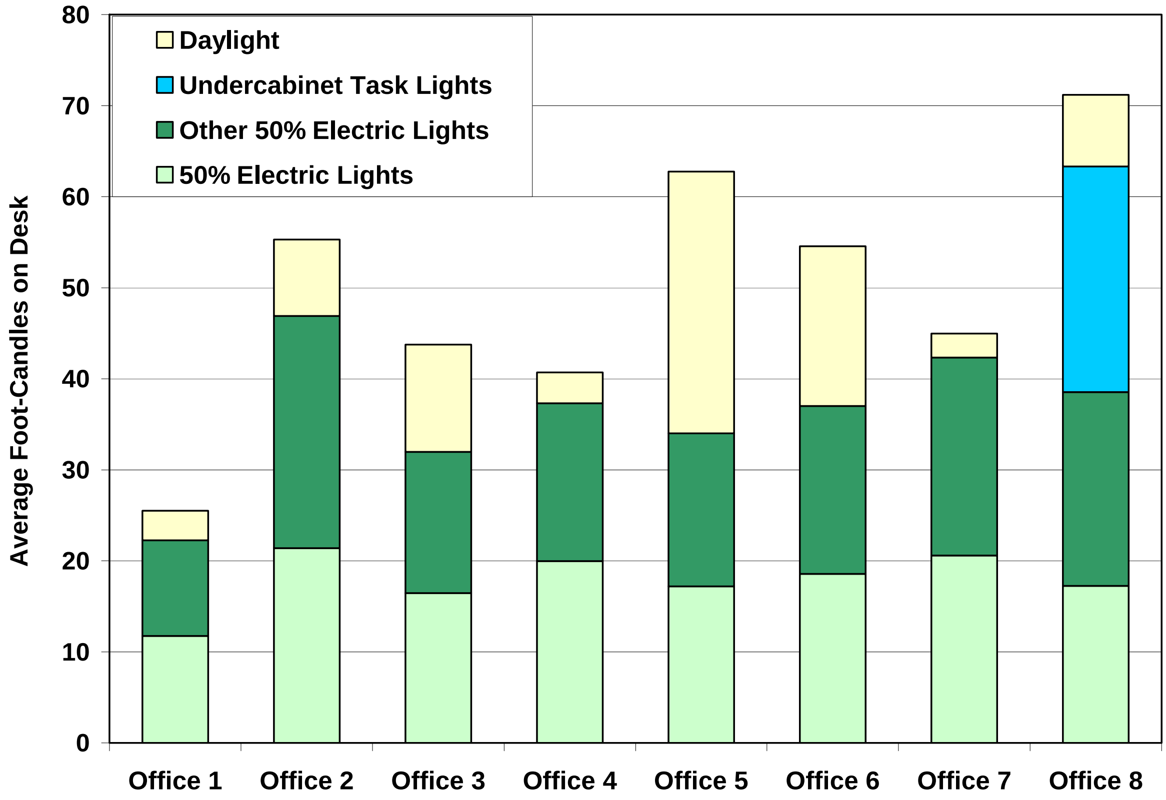

Figure 11 – Work plane illuminance, in foot-candles, on the desks of each office. The foot-candle contribution is shown for daylight (during a sunny day from 12 p.m. - 1 p.m.), 50% of electric lights, the other 50% of electric lights, and the task lighting for occupants who used it.