Pacific Gas and Electric Company

Emerging Technologies Program

Application Assessment Report #0819

High Efficiency Office: Low Ambient/ Task Lighting Pilot Project

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Large Office ("Ziggurat" Building) Site Report

High Efficiency Office: Low Ambient/ Task Lighting Pilot Project

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1. EXECUTIVE SUMMARY

PG&E's Emerging Technologies program funded the design, installation and monitoring of "low ambient / task lighting" in a section of a large office building in West Sacramento, CA (known as the "Ziggurat" due to its stepped-pyramid shape) The Ziggurat is owned by Wells Fargo, operated by CBRE, and occupied by the California Department of General Services.

The goal of the study was to determine whether light levels could be significantly reduced to save energy, while enhancing the visual amenity of the office environment. The low ambient / task approach attempts to improve the visual environment by adding controllable task luminaires that allow occupants to put light where they need it for a given task, while reducing the overhead (ambient) light level from the typical IES recommended level of 30-50 footcandles (fc) down to approximately 20 fc.

The results show that lighting energy use and peak demand were both lower under the low ambient / task lighting than under the old lighting in this specific building, and that occupants also preferred the new lighting over the old.

We analyzed the cost effectiveness of the lighting under various "scenarios" of costs and savings assumptions, which showed simple paybacks of between 4 and 12 years at this site. This lighting approach would have been more cost-effective in new construction or during tenant improvement, than as a retrofit measure, but it achieves simple paybacks under ten years in both cases. Cost-effectiveness is highly dependent upon site-specific equipment cost and labor cost assumptions, and can be expected to improve as the price of the task light fixtures reduces over time and in response to programs and policies.

Figure 1 shows that the existing lighting at the Ziggurat was already more efficient than the statewide average for large offices (as found by the CEUS study), but that the low ambient / task lighting still saved more than half the total lighting energy.

	Existing lighting	Statewide average for large offices (from CEUS)	Low ambient/ task lighting
Installed ambient lighting power density (W/sf)	1.23	Not known[1]	0.56
Installed task lighting power density (W/sf)	0.09	Not known[1]	0.10
Total installed lighting power density (W/sf)	1.32	0.97	0.66
Lighting energy use intensity (kWh/sf/yr)	3.9	4.2	1.7
Peak lighting load (W/sf)	1.26	0.84	0.65

Figure 1. Summary of Energy and Demand Impacts

[1] The CEUS study gathered data on all lighting in the surveyed spaces, including lighting plug loads, but the CEUS report does not present separate numbers for ambient and task lighting.

The low ambient / task approach introduces a different paradigm of office lighting, which goes beyond simple reductions in light level, and is complementary to the use of lighting controls, i.e. photocontrols and occupancy sensors can be used in addition to low ambient lighting to achieve deeper savings. Such control capability could likewise be used enable demand response functionality.

This specific building was suitable for the study because it is typical of many office buildings in northern California and elsewhere. It has almost continuous glazing along a window wall, and three rows of cubicles in parallel rows back from the window. The first row of cubicles receives a significant amount of daylight, the second receives little daylight but gives occupants a view out, and the third gives neither daylight nor a view. The windows are oriented north, which was suitable for the study because it maximized the amount of available diffuse daylight.

Previous lighting research shows that when occupants have increased control over their lighting, their satisfaction with their lit environment increases, and that reductions in ambient illuminance (up to a point) do not result in reductions in occupant satisfaction. PG&E therefore had a good basis to believe that energy and demand savings could be achieved while simultaneously increasing occupant satisfaction with the lighting.

This pilot study assessed the following factors:

- Lighting energy use and peak demand
- Task illuminance levels
- Occupant reactions to the new lighting
- Occupant reactions to a simulated demand response event
- Cost-effectiveness of the lighting system

Further studies with more participants would determine how far the low ambient / task approach can be taken, and what combination of ambient and task lighting yields the optimum savings and occupant response. Accommodating the needs of people with visual impairments and ageing eyes should also be a focus of further studies. One or two full-building retrofits would be a good first step toward quantifying these effects.

Additional savings could be achieved by using photocontrols and occupancy sensors, in the usual way. These controls typically save an additional 20-50% depending on the amount of daylight in the space, and the size of the control zones.

Because the study space was a typical office building, the success of this project should be achievable in many other office buildings. As offices undergo major renovations, implementation of a low ambient/task lighting approach should be a prime strategy to cost-effectively meet the requirements of California's Assembly Bill 32 (The Global Warming Solutions Act), and the Governor's executive order S-20-04.

2. DESCRIPTION OF SPACE

The "Ziggurat" building is located at 707 3rd St, West Sacramento, CA. The building is entirely occupied by the State of California Department of General Services. The north-facing side of the fourth floor was the location for the low ambient/task lighting retrofit. Figure 3 shows the layout of the space, with north toward the top of the page.

The study space included 15 cubicles in the first row (next to the north window), 6 in the second, and 4 in the third. The open office area is divided by 5' partitions in a variety of light pastel colors. The ceiling is 10' above the floor. Electric lighting is provided by three rows of continuous suspended luminaires, suspended 2' below the ceiling. Each row of lights is positioned almost centrally over its corresponding row of cubicles.

The interior finishes were typical for an office building—the walls and partitions had approximately 50% reflectance, the ceiling had 80% , the carpeting had 16%.

Figure 2. Ziggurat Open Office Area, Looking East

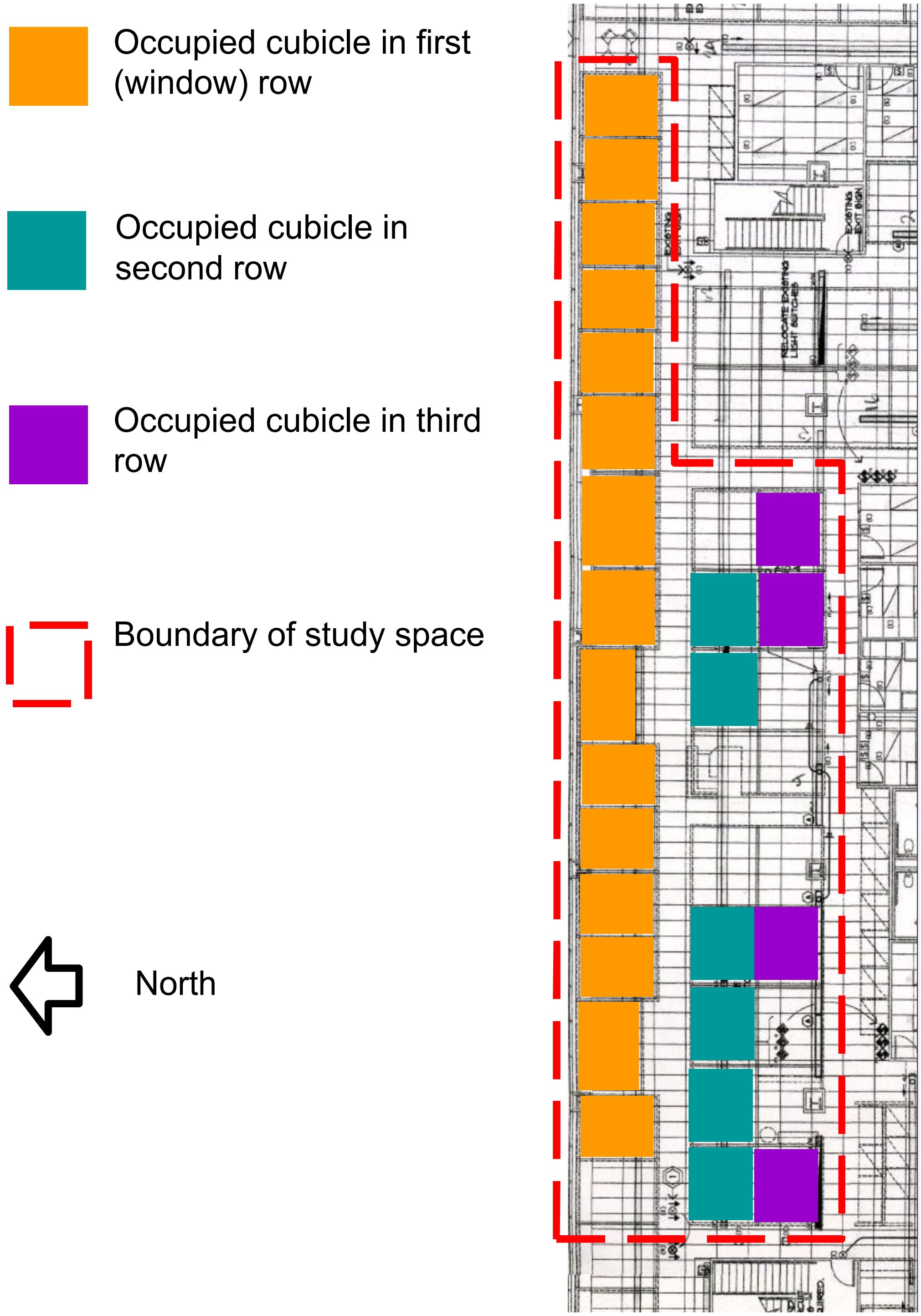

Figure 3. Existing Lighting: Reflected Ceiling Plan

2.1 Daylighting

Daylighting has a major impact on occupants' assessment of spaces, so we have included a detailed description of the daylit conditions. The sample of occupants in this building was too small to draw firm conclusions about whether occupants' assessment of the low ambient / task lighting system was affected by the daylight in their office. .

The 15 cubicles in the first row were adjacent to the almost-continuous glazing. The glazing is interrupted only by columns and other structural elements. The glass itself is double-pane with a white frit that provides a clear view out but reduces the visible light transmittance down to 28% , which is two to three times lower than the transmittance of a typical low emissivity ("low-e") double pane window.

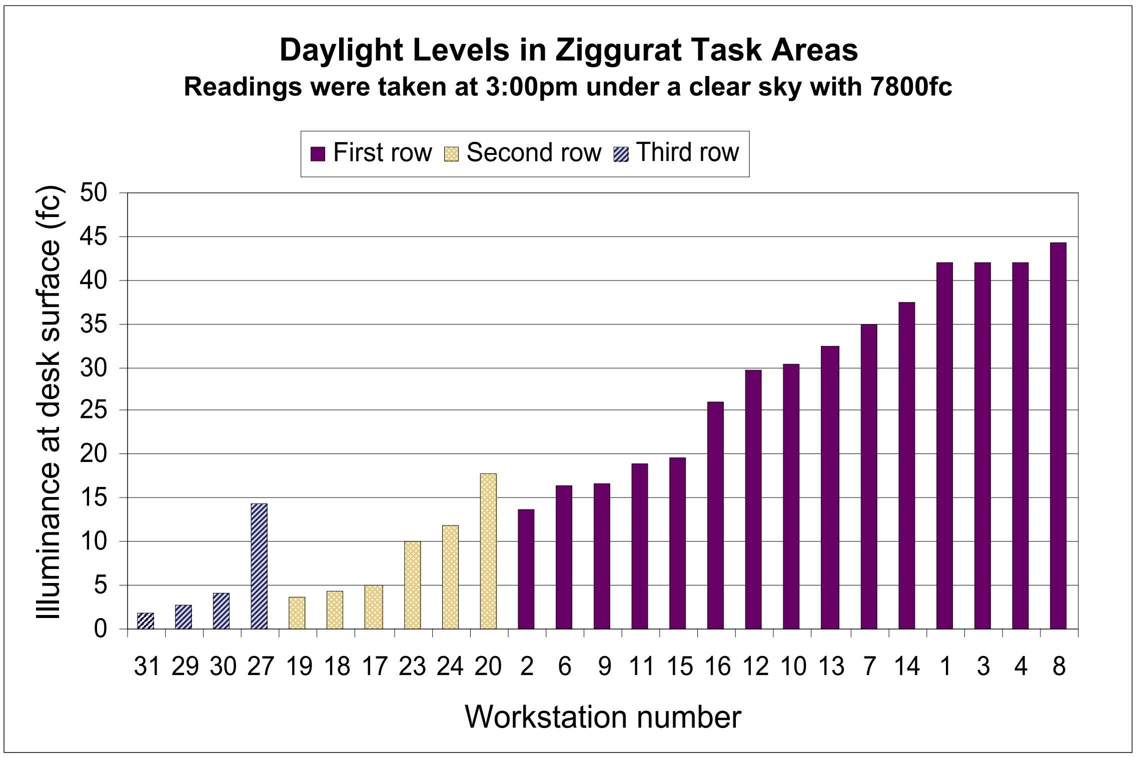

Figure 4. Daylight Levels in Ziggurat Task Areas before Retrofit

Spot measurements of daylight illuminance in task areas are shown in Figure 4. These measurements were taken under clear sky conditions at 3:00 on an June afternoon when the unobstructed exterior illuminance was 7800fc, so they are toward the higher end of typical daylight illuminances in the space over the course of a year. Note that the conditions during the study period were typical of the conditions during a utility system peak, and that during the middle of the afternoon (even with low VLT glass) approximately half the workstations had enough natural light to work by, without additional electric lighting. This potential could be used to gain additional energy savings (via photocontrols) or to achieve demand response (via automatic DR controls).

Although the first row cubicles have generous glazing, the daylight levels are less high than would be expected immediately next to a window, due to the low transmittance of the glass. The 6 cubicles in the second row have work plane daylight levels that are less than 10 fc even during the middle of the day, though they have extensive views out through the north window. The 4 cubicles in the third window have single-digit daylight levels, and no view outside.

Note that one cubicle in the third row (#27) and two cubicles in the second row (#20 and #24) are underneath emergency lights, which could not be switched off during the daylight test, therefore their daylight levels are actually less than the values shown.

The amount of daylight in a space is often expressed as a “daylight factor” i.e. the interior daylight illuminance divided by the simultaneous outdoor daylight illuminance. Office daylight factors are usually in the range 1% -10%. However, daylight factor is defined only for an overcast sky, and the sky was clear for the entirety of the monitoring period at the Ziggurat building, so we have not presented daylight factors.

2.2 Existing Lighting and Controls

The existing ambient lighting was provided by three continuous rows of suspended indirect luminaires, by Peerless lighting. These luminaires were wired to have two identical circuits (multi-level lighting) as required by California' Title 24 building code, so that the light level could be reduced by half while maintaining uniformity of illuminance.

This multi-level functionality was used to provide "time sweep" control—a lighting control system would automatically switch off one of the circuits at a predetermined time, and switch off the remaining circuit some minutes later if occupants did not switch the first circuit back on. There were no other lighting controls in the space.

Each cubicle also had one or more adjustable desk lamps with 13W CFL lamps, by Ibis. Several cubicles had additional undercabinet lamps or desk lamps, of various kinds.

Figure 5. Typical Cubicle, Showing 13W CFL Desk Lamp to the Right of Screen

Figure 6. Existing 13W CFL adjustable desk lamp

The installed lighting power density was 1.23 W/sf for the overhead light fixtures, and 0.09 W/sf for the task lighting.

2.3 Illuminance Levels in Task Areas

Ambient electric light levels in task areas are shown in Figure 7. The average ambient illuminance for each workstation was calculated as the average of three readings, taken at the left and right ends of the keyboard, and at another task area (such as a meeting desk). Values were measured with the task lights and computer screens switched off. The average ambient workstation illuminance was 37fc, with all but three of the 25 workstations falling in the 30-50fc range recommended by IESNA.

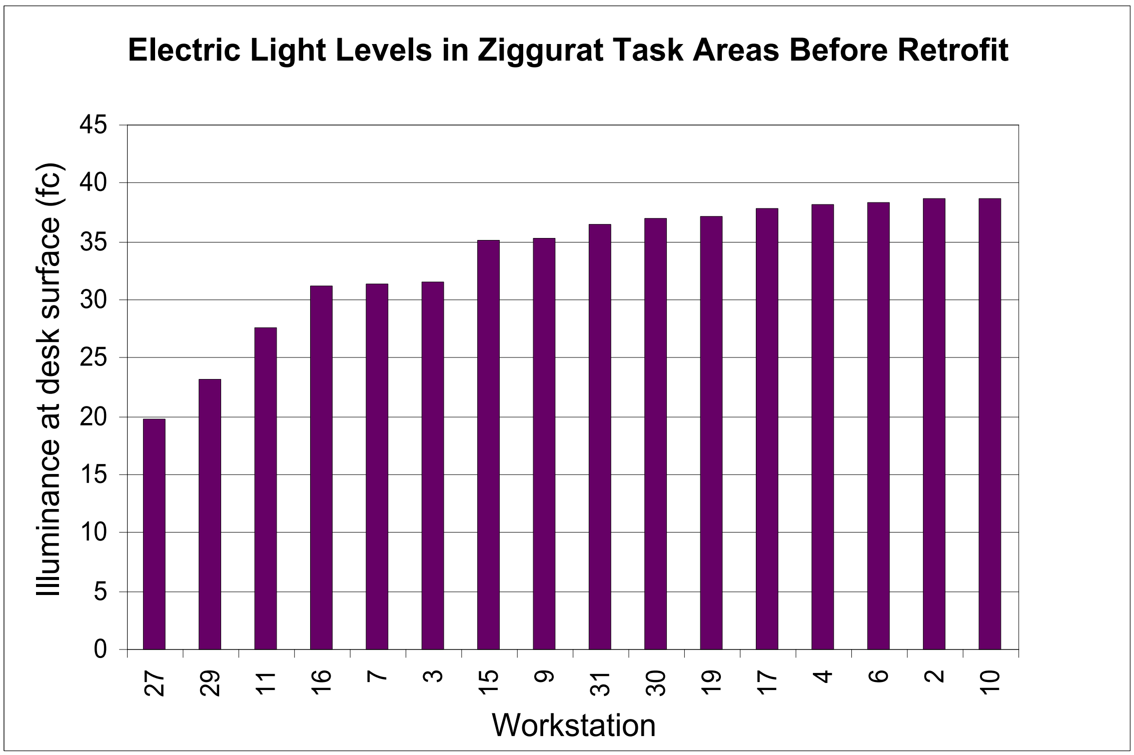

Figure 7. Measured Ambient Electric Light Levels in Task Areas Before Retrofit (excluding task light)

3. LOW AMBIENT/TASK LIGHTING DESIGN

The Department of General Services was interested in retrofitting the entire Ziggurat building with more efficient lighting, so this study acted as a pilot for that larger project. The north side of the fourth floor is typical of almost all the office space in the Ziggurat.

Detailed lighting design and specification assistance was provided by Clanton and Associates, and the overall specification for the system was provided by the Heschong Mahone Group. The new lighting was installed in August 2009.

The low ambient lighting consisted of dimmable ballasts retrofitted into the suspended fixtures, along with new lamps. The total number of lamps in these fixtures was the same as before the retrofit. The dimmable ballasts were tuned after installation to provide light levels close to the 20fc target for low ambient lighting.

The overall appearance of the space after the retrofit was almost identical to the appearance before the retrofit, with the exception that the emergency lighting was more visible, and that the task lighting in the cubicles was more visible. The emergency lighting was provided by 4-lamp ballasts, which produced a bright patch of light on the ceiling.

The study team was aware that if the occupants could see adjacent, untreated areas with higher light levels, they might feel like their lighting was inferior, so the study space was chosen so that there were few visible adjacent spaces.

Figure 8. Low Ambient Lighting: First and Second Row Cubicles, Looking East

The dimming ballasts use 32W per lamp at full output. Because the fixtures were dimmed to 40% of their full output to achieve the desired light level, we deemed the lighting power density to be 40% of the actual installed LPD. In practice, the dimming ballasts were consuming *more than* 40% of their full power at 40% light output, but we were using the dimming ballast only as a "tuning device", whereas in future low ambient projects, instant start ballasts would most likely be installed due to their lower cost, which would avoid the inherent inefficiency of dimming ballasts.

Therefore we deemed the ambient lighting LPD to be 0.56 W/sf (40% of the installed LPD[1]). The task lighting LPD was 0.10 W/sf, which is only marginally more than before the retrofit, despite there being more than twice as many task lights—70 as opposed to 29.

Note that in future projects, dimming ballasts *could* be used to add demand response capability to low ambient systems. Demand response could also be achieved by using multi-level switching of instant start ballasts, or by step dimming ballasts.

The controls of the overhead lights was the same after the retrofit as before, i.e. occupants had no individual control, and the system used a "timesweep" control to switch lights off at the end of the day. No photocontrols were installed.

Figure 9. Task Lighting After Retrofit

There were two types of task lighting installed as part of the retrofit. Figure 9a shows an adjustable 6W LED desk lamp which gave around 40fc immediately under the fixture. Figure 9b shows two 6W LED undercabinet lamps, magnetically attached to a steel cabinet, which also give around 40fc immediately under the fixtures. Details of these fixtures are shown in Appendix C.

[1] Note that even this assumption is conservative, because it is based on the efficiency of the dimming ballast at full power which, while higher than its performance at part load, is still lower than the efficiency of an instant start ballast.

3.1 Illuminance Levels in Task Areas

Electric light levels in task areas are shown in Figure 10. These values were measured with the task lights off. The open office areas averaged 17.5fc (compared to 37fc before the retrofit). Because of the suspended indirect fixtures, light levels were highly uniform across the workstations, with the exception of one or two workstations that were in a corner and fell between two rows of suspended fixtures.

All of the task areas had ambient illuminance levels significantly below the 30fc value recommended by IESNA, though the task lighting was able to increase the task illuminance above the 30fc threshold in all cases.

Compared with the average light levels predicted by the lighting designer, measured levels in the open office were 6% lower. This is a very small difference, and would not be perceptible to the naked eye. The light levels predicted by the designer included typical adjustments for light loss factor, so in the long term the difference between predicted and measured levels will be greater than 6% . The lighting designer's calculations also included detailed modeling of the partitions and furniture, so a more basic lighting model would likely result in a greater over-prediction of task illuminances.

We are not aware of any research into typical differences between predicted and measured light levels, but this difference is more of a concern with a system intended to produce only 20fc than with a system intended to produce 40fc. It may be informative to return to the Ziggurat building in two to three years and re-survey the occupants about their light levels to see if the levels have dropped to an unacceptable level.

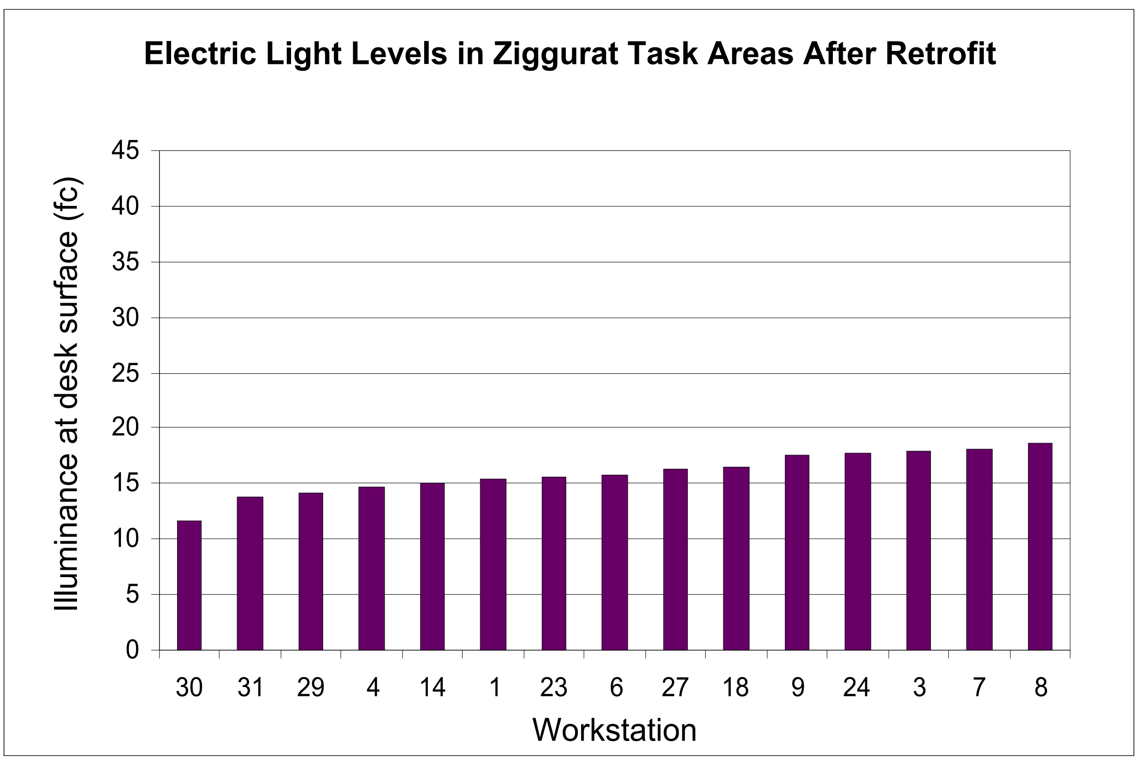

Figure 10. Ambient Electric Light Levels in Task Areas After Retrofit

4. STUDY METHODOLOGY

The Heschong Mahone Group conducted a detailed before-and-after study of light levels, lighting energy use, occupancy, time-of-use of light fixtures and controls, and occupant satisfaction. The energy use of all light fixtures in the space was individually logged over two three-week periods using light level loggers, circuit current loggers, and logging occupancy sensors. Details of the logging equipment are shown in Appendix B.

5. COMPARISON OF BEFORE AND AFTER RETROFIT

The low ambient lighting system significantly reduced both energy consumption and peak demand compared to the existing lighting, and resulted in a statistically significant improvement in occupants' assessment of the lighting system.

5.1 Occupant Satisfaction

The 25 occupants of the study area were given an online survey that asked about their views on the lighting, and their specific behaviors with regard to the lighting and blinds. The survey included the same questions both before and after the retrofit so that occupants' responses could be analyzed statistically, and in order not to introduce bias into the questions.

Occupants said that they were more satisfied with the new lighting than the old lighting in terms of their responses to every one of the questions. The improvement in satisfaction between the existing and retrofit lighting was statistically significant in several of the survey questions.

The responses to each of the satisfaction-related questions is shown below:

- **Attractiveness**

  The question asked "Do you find this room visually attractive?". Responses options ranged from *Very unattractive* (1) through *Very attractive* (7).

  The average response before the retrofit was 4.9; after it was also 4.9, i.e. there was no significant difference in average response between the before and after condition.

- **Comfort**

  The question asked "Do you feel that the lighting conditions are comfortable? ". Responses options ranged from *Never* (1) through *Always* (7).

  The average response before the retrofit was 5.4; after it was 6.0, i.e.,. the respondents rated the low ambient / task lighting as more comfortable. This difference is statistically significant at the 90% level.

- **Overall visual quality**

  The question asked "Overall, how would you rate the lighting at your personal workspace? ". Responses options ranged from *Poor* (1) through *Excellent* (7).

The average response before the retrofit was 5.1; after it was 5.9, i.e.,. the respondents rated the low ambient / task lighting as having higher overall visual quality. This difference is statistically significant at the 95% level.

- **Comparison with others' workspaces**

  The question asked "Compared to other people's workspaces, the lighting in my workspace is: ". Responses options ranged from *Much worse* (1) through *Much better* (7).

  The average response before the retrofit was 4.6; after it was 4.8, i.e. the respondents rated their workspace as more comfortable than others' workspaces in both the pre and post conditions, but slightly more so in the post condition. This result is not statistically significant.

- **Dark areas**

  The question asked "Do you ever feel that part of your workspace is too dark? ". Responses options ranged from *Always* (1) through *Never* (7).

  The average response before the retrofit was 5.3; after it was 5.6, i.e. respondents found that their workspaces were less prone to have too-dark areas under the low ambient / task lighting. This result is not statistically significant.

- **Bright areas**

  The question asked "Do you ever feel that any part of your workspace is too bright? ". Responses options ranged from *Always* (1) through *Never* (7).

  The average response before the retrofit was 5.7; after it was 5.9, i.e. respondents found that their workspaces were less prone to have too-bright areas under the low ambient / task lighting. This result is not statistically significant.

- **Satisfaction under task lighting only**[1]

  The question asked "Are you satisfied working in this room with some of the overhead lights turned off?" Responses options ranged from *Very unsatisfied* (1) through *Very satisfied* (7).

  The average response before the retrofit was 4.4; after it was 5.8, i.e., the respondents said they were much better able to work with the overhead lights switched off under the new lighting. This difference is statistically significant at the 95% level. This result is not surprising, given that many occupants had no task lighting before the retrofit, and most had only one desk lamp.

- **Preference between the old and new lighting systems**

  The question asked "Do you prefer the new lighting system to what was here before the retrofit?" Response option ranged from *Strongly prefer old lighting* (1)

[1] This question was asked before the simulated demand response event. Because the overhead lighting was centrally controlled, the occupants would not have been able to work under task lighting alone unless they were working after hours, so it is unlikely that most of them had experience of this condition.

through *Strongly prefer new lighting* (7). The average response was 5.1, i.e. respondents preferred the new lighting system. This result is statistically significant at the 99% level, i.e. the strongest result in the occupant survey. Of the 17 respondents, several were neutral but *none* preferred the old lighting to the new lighting.

5.1.1 Occupant Use of Task Lights

Occupants' use of their new task lighting is of interest in this study because it shows the extent to which task lighting energy use and savings are dependent on occupants exercising personal control via a manual switch. We have presented data about the occupants use of the new task lighting, but not their use of the existing task lighting, because their existing lighting is not a focus of this study.

After the new task lighting had been installed, occupants were asked about their typical use of task lighting during their work day. The question asked about whether and when they switch their task lights *off* (rather than *on*), because asking the question this way gives insight into both their on- and off-switching habits. Of the seventeen people who gave an answer to the question "when do you switch your desk lamp(s) off? (*select all that apply*)":

- Seven said "When I leave work"
- None said "When I leave for lunch"
- One said "When I leave my desk"
- One said "When there's enough daylight to work by"
- Two said "When I am done with a special task, like reading"
- Five said "Never--my task light is always off"
- Two said "Other", and both these people indicated that they rely on the inbuilt occupant sensor to switch their task lights off.

These results suggest a fairly low degree of interaction with the task lights, i.e. most people either only switch their task lights off when they leave work, or they never switch them on. Figure 11 shows the actual likelihood of a person switching their task lights on or off during a given hour, based on the logged data. This figure indicates that the likelihood of a task light being switched either on or off during a given working hour is about one in twelve (in Figure 11, the average likelihood during a working hour is 0.08, or one in twelve).

Figure 11 shows a morning peak of on-switching, and an afternoon peak of off-switching. It also shows that some task lighting is switched both on and off fairly often throughout the day, presumably by the people who said in the survey that they switch their task lighting whenever they leave their desk, or when they're performing a visual task.

These results suggest that, as shown in other lighting research, there is a high degree of variation in how people use their personal lighting equipment—some use it actively, some use it on a set schedule, and some never use it at all. This suggests that, following the installation of task lighting, some "horse trading" should be expected between the people who want more adaptable task lighting and people who do not want or use it.

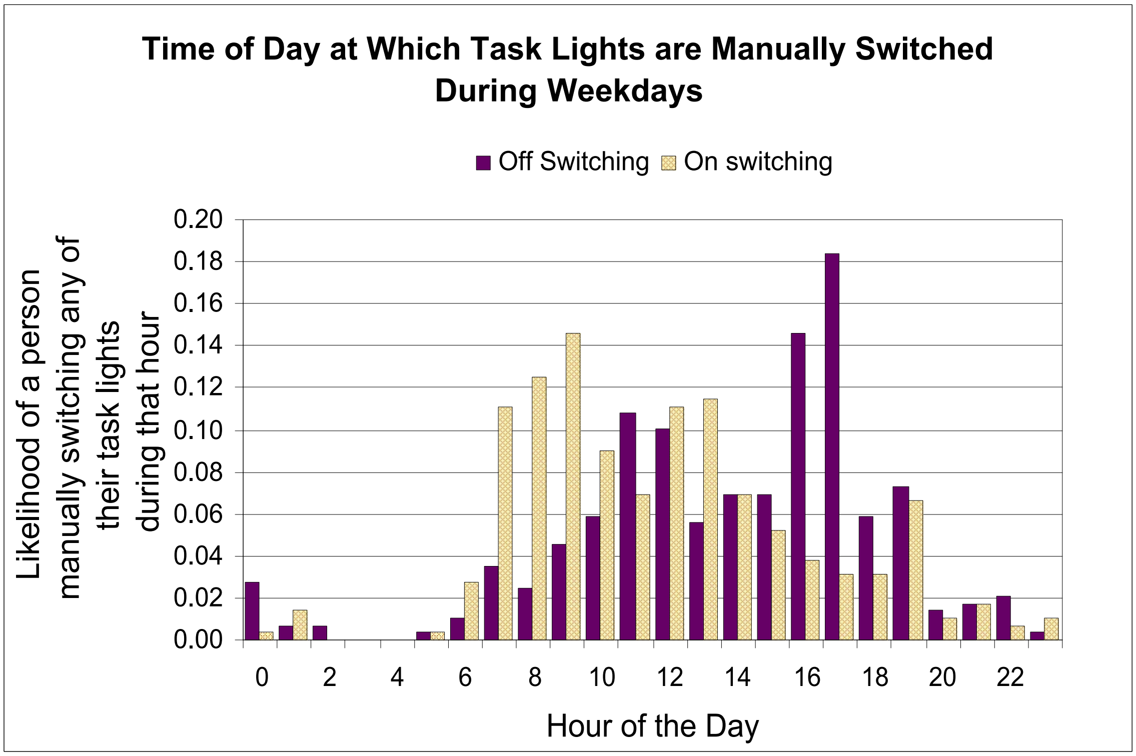

Figure 11. Time of Day at Which Task Lights are Manually Switched During Weekdays

5.2 Energy Use

Throughout this section we have applied a 23% downward adjustment to the energy consumption of the low ambient lighting system, because the installed system uses dimming ballasts which are less efficient than the instant start ballasts that would be used in future installations. The dimming ballasts were used to give the research team flexibility in adjusting light levels and running the trial demand response event. In future installations, demand response capability could be achieved by correct circuiting of instant start ballasts, or by multi-level ballasts, as an alternative to dimming ballasts.

The downward adjustment of 23% is arrived at by comparing the actual power consumption of the ambient system as installed (0.73 W/sf) with our best estimate of the power density that *would* have been used by an instant start system to deliver the same amount of light (0.56 W/sf), as calculated in section 3.

Figure 12 shows hourly lighting power density data averaged over the monitoring period, broken out by weekends versus weekdays. Figure 12 clearly shows the effect of the timesweep controls that attempt to switch the lighting off at 6pm, followed by an evening cleaning period during which the lighting is switched back on for around one hour.

By summing the hourly power consumption data over the monitoring period, and projecting this up to an entire year (with appropriate adjustments for the number of weekends and holidays), we calculated the lighting energy use intensity (for overhead lighting). This dropped from 3.9 kWh/sf/yr before the lighting retrofit to 1.7 kWh/sf/yr afterward.

The similar *shape* of the "pre" and "post" graphs in Figure 12 shows that the reduction is due to a simple reduction in load, rather than to the elimination of wasted energy outside business hours, i.e. the lighting control system was functioning in the same way after the retrofit as it was before.

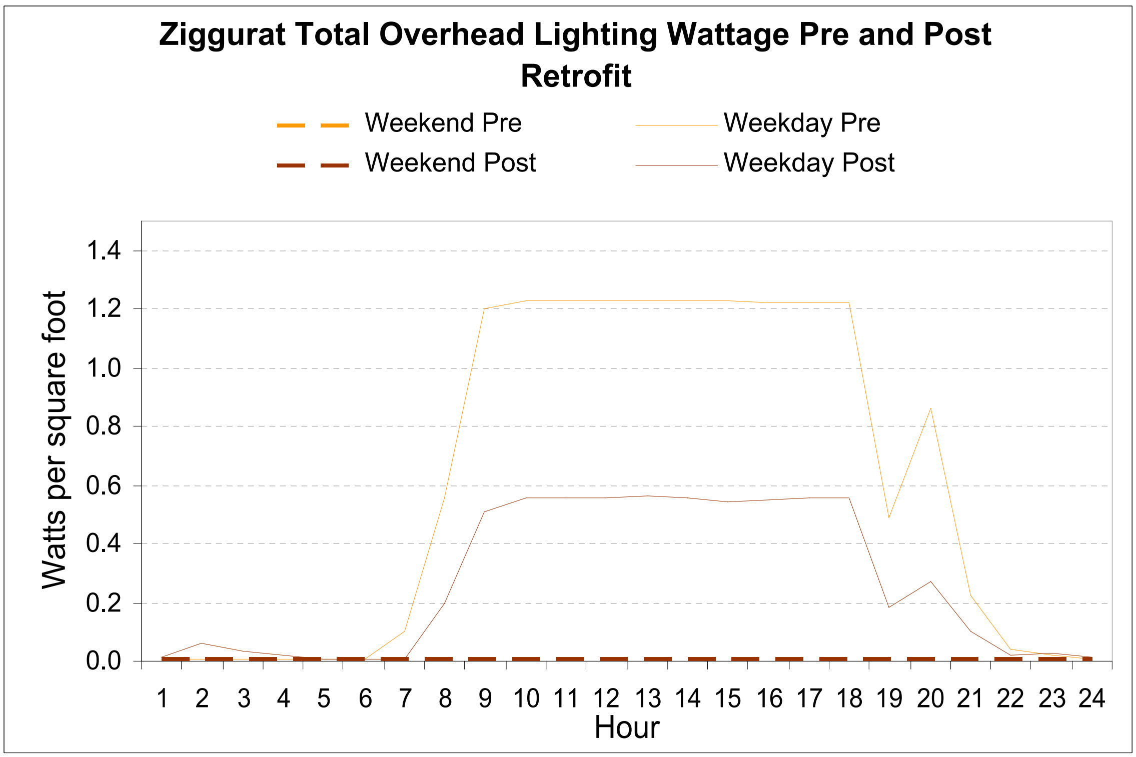

Figure 12. Lighting Power Consumption Profiles Pre and Post Retrofit

Note that the emergency lights in the space are fed by a different circuit from the rest of the overhead lighting, and that the emergency lights are left on twenty four hours a day. To maintain a proper experimental control we did not install controls to switch the emergency lighting off overnight.

Part of the experimental design was to install occupancy sensors to control the task lighting in some cubicles but not others, to investiage wheterh they achieve additional energy savings. However, during the post-installation survey only six of the occuypancy sensors were still in place, and this gave a sample that was too small to analyze statistically. The cubicles with the occupancy sensors actually used more task lighting energy (5.3 versus 2.5 hours per day, but the difference was not statistically significant).

The task lighting does not contribute significantly to the overall energy use of the space. The peak load from the 396 watts of task lighting was only 108W, compared to the peak load from the overhead lights, which, even after the retrofit, was around 2400W. Figure 13 shows the proportion of time for which the LED task lights were switched on, for both weekdays and weekends. They show that the occupants were somewhat conscientious about switching their task lights off in their personal space when they left for the evening. Close inspection of the data showed that only one person out of twenty four habitually left their task lighting on overnight.

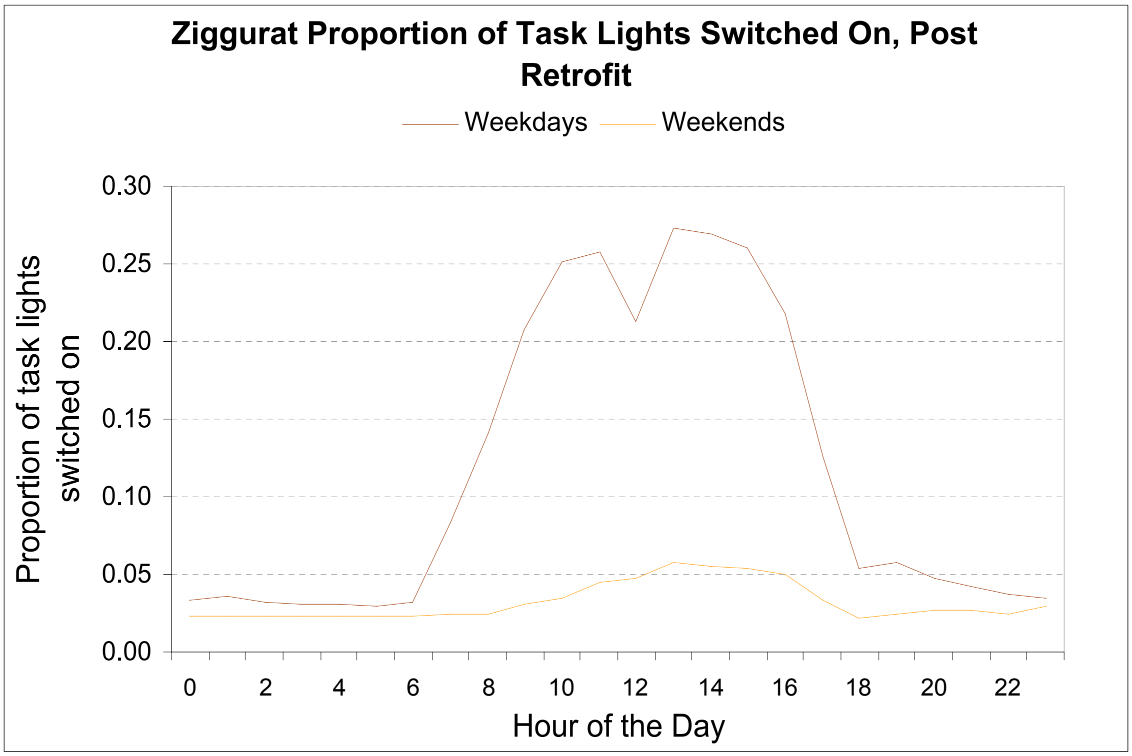

Figure 13. Use of LED Task Lighting

5.3 Peak Demand

Weekday Peak demand was reduced by 0.67 W/sf, from 1.23W/sf down to 0.56 (see Figure 12). The reduction in demand was very uniform throughout PG&E's "peak period" from 12pm to 6pm, because the overhead lighting was not switched until the end of the work day.

6. SIMULATED DEMAND RESPONSE EVENT

One of the features of a low ambient / task lighting system is its potential to achieve more dramatic lighting power reductions than a typical lighting system, in the event of a system emergency. This is because occupants should be able to continue to work for a short period under very low ambient levels (potentially as low as the 5fc recommended by IESNA for navigation) because their task lighting is still switched on and is providing sufficient illumination for work tasks. Although many existing offices have some task lighting, it is typically too patchy to rely on for task illumination in the event that the ambient lighting is switched down to a very low level.

At the Ziggurat, we conducted a simulated demand response event during which the ambient lighting was reduced from its already very low level down to an average of 12fc, a reduction of approximately 30% , or 0.18 W/sf (see Figure 14). The reduction happened over a period of less than two seconds, and was achieved by manually dimming the ballasts.

	Regular low ambient lighting	Simulated demand response event
Ambient illuminance	17.5 fc	12 fc
Ambient lighting power density	0.56 W/sf	0.38 W.sf

Figure 14. Simulated Demand Response Event Illuminance and Power Density Values

The simulated demand response event was designed to replicate what would occur if a lighting system with instant-start ballasts on multi-level switches, or programmed start multi-level ballasts were used, instead of dimming ballasts. We designed it in this way because we anticipate that most potential adopters would prefer to avoid the added cost and efficiency penalty of dimming ballasts.

Note that the reduction in illuminance was uniform across the space. The luminaires in the first (window) row were not switched off completely, although they could easily have been, given the high level of daylight in those cubicles. Also note that in new construction offices, photocontrols would likely be required in the window row (primary daylit zone) which would reduce the amount of power available for demand response.

The occupants were notified in advance that a “test” of the demand response capability of the lighting system would be conducted between 1:30 and 3:30 on a specific day. They were given a phone number to call if they had questions or concerns either before, during or after the event. No phone calls were received.

During the demand response event, the occupants used their task lighting more than they did during comparable periods on other days. The average task lighting wattage during the two hours of the event was 142W, compared to the average wattage during the same hours on other weekdays, which was 107W. This suggests that the occupants were actively using their task lights to compensate for the reduction in overhead illumination.

An online survey was sent to the occupants immediately after the event, so that the experience would be fresh in mind. 18 people completed the survey, of whom 13 responded that they had been at their desk for at least some of the time between 1:30 and 3:30 (those who had not were excluded from the analysis).

The respondents mostly did not notice the changes in the lighting, and those who did were not bothered by it. All of the respondents said they were able to work comfortably under the reduced light level, and all said that they thought that this would be a suitable approach for responding to a statewide power emergency. The respondents were asked whether they took any action in response to the changes in light level (such as switching their lights on and off), but none of them claimed to have taken any action.

The survey responses are summarized below:

- **Did you notice a change in the lighting?**

	At 1:30?	At 3:30?
No	8	10
Yes, it was perceptible but didn't bother me	5	2
Yes, and it was annoying	0	0
Yes, it was annoying and disrupted my work	0	0

- **How would you describe the lighting conditions between 1:30 and 3:30?**

I was able to work comfortably	13
I was able to continue work, but with some discomfort or difficulty	0
I was not able to continue work	0

- **Do you think that this approach of reducing light levels to respond to a statewide power emergency would be appropriate in this space, going forward?**

Yes	13
No	0

7. COST-EFFECTIVENESS

Cost-effectiveness is calculated by comparing the lighting energy savings over the expected life of the system, with the difference in initial cost between the low ambient lighting and the lighting that would otherwise have been installed. We have quoted all costs per square foot, and paybacks in terms of simple payback period. Details of the costs and savings are shown in Appendix C.

There are several different scenarios that could occur in a building:

1. Reduction of lighting wattage and light levels by simple delamping (*does not* trigger Title 24 compliance)
2. Group replacement of lamps and ballasts in existing luminaires, where the customer was intending to replace ballasts for more efficient models to reduce LPD close to Title 24 levels (*does not* trigger Title 24 compliance[1])
3. Group replacement of lamps and ballasts in existing luminaires, where the customer was *not* intending to replace the ballasts anyway (does *not* trigger Title 24)
4. Complete replacement of more than half the luminaires (triggers Title 24 compliance)
5. New construction (triggers Title 24 compliance)

The two scenarios that trigger Title 24 compliance, trigger slightly different levels of Title 24 compliance especially with regard to wiring and controls, with different associated costs. See Title 24 2008 Sections 149(b)F and I.

Note that when Title 24 compliance is triggered, the savings that can be claimed by a lighting incentive program reduce, because the baseline for comparison becomes a Title 24 compliant system, with (usually) a lower lighting power density and more controls than the existing lighting system.

We anticipate that most low ambient installations will take place under one of three likely scenarios (shown in Figure 15). We have termed these “luminaires retained—end of ballast life” (scenario 2 above), “luminaires retained—ballasts midlife” (scenario 3 above, as at the Ziggurat), and “luminaires replaced ” (scenarios 4 and 5 above). A complete explanation of the assumptions made in each scenario is given later in this section, and full details of costs are shown in Appendix C..

[1] Title 24 2008 Section 149(b)1.

	Luminaires retained (ballasts replaced)		Luminaires replaced
	End of ballast life	Ballasts Midlife	
What would the customer have done, if not low ambient / task lighting?	Would have replaced ballasts with more efficient models, at approximately T24 LPD	Would have taken no action	Would have replaced the luminaires with new ones
Basis for customer costs	Task lighting fixtures, *minus* the avoided cost of some ambient ballasts	Task lighting fixtures plus replacement ballasts	Task lighting fixtures, minus the avoided cost of some ambient luminaires
Customer cost ($/sf)	$1.91	$5.97	$0.80
Basis for customer savings	Relative to Title 24 lighting power density	Relative to existing lighting	Relative to Title 24 lighting power density
Customer savings ($/sf/yr)	$0.21	$0.48	$0.21
Simple payback (years)	9.1	12.4	3.8

Figure 15. Summary of Paybacks Under Three Likely Scenarios

"Luminaires Retained" Scenarios

End of Ballast Life Scenario

This scenario assumes that the customer was planning to replace the ballasts in their existing fixtures, but not to replace the fixtures themselves. This may occur because the luminaires have been installed for ten years or so, and ballasts have begun to fail due to end of life. Or it may occur because the customer has a desire to reduce lighting power consumption in line with corporate or institutional goals, or for financial savings.

The estimated incremental cost of the low ambient / task lighting over what would otherwise have been installed was $1.91/sf, which is the $3.06/sf for the task lighting luminaires, minus $1.15 in avoided costs because fewer ballasts are required by the low ambient system. The annual reduction in energy cost is $0.21 (see Appendix C). This gives a simple payback of 9.1 years. The payback period is highly susceptible to the cost of the task lighting and the avoided costs of the project.

Ballasts Midlife Scenario

This calculation represents what occurred during the Ziggurat retrofit, but we believe it is a less likely scenario for future projects. It assumes that the lighting system would not have been changed at all unless the low ambient / task lighting was installed, so this scenario has by far the highest costs (it includes the cost to remove and replace all ballasts), but also the highest savings since they're relative to the existing lighting.

At the Ziggurat, the total cost of the new task lighting was $3.06/sf, and the cost of the equipment and labor to install new ballasts in the overhead lights was $2.91/sf, for a total cost of $5.97/sf.

The savings, comparing the new lighting system with the *existing* lighting (not with a Title 24 baseline) are $0.48/sf/yr, giving a simple payback (without any utility incentives) o f 12.4 years.

Note that the customer would benefit from some avoided cost of spot replacing lamps and ballasts (because for the first few years the new lamps and ballasts would fail less frequently than the old ones), but lamp spot replacement costs are low, and ballasts replacement costs are hard to quantify because ballast failure rates are not well documented.

"Luminaires Replaced" Scenario

This is the most likely scenario for both retrofit and new construction projects. This calculation assumes that all of the overhead lighting would be removed and replaced with new luminaires. This typically occurs during tenant improvement, and in new construction.. Under this scenario, the avoided cost would be greater than in the "End of Ballast Life" scenario described above, because compared with a conventional lighting system, fewer *luminaires* could be used in the new lighting system (not just fewer ballasts and lamps). Under this assumption the costs of the project would be the $3.06/sf for the task luminaires, minus $2.26 ni avoided costs due to fewer luminaires and ballasts. The annual reduction in energy cost relative to a Title-24 compliant system is $0.21. This gives a simple payback period for the Ziggurat building of 3.8 years, i.e. the savings would pay for the incremental costs three or four times over, during the life of the new equipment, even with a reasonable discount rate.

8. CONCLUSIONS AND RECOMMENDATIONS

The low ambient / task lighting system in this pilot study reduced the ambient light level from an average of 37fc to an average of 17.5fc, and was highly successful in terms of saving energy, reducing peak demand, and improving occupants' satisfaction with the lighting. The reductions in energy use are large both in comparison to the existing lighting and to standard practice under California Title 24. The project was also cost-effective, with a simple payback of between 4 and 12 years, depending on what the customer would have done if the system had not been installed (i.e., the baseline assumptions).

The cost-effectiveness of the low ambient approach can be expected to improve as the price of the task light fixtures reduces over time. It is highly likely that adoption of this approach as a "standard" for State of California office buildings would place significant downward pressure on the incremental costs of such systems—significant business volume would be created by the State facilities themselves; the State practices would almost certainly be emulated by others.

Because the study space was a typical office building, the success of this project should be achievable in many other office buildings. Specifically, because this project was conducted in a building operated by the California Department of General Services, this project success may be repeated in other, similar buildings elsewhere in the state.

We recommend that owners and tenants of any office space that is undergoing a lighting renovation should consider a low ambient approach to improve the visual environment and to meet corporate goals for energy use reduction.

We also recommend that at least one or two full-building retrofits should be conducted to study more participants under a wider range of circumstances, to determine the limits of how much energy can be saved using this approach, and to ensure that the needs of people with visual impairment and ageing eyes can be accommodated at least as well as by existing lighting systems. . Further research could be used to show the extent to which lighting controls (including photocontrols and occupancy sensors) could produce additional incremental savings, and/or DR potential. Typically, additional savings in the 30% range are feasible from photocontrols (including both daylit and non-daylit areas of the space).

It would be possible to conduct this research in conjunction with an incentive program that would encourage large property owners to implement low ambient retrofits, or in conjunction with the Department of General Services if they decide to pursue this approach more generally in their offices.

It is also possible that this approach could be implemented with direct luminaires, as opposed to the indirect luminaires used at the Ziggurat. Using direct luminaire would make it possible to use low ambient lighting in a much greater number of office spaces statewide. Further study, possibly under an Emerging Technology project, would be required to determine whether the low ambient approach can be successfully implemented with direct luminaires.

APPENDIX A—LOGGING EQUIPMENT

HOBO Light Level Loggers

Size – (2.25” H x 1.75” L x .75” D) (2.75” H x 2.25” L x .75” D). Records temperature, relative humidity, and light intensity. Attaches to ceiling T-bar with clip.

Onset Current Transformers

Size – (3.0” H x 2.5” L x 1.0” D). Measures AC current and records data with attached HOBO data logger. Clamps around hot/neutral wire in circuit panel.

APPENDIX B—LIGHTING EQUIPMENT

Details of the major luminaire types used in the project are shown below:

- Finelite PLS 6W LED Desk Lamp
- Technical cut sheet: http://www.finelite.com/download_files/PLS_downloads/PLS%20Spec%20Sheets.pdf
- Finelite PLS 6W Undercabinet Lamp
- Technical cut sheet: http://www.finelite.com/download_files/PLS_downloads/PLS%20Spec%20Sheets.pdf

APPENDIX C—DETAILS OF COST-EFFECTIVENESS CALCULATIONS

Figure 16 shows all the figures used in the cost-effectiveness calculations. Further explanation of the sources of the data and the calculations used are given in the sections below the table. Note that the savings include an additional factor due to the reduction in the building's cooling load, which adds approximately 20% to the lighting savings[1].

		Title 24 2008	Existing lighting	Low Ambient lighting
	Energy use (kWh/sf/yr)	2.7 (estimated)	3.9	1.7
	Peak load (W/sf)	0.88 (estimated)	1.26	0.59
	Installed ambient lighting power density (W/sf)	0.85 (max allowed in this space under Title 24)	1.23	0.56
	Installed task lighting power density (W/sf)	0.1 (half of the max allowed in this space under T24)	0.09	0.10
	Energy savings relative to a typical T24 compliant system (kWh/sf/yr)	N/A	-1.24	0.96
A	Cost savings per year relative to a typical T24 compliant system at $0.18/kWh ($/sf/yr). Includes 20% factor for cooling load savings	N/A	0	$0.21
B	Cost savings per year relative to existing lighting	N/A	0	$0.48
C	Incremental task lighting cost relative to a similar T24 compliant system ($/sf)	0	N/A	Equipment $2.72 Labor $0.34 TOTAL $3.06
D1 D2	Reduced overhead lighting cost relative to a similar T24 compliant system ($/sf)	0	N/A	$1.15 (retain) $2.26 (replace)
E1=C-D1 E2=C-D2	Total incremental cost of low ambient system relative to similar T24 compliant system	0	N/A	$1.91 (retain) $0.80 (replace)

Figure 16. Details of Cost-Effectiveness Calculations (continued overleaf)

[1] Rundquist, R.A. ; Johnson, K.F. ; Aumann, D.J, Calculating lighting and HVAC interactions, ASHRAE Journal (American Society of Heating, Refrigerating and Air-Conditioning Engineers); (United States); Journal Volume: 35:11, and Osman Sezgen and Jonathan G. Koomey, Interactions Between Lighting And Space Conditioning Energy Use In U.S. Commercial Buildings, LBNL report number 39795.

F	Cost of replacing ballasts in existing suspended lighting with ballasts suitable for low ambient	N/A	N/A	Equipment $0.55 Labor $2.36 TOTAL $2.91
=E1/A =E2/A	Simple payback relative to similar T24 compliant system	N/A	N/A	9.1 years (retain) 3.8 years (replace)
=(C+F)/B	Simple payback relative to existing lighting	N/A	N/A	11.1 years

Figure 16 (Continued)

Equipment and Labor Costs

This section sets out the assumptions and values used for equipment and labor cost calculations.

Labor Costs

We have assumed that labor costs $100/hr[1], and that no additional design fees are incurred.

The time taken by the contractor to install all the new lighting at the Ziggurat was 128 hours. It was not possible to break this time down into component tasks, so we have estimated the components of time as follows:

- Installation of task lighting and power supplies — 15 hours
- Demounting and remounting of luminaires, and removal of existing ballasts — 60 hours
- Installation and wiring of (105) new ballasts and lamps — 53 hours

Incremental Equipment Costs

The cost of the task lighting (desk lamps and undercabinet lamps), including transformers and cabling, was $2.72 per square foot. The labor cost for installing these lights was $0.34 per square foot. This sums to a total additional cost of $3.06 per square foot.

Avoided Costs

We used an instant start ballast cost of $39 per twin-lamp ballast[1], $3 per lamp, and an installation cost of $50 (from the Ziggurat site costs, the approximate time taken to rewire

[1] From RS Means 2009. National average hourly loaded rate for an electrician is $70. Adding a typical 10% weight for California yields $77. Electricians typically add costs for callout, transportation, and/or overtime, so we have assumed average hourly rate, in practice, of $100.

a ballast was half an hour). We then multiply this total ($95) by the difference in the total number of ballasts required for the low ambient installation versus a typical installation (52). This yields a total avoided cost of $1.15 per square foot, under the "Ballast End Of Life" scenario.

Note that because of work efficiencies due to the large size of the Ziggurat office, our calculated value of $76 is slightly less than the value given in RS Means 2009 for ballast replacement ($120 per ballast[2])

Luminaires Replaced

Under this assumption, we use the avoided equipment cost and labor cost due to using fewer overhead luminaires. This is the relevant cost basis to use for new construction projects. Using the typical cost of $72/linear foot from RS Means 2009[3], the avoided cost from fewer fixtures works out to $2.26 per square foot.

Energy Cost Savings Relative to Baseline Title 24 Compliant System

Energy savings are calculated not in comparison to the existing lighting, but (more relevantly) in comparison to what *this building* would have consumed if it was lit to the allowed lighting power density under Title 24 2008. Under the whole building method, Title 24 allows 0.85 W/sf of ambient lighting and 0.2W/sf of task lighting.

Using the existing lighting data from the Ziggurat, it consumed 3.9 kWh/sf/yr with its installed wattage of 1.23W/sf of ambient lighting. If this had been reduced to 0.85 W/sf, then the energy consumption would have been reduced proportionally to 2.66 W/sf

By comparison, the *actual* energy consumption of the low ambient system was 1.70 kWh/sf/yr, an estimated saving of 0.96 W/sf/yr. This comparison does not include the difference in task lighting power consumption, because the installed task lighting wattage at the Ziggurat was 0.1 W/sf, and we do not have data on typical installed task lighting wattages or energy consumption in Title 24 compliant buildings.

Therefore the energy cost savings relative to the existing lighting are 0.96 x $0.18 x 20% HVAC multiplier, which is $0.21 /sf/yr.

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[1] From RS Means 2009, includes 10% for profit using the standard cost calculation method. Note that this cost is approximately four times higher than the cost of buying instant start ballasts in very large quantities, but RS Means does not indicate bulk costs, and we have no objective data on bulk ballast costs.

[2] Includes 10% California weighting.

[3] Includes an additional weighting of 10%, typical for California based on the figures given in RS Means