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Daylighting: Measuring the Performance of Light Shelves and Occupant-Controlled Blinds on a Dimmed Lighting System

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Abstract

The design of a daylighted space is both an art and a science. The biggest challenge facing the lighting designer is to admit only as much light as necessary and distribute it evenly throughout the space without introducing glare or heat. In warm climates such as Florida, it has become common practice in windowed spaces to specify blinds and glazing with high shading coefficients to control glare and minimize heat gain. However, this practice reduces the effectiveness of lighting systems that dim automatically. Improved systems are needed to capture natural daylight and distribute it uniformly throughout a space while controlling heat gain and glare. One such system is the light shelf. Light shelves shade the space from direct sunlight and reflect this sunlight onto the ceiling for a deeper and more uniform distribution. While this is not a new idea, little unbiased empirical data has been collected, outside the laboratory, that compares the performance (energy savings, uniformity, and level) of an automatic daylighting system.

This study measures the effectiveness of light shelves and manually controlled horizontal blinds in an automatic daylighting system. Power consumption and interior work-plane lighting levels were compared in four essentially identical private offices. Two offices were configured with an interior light shelf, one with a white diffuse top surface and the other with a specular surface. The third office had no window treatment and the fourth office had horizontal blinds, which were manually adjusted by the user. All offices had two lamp fluorescent luminaires with dimming ballasts (min. 20%) controlled by a ceiling mounted photosensor. The study showed that daytime savings ranged from 29% to 46%, with the largest savings from the office with the light shelves. The office with horizontal blinds showed the poor savings (32%) and also the poorest light uniformity and level.

Introduction

Recent introduction of electronic dimming ballasts have excited utilities, facility managers, and engineers in their search for new technologies to reduce energy. Previous use of these dimming ballasts was primarily for manual dimming in areas such as conference rooms, although now they are increasingly being used to capture savings automatically in areas where daylight is available. The most common application of these ballasts appears to be in areas daylighted by windows. Typical daylighted offices in warm climates such as Florida often have internal or external shading devices to reduce heat and glare. Common shading devices are window film, vertical or horizontal blinds, drapes, and overhangs.



Vertical blinds in an office at FSEC

While these devices often control heat and glare they do so at the expense of visible light. The reduction in visible light reduces the overall effectiveness of the dimming ballasts. For instance, in three large commercial buildings in Canada (51° N latitude) it was found that daylighting systems functioned poorly due to the use of glazings with low visible transmittance and low interior reflectance (Love, J. A., 1995).



Lightshelves in the South facing windows at FSEC

A literature review yielded few studies that examined the interaction that shading systems have on daylight-linked fluorescent dimming in the field. Schrum et al. (1996) researched the effects of window orientation on savings, however the blinds were fixed in horizontal position. Savings were found to be greatest on the southern exposure (37%). Another study conducted in a Florida school cafeteria, measured savings due to dimming at 27% although many commissioning difficulties were encountered (Floyd et al. 1996). This study expands the knowledge by examining different shading systems in "real world" offices side lighted from the south. In the study, four very similar offices were instrumented to measure power and illumination to determine how different shading devices effect power savings and illumination uniformity. The reason for conducting the study was two fold, first to select a suitable shading device for the southern offices at the Florida Solar Energy Center's newly constructed building and second to evaluate each devices performance, primarily, energy savings, illumination uniformity and glare control.

Office Monitoring

Four occupied offices at the Florida Solar Energy Center were chosen to evaluate different interior shading systems. All offices were identical in size, window opening, and lighting systems. All offices had three walls painted flat white and a single wall (perpendicular to the window) painted flat yellow, green, or blue (68%, 40%, 31% reflectance respectively). While each office did have a different colored wall, this impact appeared to be minor. Comparisons between the office with the lowest wall reflectance (blue) and the office with the greatest wall reflectance (yellow) showed only a 4% difference in average illumination levels at night with the lights on. All offices measured 9' by 13' and were daylighted on the south side by a large window that extended from desktop height to the top of the 9' ceiling. The glazing is spectrally selective to allow most of the visible light spectrum to pass while rejecting the near infrared. They transmit approximately 56% of visible light while rejecting most infrared heat (shading coefficient of 0.33). Each office was lighted by two 12 cell 2 x 4 parabolic luminaires fitted with electronic dimming ballasts (20 -100%) and T8 lamps. Ceiling mounted

photosensors measure the illumination in the space. When light levels increase the ballast throttles down to save energy. The original office design called for both interior and exterior lightshelves, however budget constraints forced the exclusion of the interior lightshelf. This created a severe glare problem at low sun angles, during the winter months, when direct sunlight penetrated through the glazing above the exterior lightshelf. Immediately the office windows became plastered with everything from posters to aluminum foil to reduce the glare and heat. To choose an effective solution to this problem three offices were configured with different shading systems as shown in Table 1. Office #213, the control, was left unchanged.

Table 1

Office #	Interior Shading Device
212	33" Interior diffuse light shelf
213	None
214	White translucent horizontal mini blind
216	33" Interior specular light shelf

Monitoring each office consisted of installing four photometers, arranged from window to wall, in each office at desktop height to measure illumination uniformity and watt-hour meters to measure power. Meters and sensors were polled every 10 seconds and 15-minute averages were recorded. Previous day's data was graphed to identify malfunctioning instrumentation and monitor the project. Lamps were aged over 100 hours and the ceiling mounted photosensors were adjusted so that each office dimmed identically.

Results

As shown in Figure 1., the greatest energy savings (46%) were achieved in the offices with the interior light shelves. It is interesting to note that the difference in energy savings between the lightshelf with the diffuse surface compared with the lightshelf with the specular surface is negligible. This appears counter-intuitive and is most likely due to the ballasts inability to dim further. Another interesting outcome is the poor energy savings achieved in the office with only an exterior light shelf. The measured power data reveals only 30% savings for this office although illumination levels were some of the highest. Even more interesting, this office saved less energy than the office with the translucent horizontal blinds. This rather unusual outcome is probably due to the location of the photosensor that controls the dimming. It attempts to measure the illumination in the room by measuring the reflected light underneath it. The photosensor design also uses an exposed lens that collects light rays running parallel to the ceiling such as the case in the offices with lightshelves and blinds. In the office with the translucent horizontal blinds (and the lightshelves offices) more light would strike the ceiling mounted photosensor and dim further, saving more energy. This was confirmed by shinning a flashlight parallel to the ceiling and observing a reduction in power.

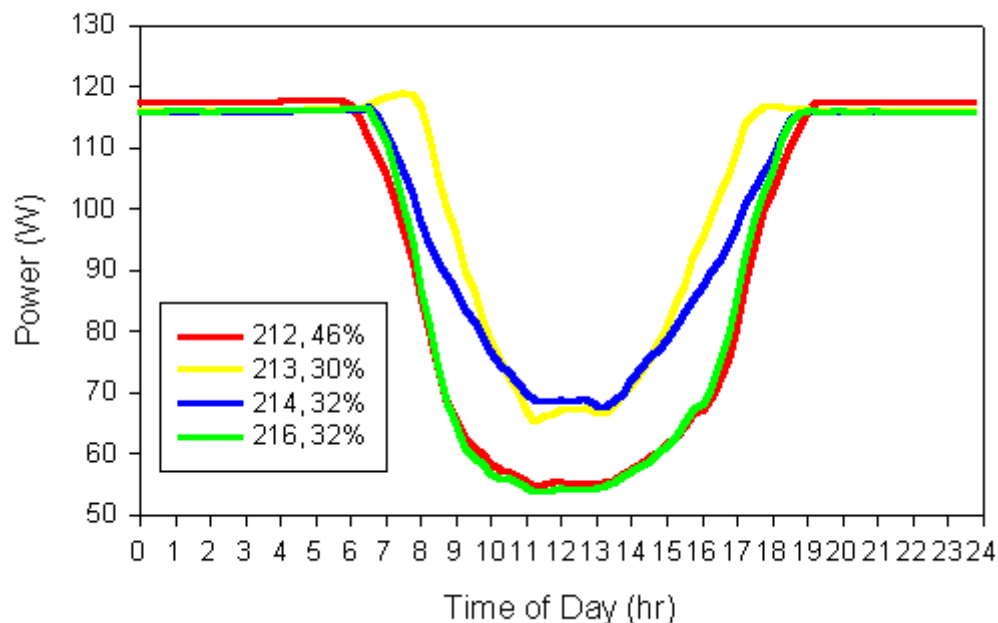


Figure 1. Average daily power usage by office.

As expected, illumination levels were greatest in the office with no interior shading device and were the least in the office with the translucent blinds as shown in Figure 2. Comparisons of individual photometers showed improved lighting uniformity with lightshelves over the control office and the office with blinds. The office with the diffuse lightshelf showed slightly higher light levels than the office with the specular lightshelf although the differences were not profound and were most likely due to differences in photometer placement. The other noticeable difference between the specular and diffuse surfaces was the bright shadows cast by the specular light shelf. While these shadows were rather intriguing, the occupant often complained about the glare.

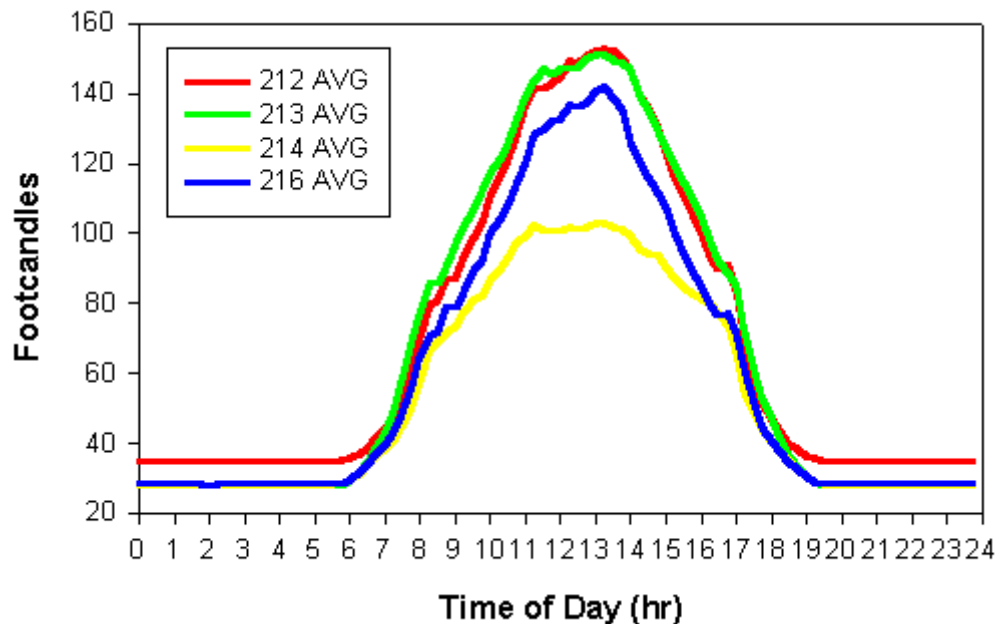


Figure 2. Average daily illumination by office.

Conclusions

In this study, the energy savings from dimming increased by more than 50% when lightshelves were used rather than horizontal blinds. The offices with lightshelves both saved 46% on average through the one year monitoring period. The office with translucent horizontal blinds saved slightly more than the control office, which had no interior shade (32% compared to 30%), although the average light levels were greater in the control office. Adding the specular surface to the top of the lightshelf had little impact on the energy savings or desktop light levels, probably due to the ballasts' inability to dim further and ceiling mounted photosensor design. Lightshelves with specular surfaces would have applications where light needs to be reflected greater distances into the interior. The increased savings, realized from the use of these light shelves, demonstrate the importance of incorporating advanced lighting control if substantial energy savings are to be achieved. Also the practice of measuring light using a ceiling mounted photosensor appears to have limitations due to the response of the photosensor to stray light. It appears that an improved design that recessed the Fresnel lens to minimize response from direct window light would perform better. This agrees with earlier investigations of controls (Rubenstein et al. 1989). It must be emphasized that these savings were achieved in offices with advanced glazing and shade control on a southern exposure. Also since the horizontal blinds were controlled by the occupant, savings will vary depending upon the occupants personal lighting preference. Savings will also vary in traditional buildings with smaller windows, darker interior surfaces, and poor shading devices (such as opaque blinds).

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