High Performance Lighting Controls in Private Offices:
A Field Study Of User Behavior And Preference

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ABSTRACT

A lighting controls study performed over a three month period provided data that can be used to determine the impact of manual switching and dimming controls on occupant behavior and attitudes and on energy use. Data were analyzed for 58 private offices on a single floor of a modern office building in Boulder, Colorado. Each office was equipped with a ceiling-mounted infrared motion sensor, a dimmer-switch at the door, and a portable dimmer-switch at or near the computer monitor, which controlled two 18-cell parabolic luminaires with three-T8 lamps and electronic dimming ballasts. Occupancy and energy data were collected using a data acquisition system, observations were made of occupant tasks and window blind usage, and surveys were conducted to measure occupant attitudes and preferences toward lighting controls.

The results show that:

1. Occupants highly value windows and window blinds.
2. Occupants typically use window blinds to occlude direct sunlight while allowing daylight to enter the office.
3. Occupants in offices with northern exposures are more likely to keep their blinds at least partially open and their lights off.
4. Occupants highly valued dimming and preferred to have a lighting control at their workstation.
5. Seventy-four percent of occupants dimmed their lights during the course of the study.
6. Occupants did not typically adjust lighting levels when they changed tasks.
7. Occupants liked having manual controls and accepted automatic controls as long that did not interfere with their activities.
8. Occupants did not notice when lighting returned automatically to previously set levels when they re-entered the room, but when asked, said that they would prefer this feature.
9. Energy use was reduced by 61% by motion sensors and manual switching and dimming controls.

INTRODUCTION

Well-formed, systematic studies of facilities are rare. The high cost of data acquisition and the difficulty of working in occupied facilities are formidable barriers to such studies. Still, understanding how occupants use and interact with their facilities is essential for improving the quality of the built environment.

In the fall of 1994, the National Center for Atmospheric Research (NCAR)[1] in Boulder, Colorado and the Lighting Research Center (LRC)[2], Troy, NY, agreed to conduct a study of lighting controls at NCAR's 250,000 ft^2 three-building Foothills Laboratory campus. The goal of the study was to evaluate the effectiveness and occupant acceptance of several lighting control technologies. The study was designed and conducted under LRC direction

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[1] The National Center for Atmospheric Research is part of the University Corporation for Atmospheric Research that operates under the sponsorship of the National Science Foundation. www.ucar.edu

[2] The Lighting Research Center (LRC) is part of the School of Architecture at Rensselaer Polytechnic Institute in Troy New York. www.lrc.rpi.edu

with funding from private, government, and utility organizations (the sponsors).

After two years of preparation and a three-day pilot test, the full-scale study began in December 1996. Over the next nine months, a mountain of data was analyzed resulting in findings that can help to shape building environments of the future[3].

The study was designed to answer the following five questions:

1. Do occupants dim lighting?
2. If they do, then does the number and location of dimmers affect occupant behavior?
3. Does manual dimming really save energy, or do energy savings result from occupants keeping lights off in perimeter offices?
4. What energy savings do manual dimming and the use of motion sensors achieve?
5. Does occupant behavior change if controls automatically restore previous light levels when occupants return to their offices (the auto-restore function)?

THE SITE AND CONTROL SYSTEM

The study was conducted using a 45,000 ft^2 floor of one of the NCAR office buildings. The floor included 96 perimeter and approximately 50 interior single-occupant offices, all of which had individual lighting and HVAC controls. The perimeter offices had continuous windows with vertical adjustable window blinds and a 4-foot overhang; however, the windows had no overhang on the north facade.

The lighting system was designed to accommodate occupant tasks and preferences in a computer-intensive work environment while eliminating wasted energy. Each office included 2 three-lamp deep-cell parabolic luminaires with 32-w 4100 K T8 lamps. The lighting controls in each office included photoelectric dimming, manual dimming and switching, ceiling-mounted infrared (IR) motion sensors, and electronic dimming ballasts. Dimming and switching controls were provided at the door and dimming was provided at the desk[4]. Dimming controls were small potentiometers. The desk dimmers were mounted on a computer monitor, keyboard, or other desk location. The motion sensor was set to maximum sensitivity and provided motion event signals to both a local lighting controller and the Building Automation System (BAS). Figure 1 shows the locations of these controls in a typical perimeter office.

Under normal operation, the motion sensor time delay was set to dim lights to 10% light output for 10 minutes after no motion was detected for 20 minutes. If motion was detected within the 10-minutes, the lights immediately returned to their previous setting.; otherwise, the lights turned off. Once lights were off they had to be manually turned back on. The HVAC system was also occupancy-based so that the temperatures of unoccupied zones were set back to standby temperatures and airflow was turned off (Morrow, 1997).

METHODS

For purposes of the study, the lighting control system was modified in three ways. First, a current sensor was connected to the two luminaires in each office and wired to the BAS. These sensors provided a close estimate of energy use and, when combined with occupancy data, allowed manual switching and dimming events to be identified. Second, the interim dim was reprogrammed to eliminate the automatic off for 1/3 of the offices. This function, called "auto restore," operated so that lights in unoccupied areas dimmed but did not turn off, unless they were manually turned off. Third, photosensors were capped to isolate manual adjustments.[5]

The study was conducted from December 1996 through March 1997. Observations of occupant tasks and window blind usage were recorded hourly during this period while the BAS collected motion and current data every 5 minutes. Data were uploaded weekly from Boulder to Troy.

Sixty perimeter and 21 interior offices were selected for the study. These offices were divided into one control and two experimental groups, manual-on and auto-restore. The study comprised 4 two-week observation periods, which were separated by acclimation periods while planned changes were made to the lighting controls and occupants adjusted to the changes. The planned changes included reprogramming the motion sensor time delay in the auto-restore offices for Periods 2-4 observations, removing the desk dimmer in the manual-on and auto-restore groups for Period 3 observations, and adding new "improved" dimmers to these two groups for Period 4 observations. The new dimmers operated the same as the original dimmers, but they were smaller and nicer in appearance. No dimmer changes were made for the control group (Maniccia et al., 1998).

[3] A full report has being published and can be ordered from the LRC.
[4] The desk dimmer also could be used to turn lights on and off.
[5] Daylight harvesting had also proved to be expensive to commission, irritating to occupants, and ineffective when used in conjunction with the other controls (Rea et al., 1998).

At the end of the study, questionnaires were distributed to occupants and collected to measure their perceived value of dimming and of having windows and window blinds, preferred dimmer location, reasons for using dimmers, and acceptance of the motion sensor auto-restore function. Occupants were asked to rate the value of several features on a scale of 1 (low) to 5 (very high).

Usable data were obtained for 43 perimeter and 15 interior offices. Data from the first week were removed from Period 1 because of a calibration error. Data were analyzed for a 10-hour business day (8:00 AM and 6:00 PM).

RESULTS

Occupant Behavior

Occupant behavior was determined by examining dimmer and window blind use patterns in the offices while they were occupied. Over the seven weeks of observations, offices were occupied an average of four hours, 36-minutes of each 10-hour day, or 46%. Seventy-four percent of the occupants (43 of 58) used their offices at least once with the lights at a dimmed setting (Figure 2). Dimmer, window blind use, and light setting (whether lights were dimmed, off, or on-full) varied by office location.

Figure 3 shows the percentage of time with lights at each setting according to office location. Occupants of interior offices rarely worked with their lights off. Occupants of offices along the north and east sides kept their lights off more than twice as much as occupants of offices along the south and west. As shown in Figure 4, these occupants also kept their window blinds open or only partially occluded, allowing daylight to enter the office.

Occupants of south and west-facing offices and interior offices dimmed more often than occupants of north and east-facing offices. The occupants of the south and west-facing offices almost always adjusted their window blinds to occlude direct sunlight and had their lights set on-full or dimmed. Consequently, their selected light settings were similar to occupants of interior offices.

The reset state also affected dimming patterns. Overall, the auto-restore group adjusted the lights more frequently than the manual-on or control groups. Although the frequency of dimming events varied, the amount of time lights were dimmed did not statistically vary between observation periods or between groups. However, the percentage of time occupants in the auto-restore group had the lights dimmed steadily increased over the course of the study while the percentage of time the manual-on and control groups had their lights dimmed remained relatively constant.

Occupant Tasks

No correlation was found between observations of occupant task and light settings (Figure 5). However when occupants were asked why they adjusted their lights they did relate light setting to a task (Figure 6). In fact, occupants did not adjust their lighting to save energy. It appears that occupants selected an appropriate level of light to fit their primary work task and then left the lights at that setting until that primary need changed.

Occupant Preferences

One-third of the occupants placed a very high value on being able to dim (Figure 7). Fewer occupants (16%) placed a very high value on being able to dim from the desk. Most people gave dimming from the desk a low or moderate value. However, occupants preferred having the lighting control at their desks instead of at the door by a margin of 5:1 (Figure 8). This preference is demonstrated in the occupant behavior data, which shows a decrease in dimming frequency when the desk dimmer was unavailable.

Almost all occupants highly valued both windows and window blinds, indicating that these are important features for a private office. In addition, occupants adjusted the window blinds three times more frequently than they did the manual dimmers.

Of those expressing a preference, 72% of the occupants preferred the auto-restore feature of the motion sensor.

Energy

Lighting controls saved energy. The automatic and manual lighting controls in the study saved 61% (Figure 9) of the energy required for a 10-hour scheduling scenario. The majority of these savings (46%) were from motion sensors and automatic dimming while the remainder (15%) was from occupant switching and dimming. The 30-minute time delay (20 minutes on full, 10 minutes at 10% dim) wasted 8% of the energy. Without the 10-minute period, this waste would have increased to 11%.

HVAC savings were not included in this study, but subsequent monitoring by NCAR found a 20% load reduction. In addition, occupancy-based HVAC control greatly reduced equipment loading and associated wear and tear.

CONCLUSIONS

This study clearly showed that occupants block sunlight with their window blinds, and that occupants in offices with northern exposures are more likely to keep their blinds at least partially open and their lights off. This finding contradicts the conventional wisdom of "daylight harvesting" in offices with southern exposures since they have the most incident sunlight.

This study also showed that the different preferences of occupants are important to consider in designing high performance lighting controls for private offices. Occupants highly valued having control over their work environment, but because no two occupants acted exactly alike, it is not possible to predict how any one person will choose to configure his or her work environment. Blinds may be open or closed and the lights may be on-full, off, or somewhere in between. A lighting control system that provides the occupant with control of window blinds and light level has the flexibility to accommodate varying occupant needs.

Overall, occupants liked having manual controls and accepted automatic controls that did not intrude when the room was in use. They highly valued the ability to control their office environments with window blinds and dimmers and appreciated the convenience of lighting controls located at their workstation. Mostly, people prefer lighting control components (and systems) that allow them control over a range of conditions to suit their individual preferences.

Lighting controls reduced energy consumption in the offices studied by 61%, 46% from automatic controls and 15% from manual controls. Furthermore, these savings were consistent over the 3-month period suggesting that designers should consider this reduced load when establishing design loads for buildings with similar circumstances.

Caveats

Several features of this particular site that may limit generalization of data include:

1. The building was oriented 18° 11' 30" counterclockwise. Therefore the office orientations were slightly rotated, which most likely affected occupant window blind behavior.
2. The study was limited to private offices with individual lighting and temperature control.
3. The study was conducted from December through March at a longitude of 40 degrees north when sun angles were low and beginning to increase.
4. Desk location and orientation varied among offices, which may have affected window blind and dimmer use.
5. The auto-restore function was a feature added for purposes of the study so the novelty of this function may have encouraged additional dimming.

ACKNOWLEDGEMENTS

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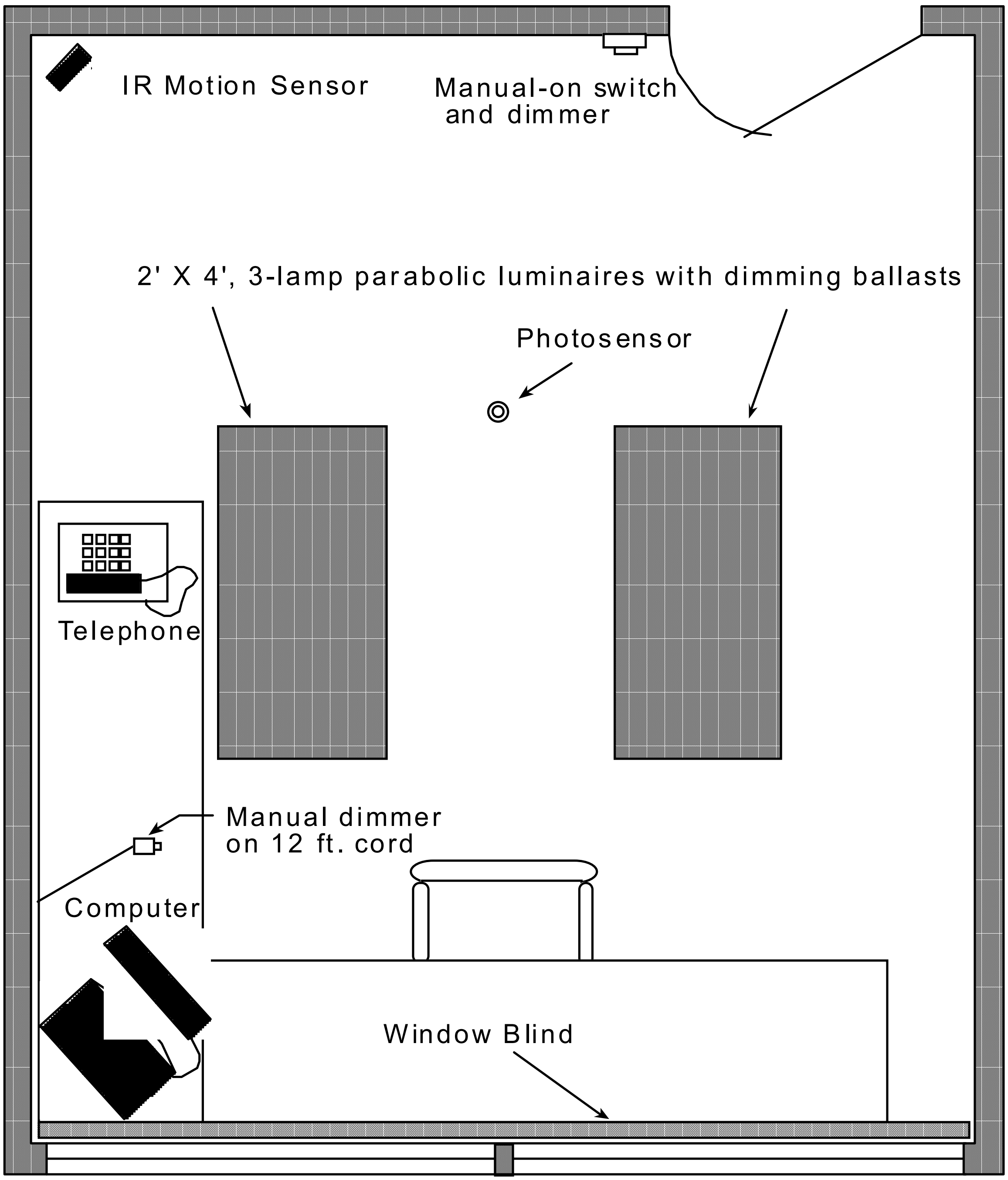


Figure 1 – Location of lighting controls in a typical perimeter office.

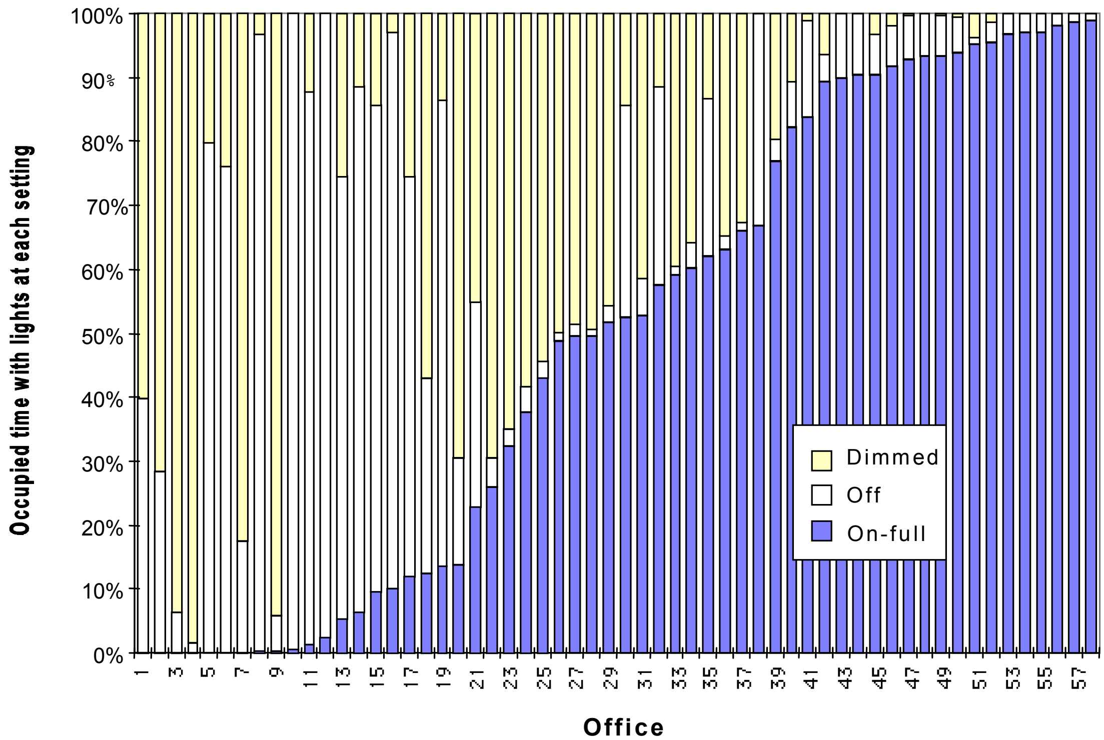


Figure 2 – Occupied time with lights in each setting for each office. (Offices are graphed in order of time with lights on-full)

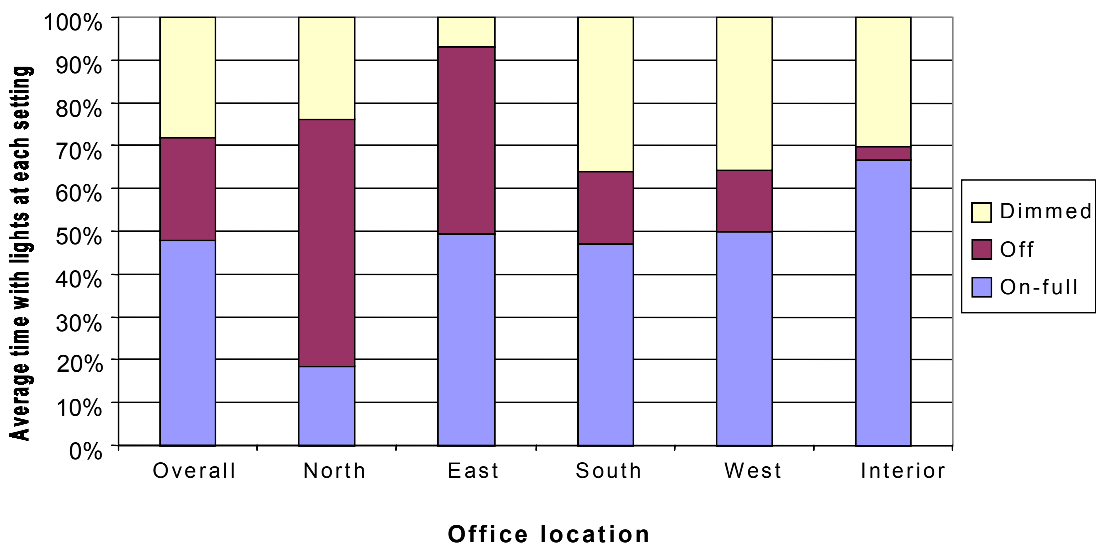


Figure 3 – Percentage of occupied time with lights in each setting according to location.

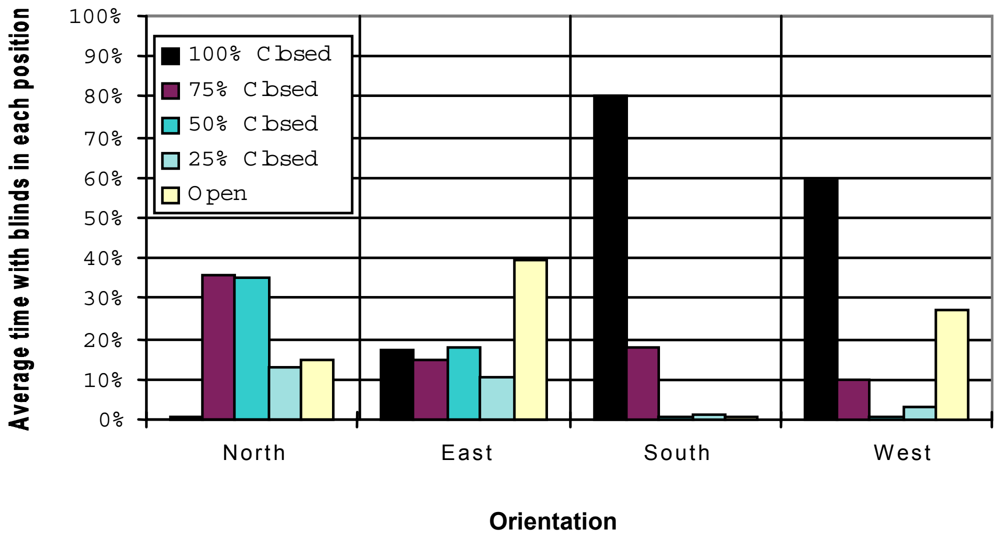


Figure 4 – Window blind position according to office location.

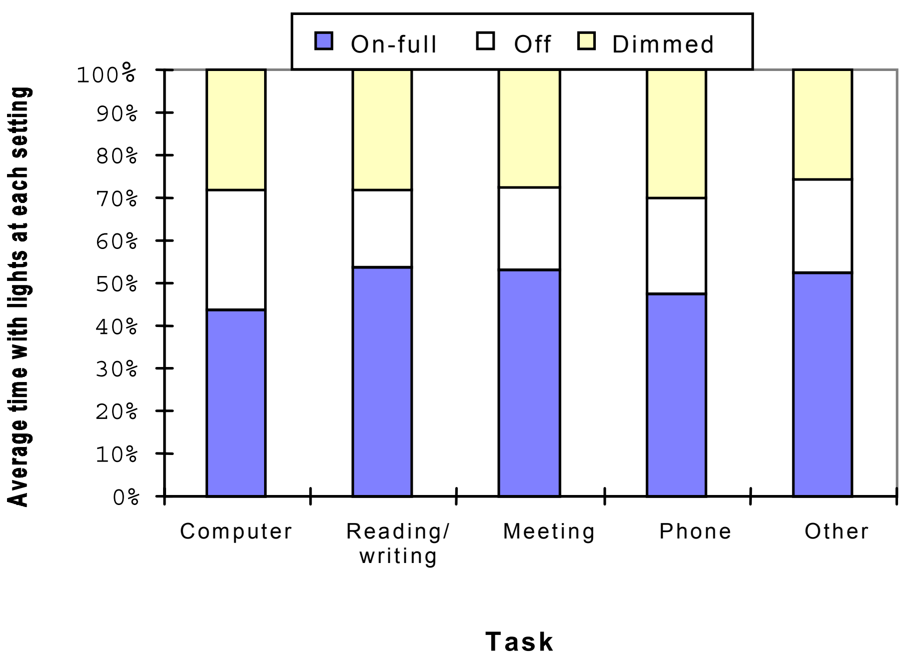


Figure 5 – Light settings during different tasks.

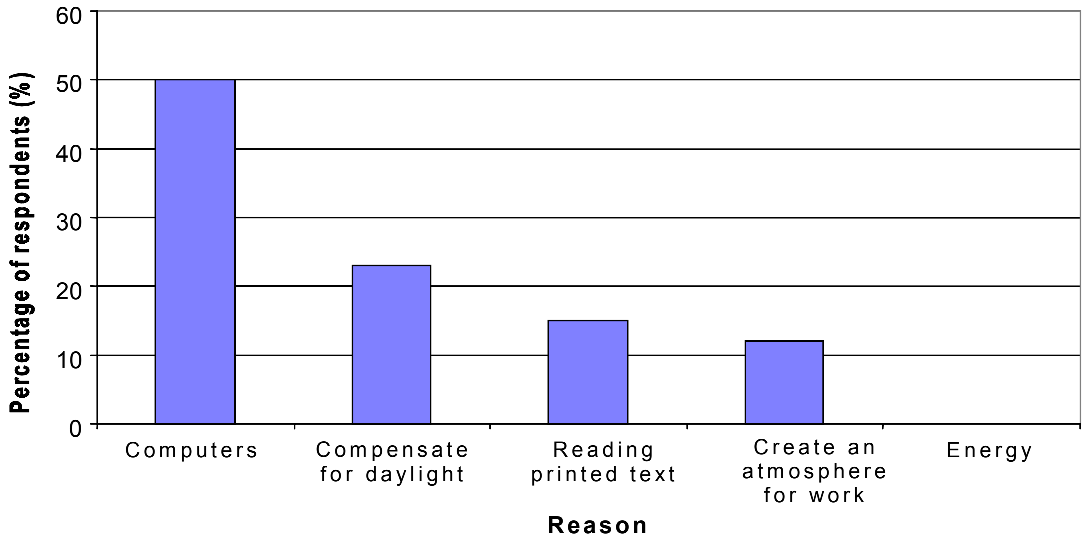


Figure 6 – Occupants' stated primary reason for adjusting lights.

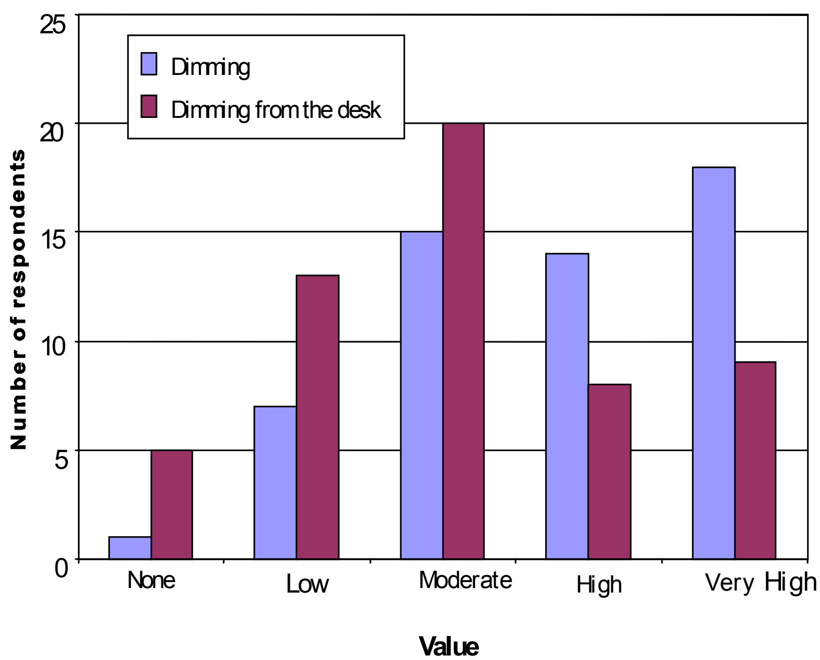
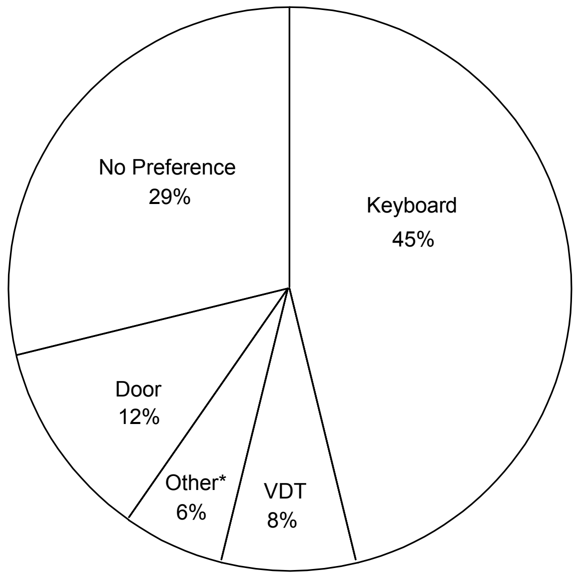
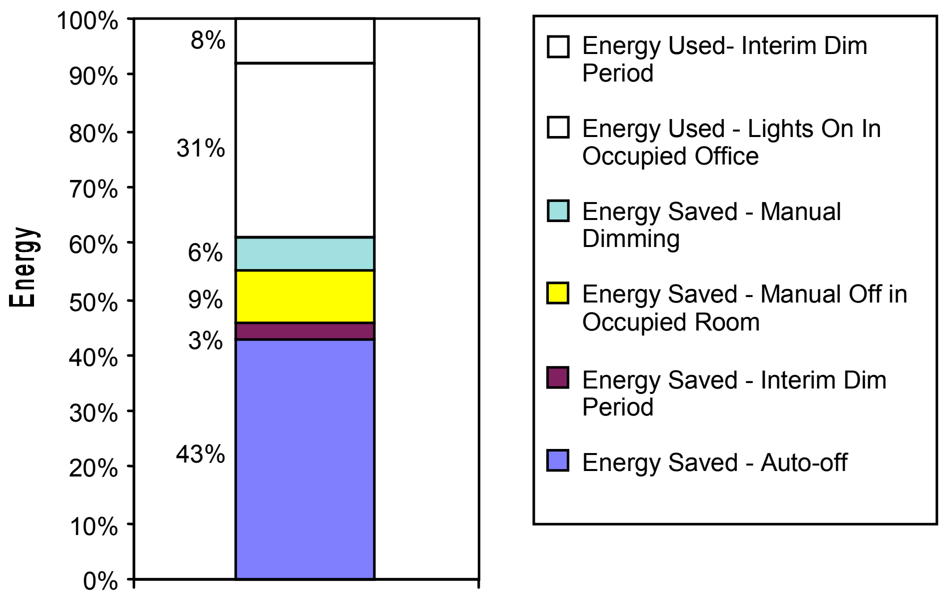


Figure 7 – Occupant ratings of dimming and dimming from the desk.



* Locations categorized as other were desktop locations not listed on the questionnaire.

Figure 8 – Occupants' preferred location for the dimmer.



100% energy use is equivalent to on-full light use for a ten-hour business day.

Figure 9 – Percentage of energy used and saved by different control techniques.