DRAFT REPORT
Under Review by
California Energy Commission

Arnold Schwarzenegger
Governor

DEVELOPING LIGHTING TECHNOLOGIES INTEGRATED OFFICE LIGHTING

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
California Lighting Technology Center

PIER FINAL PROJECT REPORT

May 2008
CEC-500-02-004

This Integrated Office Lighting System project is part of the California Energy Commission's Lighting Research Program (LRP) 1.5. This report is currently under review by the California Energy Commission and will be a part of the final report for LRP 1.5.

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Commission Contract No. 500-02-004
Commission Work Authorization No. M-18230

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Acknowledgements

The California Lighting Technology Center (CLTC) greatly appreciates and wishes to acknowledge the invaluable assistance of the following individuals:

Finelite

Terry Clark

Jeannine Fisher

Erika Faieta

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California Energy Commission

Norm Bourassa

Martha Krebs

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Please cite this report as follows:

Kevin Gauna, Erik Page, Theresa Pistochini, and Michael Siminovitch (California Lighting Technology Center). 2007. *Developing Lighting Technologies – Integrated Office Lighting*. California Energy Commission, PIER Program. CEC-500-2007-XXXX.

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

This report, *Developing Lighting Technologies – Integrated Office Lighting*, is the final report for the Developing Lighting Technologies project (contract number 500-02-004, work authorization number M-18230) conducted by the California Lighting Technology Center. The information from this project contributes to PIER's Buildings End-Use Energy Efficiency Program. For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research or contact the Energy Commission at 916-654-5164.

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Abstract

An effective strategy to reduce the lighting power density in offices while maintaining high quality lighting can have huge energy saving potential for California's one billion square feet of commercial office space. Task/ambient lighting optimizes lighting power density through a reduction in overhead lighting levels supplemented by bringing personal task lights to the workspace. However, energy intensive fluorescent task lights historically have not achieved great energy savings using this strategy. In addition, fluorescent task lights tend to over light the space, causing glare and discomfort for the user.

This project developed a task lighting system using light emitting diode (LED) technology. The individual undercabinet fixtures and desk lamps can be distributed throughout the work space to provide even illumination at less than 21 Watts per office. Combining the task lighting system with complementary low ambient overhead lighting achieves an integrated office lighting solution with unprecedented energy savings. The technology was demonstrated in three office spaces with an average energy savings of 45 percent. The commercial LED task lighting system, the Personal Lighting System, is manufactured by Finelite, Inc. The payback on current pricing is four to seven years for retrofit applications and immediate to one year for new construction or major renovation. Furthermore, if the cost of LED lighting technology decreases as projected, the economics will improve for retrofit applications.

Keywords: light emitting diode (LED) technology, personal lighting system (PLS), task lighting, low ambient design, integrated office lighting system (IOLS), task / ambient lighting

Executive Summary

Interior lighting represents 29 percent of statewide building electricity usage in California (Advanced Lighting Guidelines, New Buildings Institute, 2003). Of that, commercial offices account for 26 percent of the total lighting energy usage (RLW Analytics, Nonresidential New Construction Baseline Study, July 1999). Therefore, office lighting accounts for an astounding 7.5 percent of the electricity used in California buildings. Given the one billion square feet of commercial office space in California, a strategy to significantly reduce the lighting power density in offices while maintaining lighting quality has huge energy saving potential.

Furthermore, energy efficiency in buildings has recently been recognized as one of the most cost effective means for reducing greenhouse gas emissions. A McKinsey & Company report (Reducing US Greenhouse Gas Emissions: How Much at What Cost, US Greenhouse Gas Abatement Mapping Initiative Executive Report, December 2007) concludes that " the United States could reduce greenhouse gas emissions in 2030 by 3.0 to 4.5 gigatons of CO_2 using tested approaches and high-potential emerging technologies. These reductions would involve pursuing a wide array of abatement options available at marginal costs less than $50 per ton, with the average net cost to the economy being far lower if the nation can capture sizeable gains from energy efficiency." Lighting in commercial buildings is identified as being immediately cost effective with some of the largest impact potential (Figure 1).

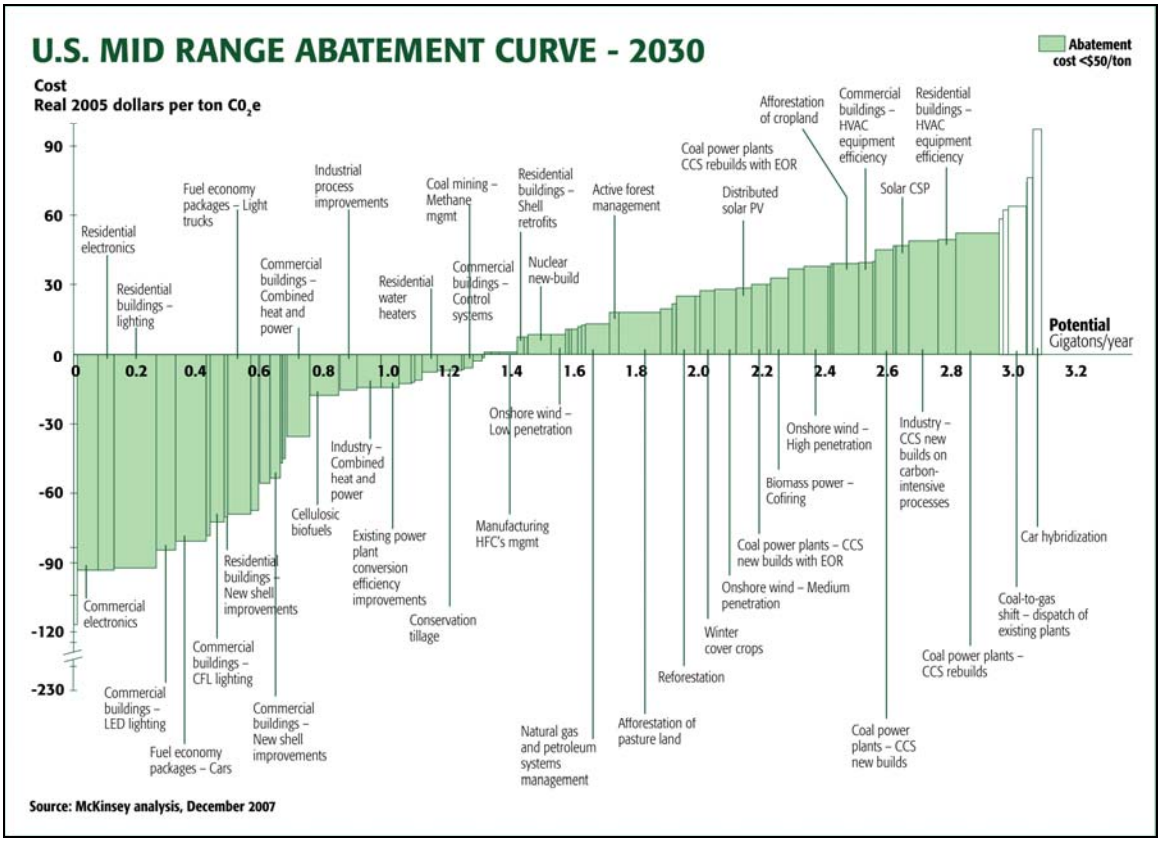


Figure 1. The U.S. mid-range abatement curve identifies reduction of CO_2 reduction from commercial lighting as immediately cost effective with large impact potential.

This PIER Integrated Office Lighting System (IOLS) project seeks to develop a technology solution to significantly reduce the lighting power density needed to adequately light the office while maintaining or improving lighting quality and user satisfaction. In a two year research and development effort, the IOLS project developed a LED-task / low ambient lighting system for offices that results in achieving an overall lighting energy savings potential in California commercial office space up to 60 percent. Since California commercial building stock is among the most energy-efficient in the nation, savings potential is even greater for the United States as a whole. Additionally, the project focused on developing a solution that is easy to implement, affordable, and provides flexibility for the end user.

Beginning in 2006, the California Lighting Technology Center (CLTC) and Finelite, Inc. (Finelite) partnered to study office lighting and set out to develop an Integrated Office Lighting System. The study quickly narrowed in on the concept of task / ambient lighting and identified why this design concept has not historically achieved great energy savings for office lighting. Essentially, traditional straight tube and compact fluorescent task lighting approaches over-light the task and create excessive contrast ratios, which, in turn, creates glare and drives the ambient lighting levels to remain high to compensate for this shortcoming.

Thus, the major effort of this project sought to develop an ideal task lighting system, with an overall objective of developing, demonstrating, and commercializing an office task / ambient lighting system that:

1. Operates at about 0.7-0.8 W/ft² of total connected load;
2. Provides uniform illumination of at least 30 footcandles; and
3. Uses no more than 25 Watts of LED task lighting per office.

To accomplish this objective, CLTC and Finelite:

1. Determined that white light emitting diode (LED) technology promised to be the appropriate technology solution and developed a concept LED task light for the IOLS by evaluating commercially available task lights and selecting features for the new LED task lighting system.
2. Developed an initial prototype of the LED task lighting system by designing optics, electronics, fixtures, and power supply user interface. Evaluated and selected the LED source and driver.
3. Evaluated the prototype LED task lighting system performance in a laboratory environment including thermal analysis, luminance, and illuminance measurements.
4. Reviewed and tested prototype lighting control systems for the IOLS.
5. Conducted several field demonstrations of LED-task / low ambient lighting systems utilizing the LED task lighting system and monitored performance, energy use, and user satisfaction.

6. Commercialized the technology for widespread availability. Finelite developed specifications and marketing materials for the LED task lighting systems and offered it through the Finelite catalog.

The LED task lighting system that evolved from the research and development effort of this project is commercially produced by Finelite under the brand name Personal Lighting System (PLS). PLS is a patent-pending system that features:

1. A family of luminaires comprised of 3-, 6-, and 9-Watt Desk Lamps and 3-, 6-, and 9-Watt Undercabinet units with superior lumen distribution and optical performance;
2. A centralized power supply with occupancy sensing capability for automated on/off control;
3. Highly engineered and tested thermal management capability to ensure long-term, high-quality operation of the LED light source; and
4. Modular connecting cables and on/off manual switching.

To test the LED task lighting system in applications, several field demonstrations were conducted. Three of these demonstration projects are presented in this report – Department of Mental Health (DMH) (Sacramento, CA), Department of Motor Vehicles (DMV) (Sacramento, CA), and Gexpro (Hayward, CA). These projects, on average, demonstrated a total lighting energy savings of 45% and will save $1,024 per cubicle over the lifecycle of the system (Table 1).

	% Energy Savings (Task)	% Energy Savings (Ambient)	% Energy Savings (Total)	Simple Payback	Lifecycle Savings ($/ per cubicle)
DMH	86%	32%	49%	5.8 years	$895
DMV	84%	20%	28%	4.3 years	$1,229
Gexpro	66%	58%	59%	7.2 years	$948
Average	**79%**	**35%**	**45%**	**5.8 years**	**$1,024**

Table 1. Energy savings at three sites demonstrating task/ambient lighting with the PLS.

User satisfaction is studied at these three demonstration sites plus additional sites at United Stationers (Sacramento, CA) and Breathe California (Sacramento, CA). A total of 50 respondents rated the PLS and a subset of 28 rated the ambient lighting. The rating system is based on a ratio of positive to negative responses. Ratings were collected before and after installation of PLS and any changes to the ambient lighting system. After installation of PLS, the satisfaction ratio was overwhelmingly positive, exceeding 10:1 for all categories queried. This result is a three to ten times improvement over the previous task lighting system (Figure 2). Likewise, the reduced ambient lighting rated significantly higher than the previous ambient lighting, ranging in a two to tenfold improvement depending on the category (Figure 3).

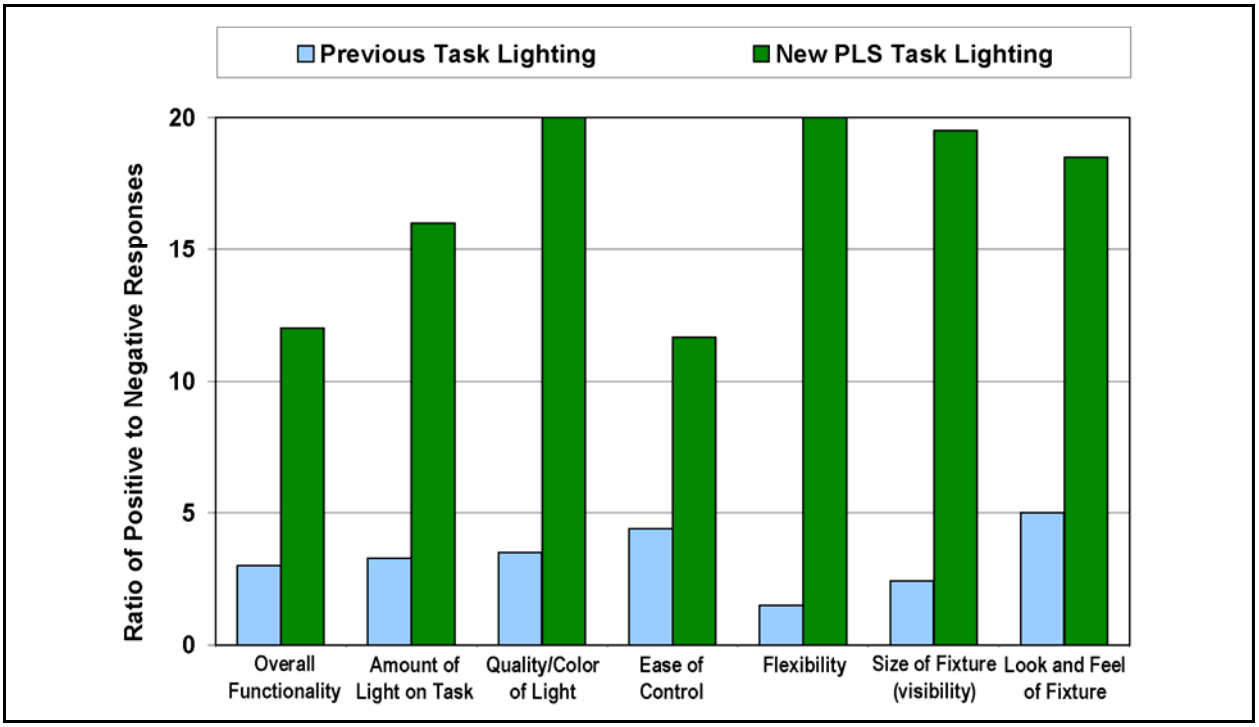


Figure 2. The PLS rated significantly higher than previous task lighting in all seven categories surveyed, especially for quality/color of light, flexibility, size of the fixture, and aesthetics.

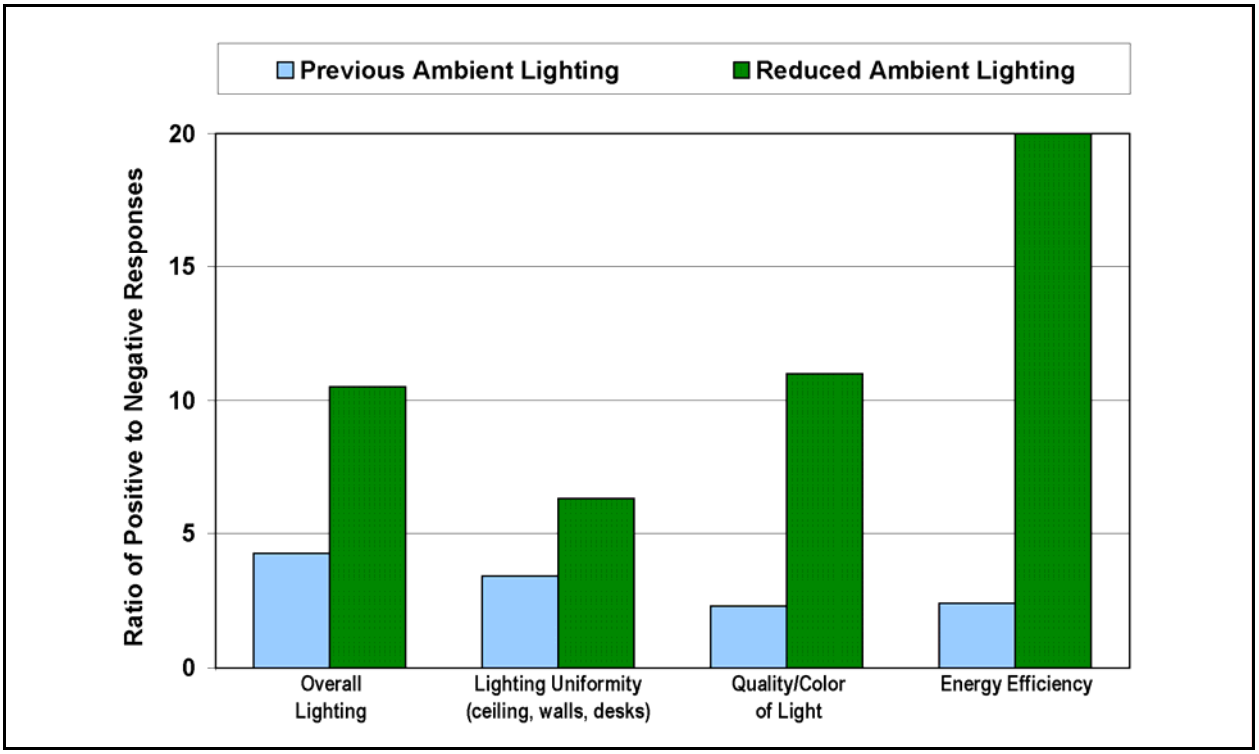


Figure 3. The reduced ambient lighting rated significantly higher than previously installed lighting, particularly for perceived energy efficiency, light quality, and overall performance.

Although the improved satisfaction with the ambient lighting system is based on reducing the lighting levels, concerns about low levels of illumination were expressed at the Breathe California site. In this project, employees were encouraged to use the task lighting and avoid the use of any overhead lighting. This learning underscores that task lighting alone cannot replace ambient lighting entirely. Approaching LED-task / low ambient lighting as a complete and integrated system is paramount to achieving low power densities and user satisfaction.

For new construction or major remodel, IOLS is immediately cost effective since the low ambient design typically results in installing less lighting equipment than standard practice. In retrofit construction, cost effectiveness will vary based on the type of retrofit approach. Based on the projects studied, a de-lamping strategy for the ambient system can result in a simple payback as soon as 4-7 years. A one-for-one ambient luminaire replacement would typically provide for a simple payback on the order of 7 years.

Key findings of the IOLS project include:

1. Reduced energy usage by 28-59% for California office space.
2. Achievable lower lighting power density ranging between 0.50 and 0.65 Watts/sf for typical open office space, 45%-60% lower than CA Title 24 2008 and ASHRAE 90.1 2004 (Figure 4).
3. The quality and energy efficiency of office lighting is directly related to the quality and energy efficiency of the task lighting.
4. Poor quality task lighting is costly.
5. The LED-task / low ambient lighting outcome of IOLS results in tremendously improved user satisfaction through increases in lighting quality and flexibility to address individual user needs.
6. The LED-task / low ambient outcome of IOLS is cost effective.

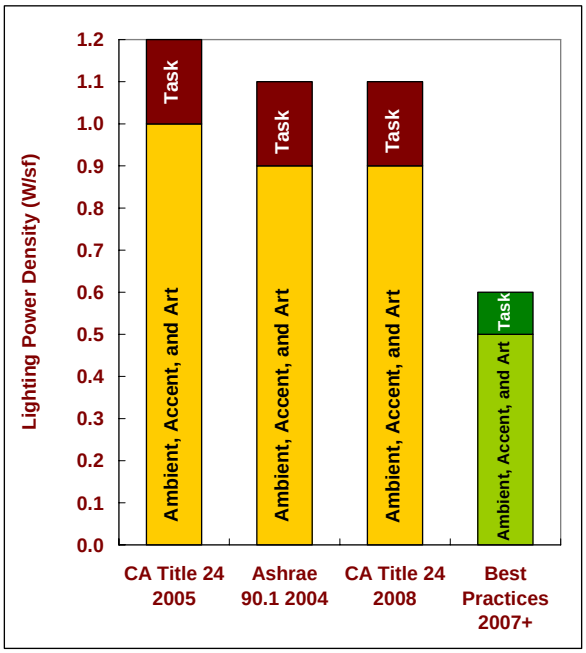


Figure 4. Best practices with task/ambient design can exceed CA Title 24 2008 and ASHRAE 90.1 2004 requirements by 45-60%.

Over the duration of this project, Finelite and the CLTC have provided presentations highlighting the results of this project to interested audiences including utility representatives, corporate entities, the State of California, and lighting designers. However, continued work is needed to build awareness among these audiences that the viability of IOLS is a documented, achievable, and cost-effective strategy with outstanding lighting quality.

Ongoing field testing of the IOLS is continuing through the California Energy Commission & California Institute for Energy and Environment's PIER demonstration program. Results from these studies are expected to add to the body of knowledge on the application of task/low ambient and the IOLS. This new information is expected to help to grow the IOLS market as well as provide input for future IOLS product modifications.

1.0 INTRODUCTION

1.1. Task/Ambient Lighting Design Basics

Office spaces traditionally rely on a lighting design approach referred to as general lighting, where ceiling-mounted luminaires provide an overall uniform level of illumination sufficient for both task and ambient (fill) lighting. This strategy results in the level of illumination being sufficient for tasks in virtually all locations, regardless of whether tasks are being performed at those locations or not. Furthermore, occupants of office spaces have varying lighting requirements, and different visual tasks demand variations in lighting to produce ideal lighting conditions. Computer monitors require diffuse, ambient light with low screen glare effects, while printed materials require more light directed to a specific task plane (typically a desk surface) to avoid eye fatigue caused by low light levels. These task requirements drive target illuminance levels.

In summary, the traditional lighting approach with ceiling mounted luminaires has the following shortcomings:

1. Non-task areas are over-illuminated;
2. Since illumination levels drop by the square of the distance from the light source, lighting the task with a ceiling-mounted luminaire is an inefficient approach;
3. It is not adaptable to individuals and does not truly address the occupants' visual requirements to perform tasks, resulting in sub-optimal user satisfaction.

The task / low ambient approach has the potential to address these shortcomings and yield significant energy savings and increased user satisfaction. In order to reach that potential, however, the task / low ambient design must meet certain technical requirements. The ambient lighting must provide fill lighting in non-task areas and some of the required illumination in task areas, accounting for obstructions such as workstation partitions, binder bins, and shelves. The quality of the ambient lighting will, to a large extent, dictate the degree of shadowing and glare that users will experience in the office environment.

The Illuminating Engineering Society of North American (IESNA) recommends a target illuminance of 30 footcandles for open offices. In task / ambient design, this means that the ambient lighting should provide 10 to 20 foot candles at task locations. Task lighting should provide an additional 20 to 40 footcandles at task locations while avoiding distinct pools of brightness and direct glare. The resulting illuminance from the task / ambient system is 30 to 60

footcandles. Furthermore, the combined results of the task/ambient approach should preserve 3:1 luminance ratios between adjacent tasks.[1]

The technical challenges of task / ambient design are difficult to overcome based on the capabilities of traditional lighting technologies, particularly with regard to the task lighting. A standard straight-tube fluorescent undercabinet fixture or compact fluorescent desk lamp provides significantly more task illumination than required, well in excess of 20 to 40 footcandles. Essentially, traditional straight tube and compact fluorescent task lighting approaches over-light the task and create excessive contrast ratios, which, in turn, creates glare and drives the ambient lighting levels to remain high to compensate for this shortcoming (Figure 5, left). Reduced overhead lighting combined with LED task lighting promises balanced lighting at a low power density (Figure 5, right). The goal of this project is "to develop, demonstrate, and commercialize an office task-ambient lighting system that operates at about 0.7 to 0.8 Watts/sq-ft total connected load, providing uniform illumination of at least 30 fc, while using no more than 25 W of task lighting." In this context, the LED-task / low ambient solution developed by this project is termed an Integrated Office Lighting System (IOLS).

1.2. Task Light Design

Task lighting has long been known as a practical method to achieve adequate illumination levels for various individual needs and to compensate for obstructions in the environment. Regardless of the quality of the ambient lighting system, shadows created by furniture cause illumination levels in task areas to drop below the IESNA recommended target value of 30 footcandles for open plan offices. In addition, the quality is unacceptable with high contrast ratios and dark vertical surfaces (Figure 6, left). Traditional undercabinet fixtures with a linear fluorescent lamp eliminate shadows (Figure 6, middle) but result in vertical illumination levels as high as 100-200 footcandles and horizontal illumination levels as high as 90-120 footcandles, well in excess of the target illumination. Contrast ratios are excessive and the possibility of reflected glare from paper tasks is increased. In addition, traditional task lighting has lumen waste beyond the immediate task area. Modulating the output of the fluorescent undercabinet fixture to achieve the appropriate target illumination levels would provide the correct lighting quality but at great expense and minimal energy savings.

Up to this point, task lights that provide even lighting on the work plane (Figure 5 and Figure 6, right), have been hard to find and expensive. With recent advances in white light emitting diode (LED) technology, California Lighting Technology Center (CLTC) and Finelite identified a market opportunity for an energy saving task light system using this emerging technology. While LEDs are evolving rapidly, warm white LEDs for lighting can produce 45-50 lumens per watt (lm/W) with a color rendering index (CRI) of 75+. Their useful life is expected to be 30,000-50,000 hours, or 10-17 years if operated 8 hours per day. CLTC and Finelite anticipate that well-designed LED task lighting could meet the demands for energy efficient, high quality, affordable task lighting. New LED task lighting technology would complement Finelite's

[1] ANSI/IESNA RP-1-04 American National Standard Practice for Office Lighting, Table 1 and Annex B.

existing energy efficient overhead lighting products, making the ideal Integrated Office Lighting System available to the marketplace.

1.3. Low Ambient Lighting Design

CLTC and Finelite theorized that having the appropriate task lighting with optimal illumination would allow ambient lighting design at significantly reduced light output and unprecedented energy savings. Incorporating well designed task lighting into the workspace means that a low ambient design works without sacrificing utility or user acceptance. Low ambient design is achievable with readily available products, including high efficiency single lamp cross section pendants and one- or two-lamp high efficiency troffers. This project studies applying LED-task / low ambient design to the main office space. To achieve balanced illumination throughout the office which includes support areas, the low ambient design should be carried throughout the office space to hallways, break room, bathrooms, etc (Refer to Appendix B). This generates additional energy savings and provides even illumination and balance for the building occupants.

Figure 5. Reduced overhead lighting with fluorescent task lighting results in high contrast ratios with an over-lit work plane (left), while reduced overhead lighting combined with LED task lighting promises balanced lighting at a low power density (right).

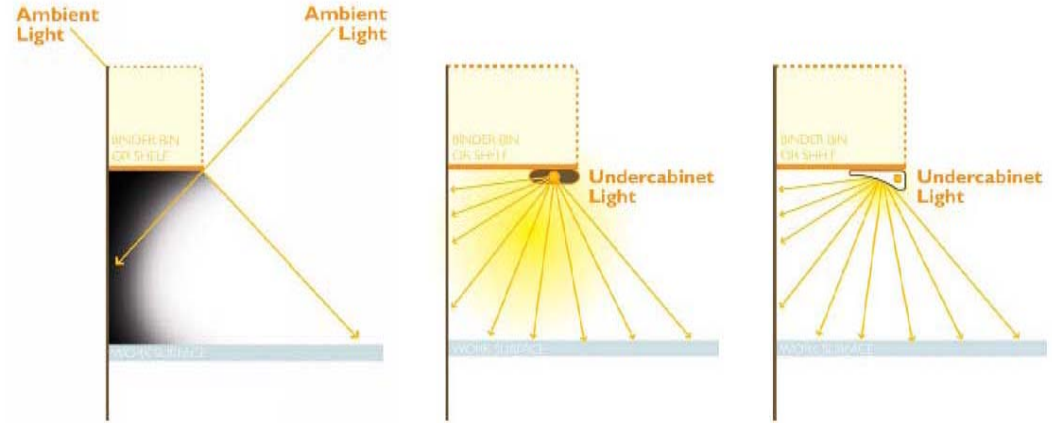


Figure 6. Obstructions from furniture create shadows on the vertical surfaces (left); adding a fluorescent undercabinet eliminates the shadow but over lights the space (middle); while LED task lighting promises to provide an ideal level of light with substantial energy savings (right).

1.4. Project Objectives

The main objective of the Integrated Office Lighting System (IOLS) project is to develop, demonstrate, and commercialize an office task / ambient lighting system that:

1. Operates at about 0.7-0.8 W/ft² of total connected load
2. Provides uniform illumination of at least 30 footcandles
3. Uses no more than 25 Watts of LED task lighting per office

To accomplish this objective, CLTC and Finelite:

1. Determined that white light emitting diode (LED) technology promised to be the appropriate technology solution and developed a concept LED task light for the IOLS by evaluating commercially available task lights and selecting features for the new LED task lighting system.
2. Developed an initial prototype of the LED task lighting system by designing optics, electronics, fixtures, and power supply user interface. Evaluated and selected the LED source and driver.
3. Evaluated the prototype LED task lighting system performance in a laboratory environment including thermal analysis, luminance, and illuminance measurements.
4. Reviewed and tested prototype lighting control systems for the IOLS.
5. Conducted several field demonstrations of LED-task / low ambient lighting systems utilizing the LED task lighting system and monitored performance, energy use, and user satisfaction.
6. Commercialized the technology for widespread availability. Finelite developed specifications and marketing materials for the LED task lighting systems and offered it through the Finelite catalog.

2.0 BACKGROUND

In interior office lighting, illumination is often provided through a combination of overhead luminaires and task lighting. Overhead lighting is generally well understood. High-quality, suspended, direct-indirect lighting can meet or exceed the 2005 Title 24 goal of 1.0 W/ft² or less in virtually every situation. Recessed solutions are also available that can meet the same lighting power density requirement.

Task lighting is more complicated and usually not deeply discussed in guidelines or regulations. The current version of Title 24 (2005) requires new construction and major retrofit of office lighting have a total load of less than 1.2 W/ft², which includes all overhead and portable lighting. If the portable lighting load is not known at the time of permitting, 0.2 W/ft² of portable lighting is assumed with 1.0 W/ft² remaining for overhead lighting. Although an assumed portable lighting load of 0.2 W/ft² is accounted for, there is no mechanism for limiting the power. In standard practice portable lighting often exceeds the 0.2 W/ft² allowance. Undercabinet linear fluorescent and free standing compact fluorescent task lights may result in a load as high as 0.5 W/ft². Providing high quality task light that provides adequate illumination to complement the overhead lighting at less than 0.2 W/ft² is a challenging prospect.

In addition, the demographics of American society indicate that the workforce is aging. The eye deteriorates with age and older workers may require two to three times as much light to perform the same task as a younger worker. Appropriate task lighting for this subset of workers makes them more productive, without lighting the entire space to an unnecessarily high level. Illumination requirements of the aging workforce are increasing while allowable lighting power densities mandated by Title 24 are decreasing (Figure 7). LED-task / low ambient lighting design can close this gap.

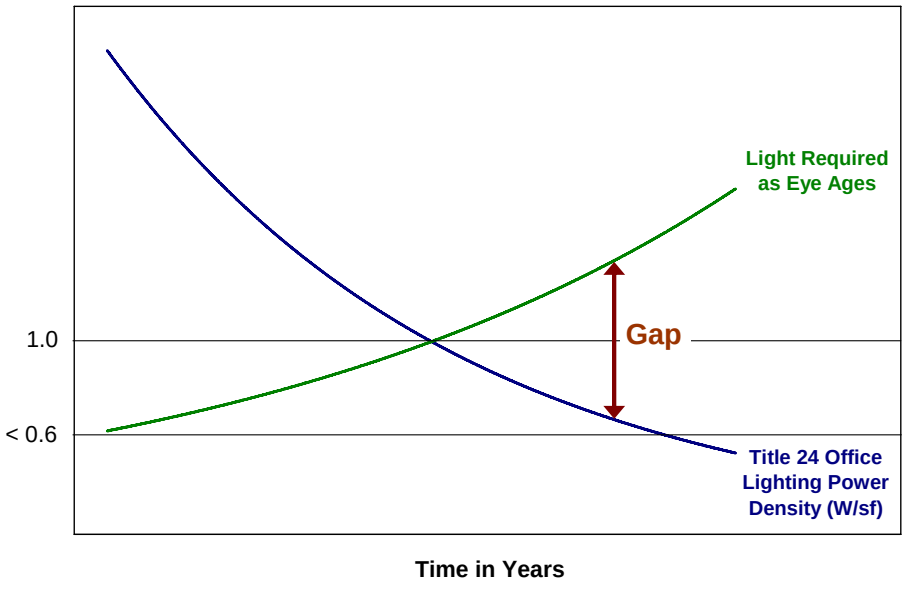


Figure 7. There is an increasing need to provide appropriate task lighting as the aging workforce trend is balanced against the trend to reduce lighting power densities in Title 24 and other energy standards such as ASHRAE 90.1.

LED task lights have the capability to solve the critical "task" piece of the task ambient puzzle, but as an emerging light source technology with unique characteristics, luminaire design must be carefully executed. LEDs must be thermally managed, color uniformity must be controlled, and the cost must compete with traditional task lighting. California Lighting Technology Center and Finelite joined forces to bring an LED task lighting system to market, leveraging the product development strengths at CLTC with the manufacturing and production experience at Finelite.

California Lighting Technology Center and Finelite worked together on past projects funded by the PIER program which laid the groundwork for the Integrated Office Lighting partnership. These previous projects include:

1. Portable Office Lighting Systems, which developed and demonstrated a task / ambient office floor lamp designed to replace overhead office lighting. Although user response and energy savings were excellent, Finelite did not fully commercialize this product, citing high cost to manufacturer the product and concerns of consumer acceptance. However, this project laid a foundation for further thinking about how to incorporate task / ambient lighting in offices.
2. Demonstration of the Integrated Classroom Lighting System, which utilizes Finelite's indirect luminaires to light classrooms with a power density less than 0.9 W/ft^2. CLTC evaluated this system in 16 classrooms at four California State University campuses. On average, energy consumption was reduced by 68% with a cost savings of $354 per year per classroom. This project led to the desire to achieve similar results for open offices. However, office furniture blocks light and creates shadows on desktops, creating additional challenges in utilizing low power density overhead lighting. This fundamental situation led to conceptualizing a superior task lighting product to supplement Finelite's existing indirect luminaire products.

3.0 PROJECT APPROACH

3.1. System Features

Finelite and CLTC purchased and qualitatively evaluated a cross section of LED task lights on the market at the start of the project. A high quality 18W compact fluorescent task light was used as a benchmark for comparing LED task lights. In general, the LED products evaluated performed poorly over time. Problems noted were high lumen depreciation, inadequate optical performance, and undesirable color temperatures including bluish light. The most impressive product purchased was the 20W Halley LED task light, which won the 2006 Department of Energy "Lighting for Tomorrow" competition. Desirable features of this product include versatile adjustment and full range dimming. However, the relatively high power consumption and price point (~$500) fall short of the requirements for practical task lighting in offices.

After evaluating a selection of existing task lights, CLTC conducted a series of brainstorming sessions to develop system features and product parameters. Early on it was decided to focus on the unique properties of LEDs and leverage the capabilities of this new light source. A key early concept was to use smaller wattage increments in the task luminaires, allowing the user to have multiple smaller task lights instead of a single, higher wattage light. This allows for a customizable system that distributes light evenly across the work plane (Figure 8, left). Dimming was not pursued in the first round of development in order to reduce cost and complexity.

Another early key concept of the task light system is a centralized, universal power supply. (Figure 8, right). The universal power supply converts wall power (120V AC) into a low voltage (24 V DC) output. Each luminaire plugs into the universal power supply and has an on board driver circuit to regulate that luminaires' power. This approach has several advantages:

1. Luminaires of different power levels can operate with one power supply.
2. Only one AC power conversion is necessary.
3. Allows for possible integration of the driver circuit and LEDs onto the same circuit board.
4. Ability for global control of all luminaires attached to the power supply, enabling central occupancy sensing.
5. As LED technology evolves, individual luminaires can be added and replaced while maintaining the same power supply and controls.
6. The power supply can limit the total plug load power and allow lighting designers to specify total lighting power densities. This power-limited supply can also make it easier for utilities to rebate the product.

The development of the universal power supply is one of the innovative outcomes of this project. Its centralized approach, providing for power limiting, control integration, and long-term flexibility for the user is a patent-pending feature of the commercialized system.

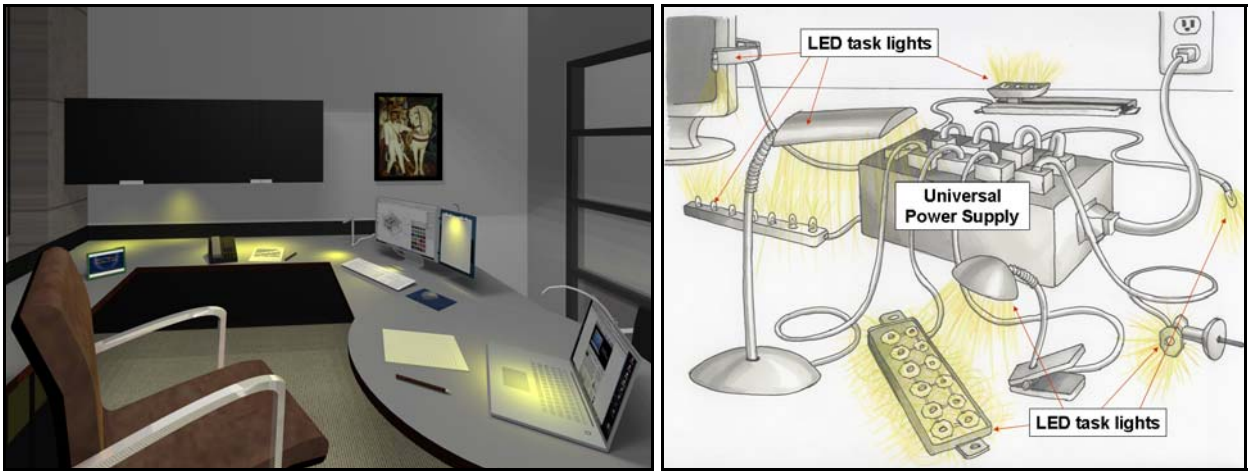


Figure 8. Early brainstorming sessions for developing the task light system led to the concept of multiple smaller task lights (left) and a single universal power supply (right).

3.2. Product Development

Development of the LED task lighting system was divided into several categories:

1. Selection of the LED source and driver design
2. Desk lamp design
3. Undercabinet lamp design
4. Power supply and occupancy sensing design

In the initial brainstorming the idea was also to have very small (1W) feature lights for the system to light a calendar page, artwork, picture, etc. This was initially investigated and then ruled out because the cost of that product was not justified by the small light output and limited functionality. The decision was made to focus development effort on incremental wattage desk lamps and undercabinet units.

3.2.1. Technology Assessment – LED Source and Driver

California Lighting Technology Center evaluated several LED packages to select a source for the task lighting system. The evaluation parameters included total luminous flux, color, efficacy (lumens per watt), thermal performance, and cost. Luminous flux and resulting efficacy were measured at CLTC in the integrating sphere. Light emitting diodes from manufacturers Cree, Lumileds, Nichia, and Osram were tested (Table 1). The continuous rapid evolution of LED technology made this process challenging, as technical performance had to be balanced with commercial availability.

Manufacturer	Model #	Luminous Flux (lumens)	Correlated Color Temp. (K)	Efficacy (lumens/watt)	Cost
Cree	X-Lamp	30-35	>3500	~30	High
Lumileds	Lexion	25-35	>3500	~30	Medium
Nichia	083	35-40	>2700	~40	Low
Nichia	Jupiter	25-35	>2700	~30	High
Nichia	Rigel	20	>3000	~35	Low
Osram	Dragon	25	>3000	~25	Medium

Table 2. Matrix of LED packages evaluated for the task lighting system.

Ultimately, CLTC and Finelite selected the new 083 LED from Nichia for the task lighting system. The Nichia 083 LED package has high efficacy and a wide range of available color temperatures at a competitive cost. Another advantage of the Nichia 083 LED package is that each discrete 1 - Watt LED used at the product design level is comprised of six individual chips at the micro level (Figure 9). This feature means that failure of the entire 1W LED is an extremely unlikely event, which greatly enhances the long-term reliability of the system.

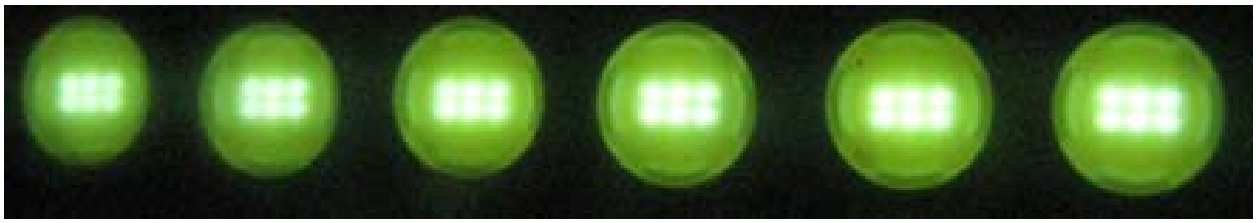


Figure 9. Each Nichia 083 LED is comprised of six individual chips which enhances the long-term reliability of the system.

Once the LED package was chosen, further engineering development occurred to understand how to best combine multiple LED packages into a single product. LED production has a wide range of variability. After being manufactured, each LED is tested for luminous flux and chromaticity (which is correlated to color temperature). The LED is binned according to these properties. Finelite and CLTC specified two allowable bins for lumen flux (43-51 and 51-60 lumens) and two allowable bins for chromaticity. Both chromaticity bins correlate to a warm white color temperature, but one bin leans towards the green spectrum while the other leans toward the red spectrum. Various tests were conducted to determine how to combine LEDs from different bins. When possible, equally mixing LEDs from different bins yielded the optimal result.

The driver electronics were chosen to match the performance criteria for the system. Utilizing a constant current driver is an efficient and accurate method for operating LEDs. The LED driver

converts the 24 Volt output from the power supply to 12-14 Volts operating at a constant current. In addition to meeting current regulation specifications, the driver components had to be small enough to allow bundling with the LED circuit board. Designs from Supertex, a manufacturer in San Jose, California, met the system requirements. Supertex assisted in the design and development of the driver electronics and presently supplies the driver chip for the commercial system. The power supplies have been continually improved and developed to meet or exceed the first Energy Star requirements for Solid State Light Luminaires (expected to be finalized in September 2008).

3.2.2. Desk Lamp Design

Design of the desk lamp included three areas: the lamp head, the lamp head articulation, and the base and arm design.

Desk Lamp Head Design - The head design for the desk lamps was a key area of development and determined many of the aesthetic properties of the system. Several head designs were made, each incorporating a slightly different optical method and heat-sinking path. Heads were CNC machined, hand machined, and aluminum sand cast. More than a dozen designs were fabricated, with each requiring extensive work and a functional representation of a different aesthetic concept. Each design required a working LED array to test optical performance, which meant that circuit boards were necessary. Some of these boards were built around a common theme while some were unique to a specific prototype. Each lamp head design was evaluated based on the following properties:

1. Aesthetic appearance
2. Ability of the lamp head to dissipate heat from the LEDs
3. Lumen distribution and optical performance
4. Ease/cost of manufacturer

An early decision in optical performance regarded whether to place the LEDs with individual reflectors or in a line with a single reflector (Figure 10). Prototyping the different designs revealed that the best optical performance was achieved with a line of LEDs inside a single reflector. This reduced the spacing between the LEDs and shadows on the work plane. The design allowed for lower tolerances on the LED positions on the circuit board, because each LED is not attempting to fit inside an individual reflector. Overall, the design was simpler, less expensive, and provided the best performance.

California Lighting Technology Center evaluated aluminum and copper as potential materials for the lamp head and tested their thermal performance. Copper performed slightly better than aluminum, but aluminum met the design requirements at a reduced cost. Various fin designs were tested to determine the appropriate surface area needed to dissipate heat from the LEDs at various wattages. The final design (Figure 10, left) has fins in a flat head radiating out from the LED source. Finally, the head shape was determined. A rectangular head in the proportion of the golden ratio (length/width=1.6) was chosen for aesthetic balance.

California Lighting Technology Center and Finelite decided to prototype designs with 3, 6, and 9 LEDs using 3, 6, and 9 Watts respectively. These were chosen to produce outputs of 130, 240, and 350 lumens which provide options for a wide variety of applications. Designing the product in increments of 3 Watts is also key to the design of the power supply, described in section 2.2.4.

Figure 10. The final desk lamp design (left) features the LEDs in a row with a single optical reflector, although multiple reflector designs were tested during product development (right).

Desk Lamp Head Articulation Design - The desk lamp design includes a mechanism to allow the head to rotate so that the user can direct the light onto the task. It moves in three different directions for maximum adjustment and flexibility. The design for the prototypes included three separate joints that each provided one degree of freedom (Figure 11, left). Finelite later simplified this to a single rotating ball joint design to reduce costs in the commercialized product (Figure 11, right).

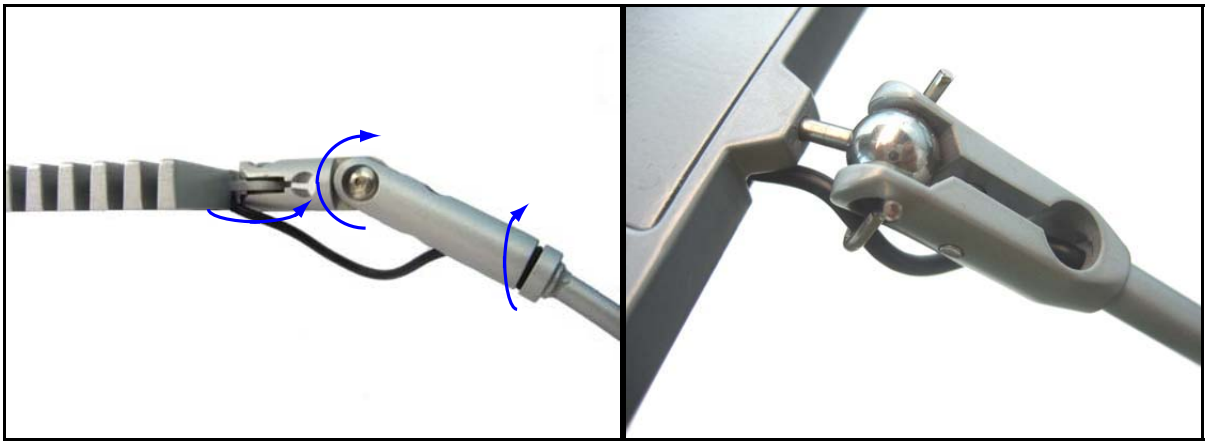


Figure 11. The initial prototype (left) featured three rotating joints for the head articulation, while the commercialized product uses a single ball joint to achieve three degrees of freedom (right).

Desk Lamp Base and Arm Design - Several arm designs were evaluated for their aesthetic qualities. The final design chosen is a curved arm in three lengths to accommodate the different wattage desk lamps and provide the appropriate distance between the lamp head and the work plane (Figure 12). The weighted base was designed to provide stability for the lamp. The joint between the arm and base provides two additional axes of movement. The arm swivels on the base and rotates to adjust the distance between the lamp head and the work plane. In the prototype design, a lever released the vertical adjustment (Figure 13, left). Finelite added a spring mechanism to the commercialized product to facilitate easy, one hand adjustment with no lever (Figure 13, right).

Figure 12. Curved arm design of increasing height for 3, 6, and 9 Watt desk lamps.

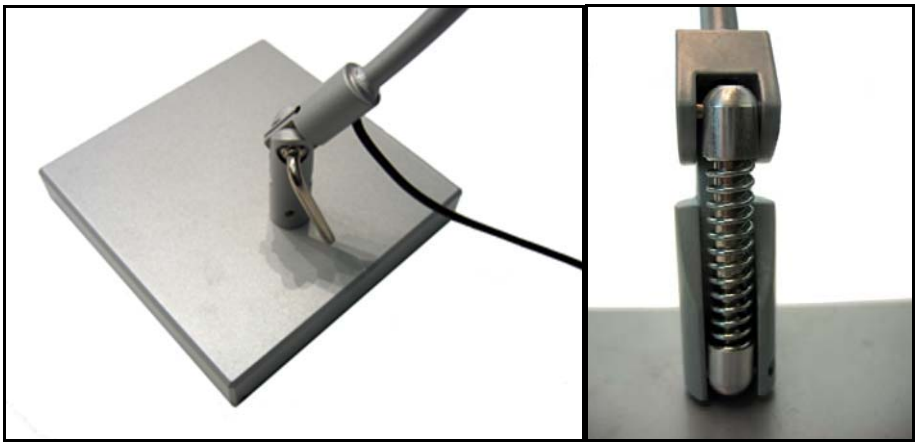


Figure 13. The initial prototype base (left) featured a lever to release the vertical adjustment, while the commercialized product (right) has a spring mechanism to facilitate easier adjustment.

3.2.3. Undercabinet Design

The undercabinet luminaire utilizes the same LED sources and driver electronics. The design is more straightforward because:

1. The unit is hidden, so aesthetics are less of a concern;
2. Heat dissipation is easier since the LEDs are spaced farther apart; and
3. The unit is not mechanically adjustable.

For the undercabinet luminaire, CLTC and Finelite first determined the number and spacing of the LEDs. In order to simplify the product manufacturing, one product design was made that can be manufactured with either 6 or 9 LEDs (using 6 or 9 Watts, respectively). The 9 LEDs are evenly spaced 2.25" apart. In the 6 Watt version, the 3rd, 5th, and 7th LEDs are omitted (Figure 14). CLTC and Finelite designed the fixture frame, an aluminum extrusion, to hold the LED array at the proper angle. The reflector design optimizes distribution of the light onto the work plane and the vertical surface, providing uniform top-to-bottom light distribution and wide lateral throw. A nominally 2' long unit sufficiently and evenly illuminates the workspace under a 4 foot long section of shelves or binder bins. The commercially available product line also includes a 1' foot long 3 Watt undercabinet luminaire.

Figure 14. The 6 and 9 Watt undercabinet luminaries were designed to use the same frame and circuit board, with 3 LEDs omitted in the 6 Watt version.

3.2.4. System Design – Controls, Occupancy Sensing, and Power Supply

CLTC investigated the feasibility of an individual user control to operate both the task lighting and ambient lighting. The investigation led to determining that several lighting control manufacturers already have commercially available systems that provide comprehensive integrated control of all building lighting that would extend beyond the scope of task / ambient lighting within the office spaces themselves. In addition, since the nature of the task lighting is localized to individual workspaces with intermittent occupancy, the most energy savings would be achieved through straightforward occupancy-sensor control of the task lighting. CLTC and Finelite determined that even a modest cost added from an ambient lighting controls system would be hard to justify economically. This is because the low power density of the ambient lighting system leaves little additional saving available from control systems and because the cost of individual controls systems are relatively high. For example, an office with a low-ambient system might expect to save up to $6.00 per year if a controls system is added that

gives users local switching/dimming control over their ambient lighting.[2] But controls for such systems (even for switching rather than more expensive dimming systems) were expected to exceed $75 per control point, offering a payback that exceeds 12 years. For these reasons, the CLTC and Finelite jointly determined that adding controls to integrate the task and ambient lighting together would create a market barrier to wide-scale adoption of the Integrated Office Lighting System, rather than enhance it. Therefore, the concept of integrated lighting controls was not pursued further and resources were shifted to other aspects of the systems' development.

A significant design attribute of the task lighting system is the central power supply that incorporates occupancy sensing (Figure 15, left). This allows the entire system to turn on and off based on occupancy, yielding additional energy savings and convenience for the user. The optional infrared occupancy sensor is manufactured by Watt Stopper.

The power supply design allows up to 21 Watts of load with up to four plugs (Figure 15, right). For example, one user may have two 9-Watt undercabinet luminaires and one 3-Watt desk lamp, while another user may have two 6-Watt desk lamps and a 6-Watt undercabinet luminaire. The power supply is flexible to support a wide variety of combinations. Finelite outsourced the power supply design once these basic requirements were determined. The commercially available product line also includes a 9-Watt and a 60-Watt power supply, both of which will meet the upcoming Energy Star requirements for Solid State Luminaires (to be finalized in September 2008).

Figure 15. The central power supply incorporates an occupancy sensor (left) to control up to four luminaires with a load up to 21 Watts (right).

[2] Assumptions: Baseline ambient lighting power density = 0.46 W/ ft², ambient lighting power density when dimmed = 0.23 W/ ft², office size = 100 ft², total hrs of operation per yr = 3,000, hrs operated at dimmed level = 1,500, electricity cost = $0.17/kwh.

4.0 PROJECT OUTCOMES

4.1. Prototype Production

When the major electrical and mechanical design decisions were made a batch of 100 systems was fabricated. These were full systems including all of the luminaires, meaning that 700 different product components were made including:

1. Desk Lamp – 3 Watt
2. Desk Lamp – 6 Watt
3. Desk Lamp – 9 Watt
4. Undercabinet – 6 Watt
5. Undercabinet – 9 Watt
6. 21 Watt Power Supply
7. Occupancy Sensor

The mechanical parts for the lamps were fabricated, painted, and assembled. The electronic parts were contracted and assembled. The systems were divided for distribution to complete several demonstrations of the product. Finelite named the product Personal Lighting System (PLS) to reflect the high degree of flexibility of the system.

4.2. Product Demonstration

CLTC and Finelite demonstrated integrated office lighting in a variety of environments reaching over 100 users in a six month period from March to August, 2007. The first phase of the installations focused on testing the PLS, building awareness, and collecting feedback. The second phase of installations continued to test the system while gathering data on energy savings at three sites: the Department of Motor Vehicles, the California Department of Mental Health at the Bateson Building, and Gexpro.

4.2.1. Demonstrations – PLS Awareness and Testing

CLTC and Finelite distributed over 50 PLS demonstration units to political, educational, and commercial stakeholders to test the product and spread awareness. The test locations included:

1. The reception area of Governor Arnold Schwarzenegger's office and the offices of Secretary Rosario Marin, Commissioner John Geesman, Assemblyman Ira Ruskin, Integrated Waste Management Board member Gary Peterson, Assembly Transportation Committee consultant Howard Posner, and Vice President of Majestic Management Company, Dennis Daze.
2. Offices of key staff at California utilities including Southern California Edison and Pacific Gas and Electric Company.

3. Offices of building and energy managers at California State University, University of California, and University of the Pacific.
4. Twenty offices at University of California, Santa Barbara, which were toured at the campus' 2007 Sustainability Conference.
5. Single offices at companies including Oracle and Nichia and eight private offices at United Stationers in Sacramento. Sacramento Municipal Utility District (SMUD) funded the PLS at United Stationers through their emerging technology program.

Figure 16. Example installations intended to test the PLS and increase awareness at Governor's office reception area (top left), office of Secretary Rosario Marin (top right), office of Denis Daze, Vice President of Majestic Management Company (bottom left), and United Stationers (bottom right).

4.2.2. Demonstrations – IOLS Energy Savings in Retrofit Applications

In the second phase of the demonstrations, the PLS was tested as part of IOLS in three different open office lighting retrofits (Table 2):

1. **Task light replacement –** In the Bateson building, 18 employees of the California Department of Mental Health (DMH) received a PLS in place of undercabinet fluorescent lighting. Although de-lamping the overhead lighting was not planned, employees later removed a portion of the overhead lighting, effectively resulting in a de-lamping approach.
2. **Task light replacement, de-lamp overhead –** At the Department of Motor Vehicles (DMV), walkways were de-lamped to reduce ambient lighting load by 20%. In addition, the PLS replaced undercabinet fluorescent lighting for 11 employees.
3. **Task light and overhead light replacement –** The Gexpro demonstration replaced 10+ year-old ambient lighting with a Finelite direct/indirect ambient lighting system. In addition, the PLS replaced undercabinet fluorescent lighting for a 54 employee office space.

Methodology – Calculation of energy and maintenance savings

Complete calculation showing energy savings, maintenance savings, and the resulting payback period are available in Appendix A. The same methodology was used for each demonstration site, with the following parameters applied:

1. Average energy cost of $0.17 per kWh, which may vary throughout California.
2. Ambient lighting operation of 3750 hours per year (15 hours per day, 250 days per year).
3. Fluorescent task lighting operation of 2000 hours per year (8 hours per day, 250 days per year), unless otherwise noted.
4. PLS operating hours as monitored by plug load data recorders.
5. Fluorescent ambient lighting load obtained by lighting audit or actual measurement with current transducer.
6. Fluorescent task lighting load obtained by lighting audit.
7. Maintenance cost of $3 per lamp per year for ambient system and $5 per lamp per year for fluorescent task fixtures.
8. The simple payback divides the cost of the system by energy and maintenance savings. The economic benefit of the improved quality of lighting is not considered.

Site	Lighting Retrofit	Initial W/ft²	Reduced W/ft²	Energy Savings* (%)	Energy Savings ($/year per cubicle)	Mainten. Savings ($/year per cubicle)	Simple Payback	Lifecycle Savings ($/ per cubicle)
DMH	De-lamp overhead	0.79	0.58	27%	$19.47	$2.89	5.8 years	$895
	Under-Cab to PLS	0.74	0.16	86%	$24.61	$15.83		
	Total	**1.54**	**0.74**	**44%**	**$44.11**	**$18.72**		
DMV	De-lamp overhead	1.51	1.21	20%	$35.13	$5.17	4.3 years	$1,229
	Under-Cab to PLS	0.44	0.10	84%	$22.92	$15.00		
	Total	**1.95**	**1.31**	**25%**	**$58.05**	**$20.17**		
Gexpro	Replace overhead	1.08	0.46	58%	$48.68	$11.59	7.2 years	$948
	Under-Cab to PLS	0.31	0.13	66%	$7.17	$6.48		
	Total	**1.30**	**0.56**	**59%**	**$55.85**	**$18.07**		

Table 3. Summary of demonstrations of IOLS in three open office environments.

***The energy savings calculation includes additional savings from the occupancy sensor for the PLS.**

Bateson Building – California Department of Mental Health

Eighteen employees of the California Department of Mental Health, located in Sacramento's Bateson Building, received the PLS in place of undercabinet T8 fluorescent task lighting (Figure 17). The area under study is 2045 square feet. After using the PLS, most employees decided to lower overhead lighting levels by de-lamping fixtures above their cubicles. The result is a reduction of total lighting power density from 1.54 W/ft² to 0.74 W/ft².

The PLS installations consist of a combination of LED undercabinet fixtures and portable desk lamps, with a range of 15-21 Watts per cubicle (average 18 Watts). Six cubicles were monitored to record their actual power consumption over a period of one month. Occupancy sensing turned the unit off when the workspace was vacant. On average, the PLS was on 5.3 hours per work day (Figure 18). Occupancy sensing delivered an additional 35% energy savings in this

demonstration (when compared to a system operating an assumed baseline of 8 hours per day).[3]

The task lighting power density for the PLS is 0.16 W/ft² compared to 0.74 W/ft² for the previously installed fluorescent task lighting. The reduction in lighting power density combined with occupancy sensing saves $443 per year ($24.64 per year per cubicle). Since the PLS does not need lamp or ballast replacements over its lifetime, an additional $285 per year ($15.83 per year per cubicle) is saved in maintenance costs.

A reduction in overhead lighting was not originally planned for this demonstration. However, many employees reduced their overhead lighting by disconnecting lamps from the fixtures or simply foregoing a maintenance call when the lamp failed. Several months after installation of the PLS, the overhead lighting had been reduced 32%, with 21 out of 66 lamps not functional and employees reportedly content with the overhead lighting level. This reduction saves an additional $282 per year in energy costs and $152 a year in maintenance costs. In this demonstration, the combined energy and maintenance savings for the integrated office lighting is $1,131 per year for a simple payback of 5.8 years. The lifecycle cost savings over the anticipated 20-year life of the eighteen Personal Lighting Systems installed is $16,110, or $895 per each system installed (see Appendix A for calculations).

Figure 17. Example cubicle lighting at the Department of Mental Health inside the Bateson Building with former undercabinet T8 fluorescent lighting (left) and new PLS (right).

[3] The baseline task lighting was not metered at this site. The 8 hour baseline assumption was based on the operating hours and characteristics of the site as well as metered task light baseline data from other sites.

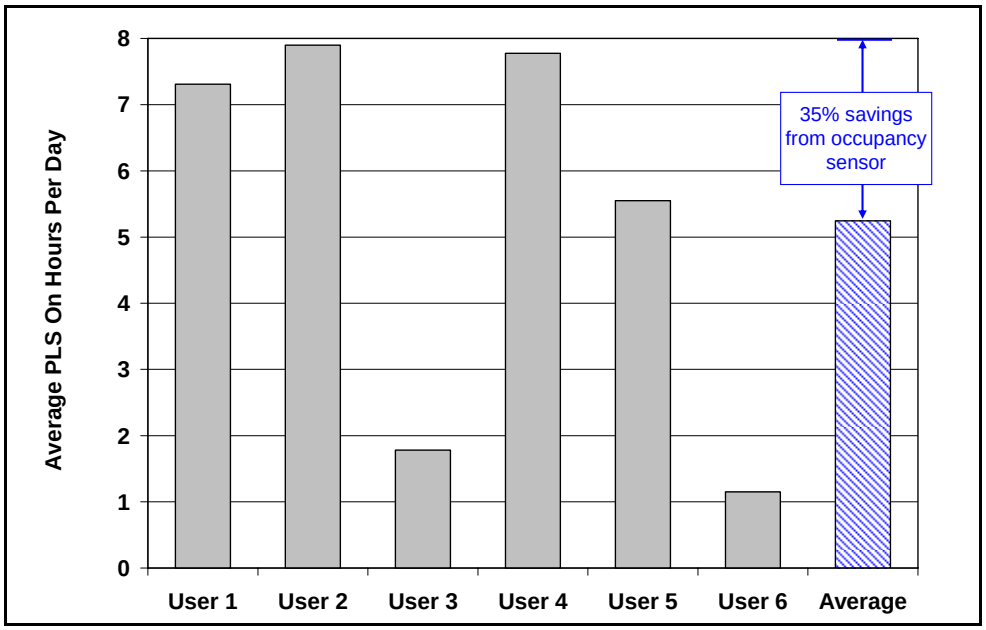


Figure 18. Average number of PLS on hours for six users at the DMH Bateson Building over a period of one month. Occupancy sensing turned the unit off when the workspace was vacant for an additional 35% energy savings.

Department of Motor Vehicles

The CLTC and Finelite assisted the Sacramento Department of Motor Vehicles, Facilities Construction and Maintenance Section, with power conservation by reducing ambient lighting and replacing fluorescent undercabinet task lights with the PLS in eleven cubicles. The demonstration area, a total of 2016 square feet, reduced the total lighting power density from 1.95 W/ft² to 1.31 W/ft². The delamped power density is still relatively high as only areas over walkways where delamped, resulting in minimal lighting reductions in the workstation area. The following yearly savings are estimated:

1. De-lamping 20% of overhead lighting from walkways saves $386 a year in energy costs in the eleven cubicle office area. Reducing the number of lamps saves $57.
2. Replacement of three T8 fluorescent under cabinet lamps with the PLS (one portable lamp and two undercabinet lamps with occupancy sensor) reduced energy consumption in each cubicle from 80 Watts to 18 Watts. Occupancy sensing netted an additional 30% energy savings. The total energy savings is $252 per year ($22.92 per year per cubicle) or 84% savings. Elimination of lamp and ballast maintenance saves an additional $165 per year.
3. This demonstration saves $860 in energy and maintenance costs per year, for a simple payback of 4.3 years. The lifecycle cost savings over the anticipated 20 year life of the eleven Personal Lighting Systems installed is $13,519, or $1,229 per PLS installed (see Appendix A for calculations).

In addition to saving energy, the retrofit positively impacted lighting quality by providing a more even distribution of light onto the work plane (Figure 19).

Figure 19. Example cubicle at the DMV office in Sacramento with undercabinet fluorescent task lighting system before retrofit (left) and PLS after retrofit (right) which yielded an 82% energy savings from lower wattage lighting combined with occupancy sensing controls.

Gexpro

CLTC and Finelite installed new ambient and task lighting at the Gexpro office in Hayward, CA. The 6616 ft² open office area has 54 cubicle workstations, of which 35 were occupied at the time of installation. The open office area is enclosed by private offices and receives minimal daylight. Finelite series 12 ID T8 fixtures replaced the 10+ year-old indirect lighting and the PLS replaced undercabinet T8 and T12 fixtures. This demonstration reduced the total lighting power density from 1.39 W/ft² to 0.59 W/ft²

Luminance maps were constructed to determine the distribution of light on the work surfaces before and after installation of the new ambient system (Figure 20). At this stage of the project the existing fluorescent undercabinet fixture was still in use on the right side of the desk. The resulting luminance maps show that the distribution of ambient lighting on the work plane is similar before and after the retrofit (Figure 20). The luminance of the left side of the desk and cubicle walls ranges between 10-50 cd/m² while the area lit by the fluorescent undercabinet fixture ranges from 50-200 cd/m².

While the retrofit maintained previous ambient lighting levels, the energy consumption was significantly reduced. The ambient lighting in the baseline office environment was monitored to determine usage. The ambient lighting was on, on average, from 5:30am to 8:30pm Monday through Friday, or 15 hours per work day. The baseline ambient lighting system load was 7151 Watts while the new system load is only 3027 Watts, a 58% energy savings. At the Gexpro energy cost of $0.17 per kWh, the cost savings is $2,629 per year. The reduction in the number of lamps saves an additional $387 per year in maintenance costs.

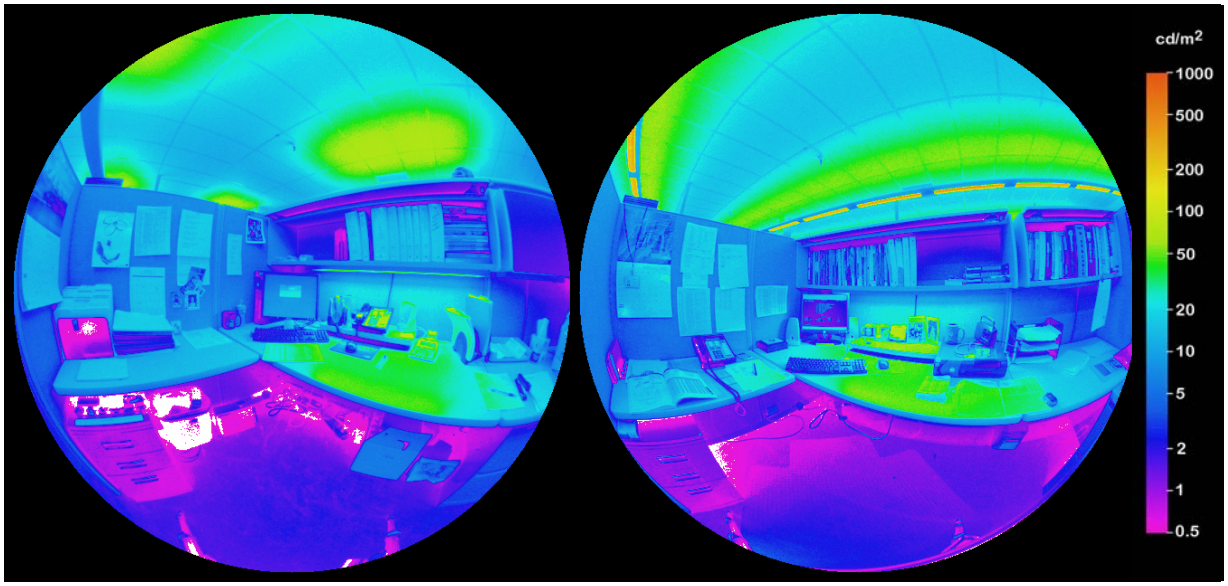


Figure 20. Luminance maps of typical cubicle at Gexpro before (left) and after (right) installation of a new ambient overhead indirect/direct lighting system. Luminance of the work surfaces is similar in both cases.

The PLS replaced the existing undercabinet fluorescent lighting. The baseline environment contained a mixture of fluorescent fixtures with a lighting power density of 0.31 Watts/ft². Each PLS was configured for the user based on desk layout and expected tasks. The final layouts consisted of a combination of undercabinet and portable LED task lights, with a range of 9-21 Watts per cubicle (average 16 Watts). The lighting power density of the new task lighting is 0.13 Watts/ft², a reduction of 66%.

Before retrofit, the existing task lighting was on an average eleven hours per day. After PLS installation, five systems were monitored to record actual energy consumption. On average, the PLS was used nine hours per day when the space was occupied (Figure 21). Occupancy sensors turned the unit off when the workspace was vacant. This function improved energy efficiency but is less critical in this application than in the Bateson building demonstration since the cubicles at Gexpro are more frequently occupied. Even so, occupancy sensing reduced the average on time from 11 to 9 hours a day, a 20% savings.

The reduced task lighting power density combined with occupancy sensors saved a total of $626 per year ($11.59 per year per cubicle) in energy costs. Because the PLS does not need lamp or ballast replacements over its lifetime, an additional $350 per year ($6.48 per year per cubicle) is saved in maintenance costs. The total energy and maintenance savings for the integrated office lighting is $3,991 per year for a simple payback of 7.2 years. The lifecycle cost savings over the anticipated 20-year life of the eleven PLS systems installed is $51,192 or $948 per PLS installed (see Appendix A for calculations).

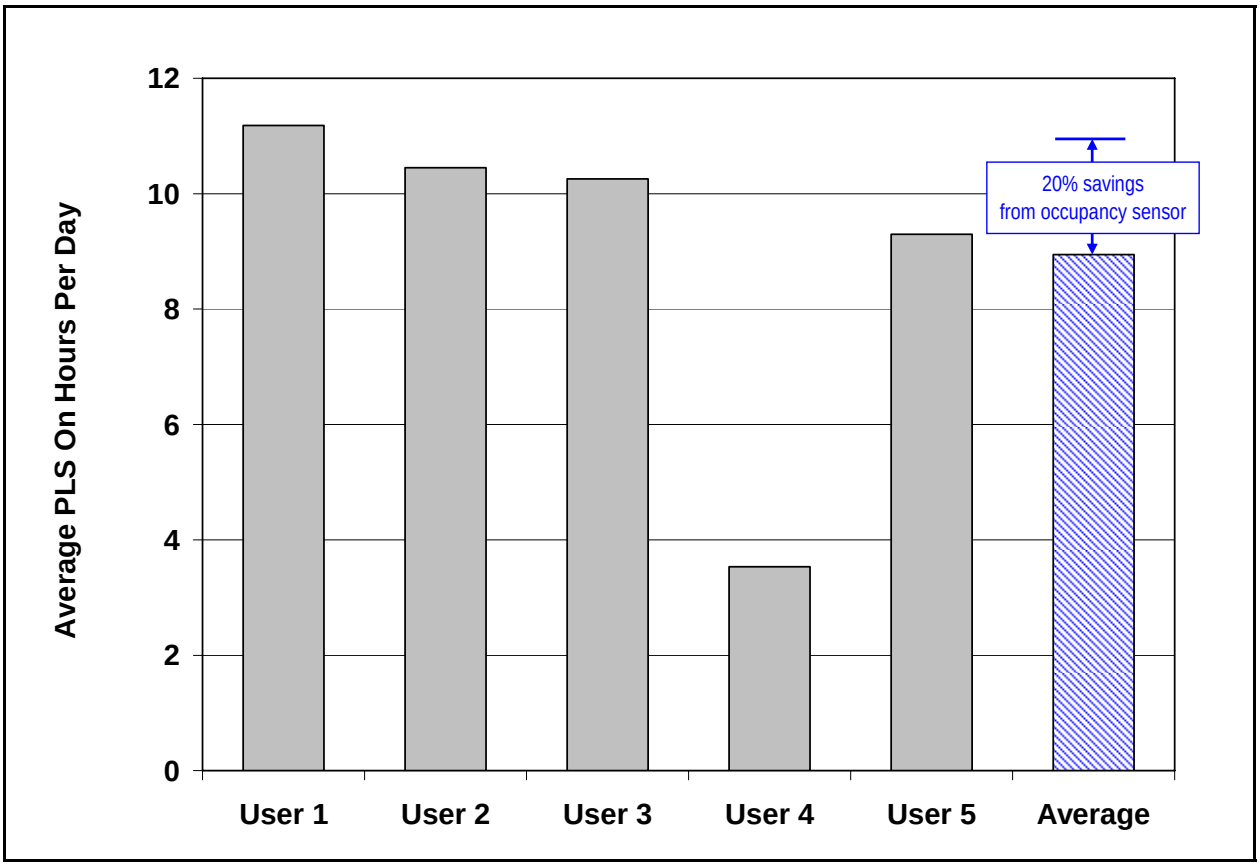


Figure 21. Average number of PLS on hours for five users at Gexpro over a period of three weeks. Occupancy sensing turned the unit off when the workspace was vacant for an additional 20% energy savings.

Summary of Key Findings

Each demonstration provided a unique retrofit scenario with slightly different solutions. However, some common findings were discovered at all three demonstration sites. Before retrofit, existing task lighting ranged from 0.31-0.74 W/ft², well above the current Title 24 allowance and expectation of 0.2 W/ft². The installed PLS consumed 0.10-0.16 W/ft², well within the current Title 24 allowance. Another common finding is that occupancy sensing reduced the on-time of task lighting hours by 20-35%. Because power consumption of the PLS is so low, these energy savings may not support the incremental cost of the occupancy sensor. Analysis of the data showed that simple payback improved by a few months when the occupancy sensor was removed from the system. The occupancy sensor provides the additional benefit of turning the system on when entering the office, which is a convenience appreciated by many users.

Each demonstration had varying baseline conditions and retrofit solutions, which resulted in a different energy story and payback. The Bateson building had extremely high power density for task lighting. Installation of the PLS alone provided significant energy savings. High user satisfaction of the PLS system was evident when employees voluntarily de-lamped 30% of the ambient lighting. This supports that a de-lamping strategy is a viable strategy for reducing ambient lighting. The DMV had the lowest density of cubicles in the open office area. Reducing

overhead lighting by a conservative 20% led to significant energy savings for the 11 cubicles in the demonstration. Based on ambient lighting power densities obtained in the DMH and Gexpro study, the DMV could obtain additional savings with a more attractive payback with additional de-lamping. At Gexpro, the existing task lighting density was low in comparison to the other demonstration sites. The PLS still offered 66% energy savings. The payback at Gexpro is less favorable than the other sites due to the cost of the new ambient lighting system. While a de-lamping strategy could have been employed, Gexpro desired new fixtures for improved lighting quality and aesthetic design.

Lifecycle cost savings ranged from $895 to $1,229 per PLS system installed. While the payback in these retrofit demonstrations is 4-7 years, the economic benefits of improved lighting quality are not considered.

User satisfaction presented in section 4.2.4 clearly shows a preference for the IOLS. Improved employee satisfaction resulting productivity increases are incredibly valuable yet difficult to quantify.

4.2.3. Potential IOLS Energy Savings in New Construction and Major Renovation Applications

While the payback for the retrofit demonstrations is 4-7 years, the payback on new construction and major renovations is more favorable at approximately 1 year, and in some cases immediate. As an example, cost and performance estimates are compared for a new installation of overhead and task lighting in a 5792 ft² office space with eight enclosed offices and 23 cubicles. The following lighting options are compared:

1. Baseline - A traditional approach with overhead 2'x4' 3-lamp high performance T8 parabolic troffers with 8'x10' on-center spacing. Each workspace has an 18W fluorescent desk lamp and one or two 25W fluorescent undercabinet luminaires.
    a. This approach uses 1.18 W/ft².
    b. The installation cost is $4.16 per square foot (Table 4).
    c. The lifecycle cost over a 20 year period (selected for comparison for correlation to the expected PLS life) is $18.48 per square foot (Table 4).
    d. The desk in a simulated cubicle is illuminated with 26-167 footcandles, with an average of 79 footcandles (workplane illuminance). The desk in a private office is illuminated with 44-189 foot candles, with an average of 87 footcandles (Figure 22, left).
2. IOLS - An IOLS approach with low ambient overhead 1-lamp high performance T8 direct/indirect lighting with 12' on center spacing. Each workspace has a PLS with a 6W desk lamp and one or two 6W undercabinet luminaires.
    a. This approach uses 0.53 W/ft², a 53% energy savings.
    b. The installation cost is $4.47 per square foot, a 7% increase.

c. The simple payback for the increased installation cost is 1 year.

d. The lifecycle cost over the 20 year life of the PLS is $10.70 per square foot, a 42% savings from the baseline.

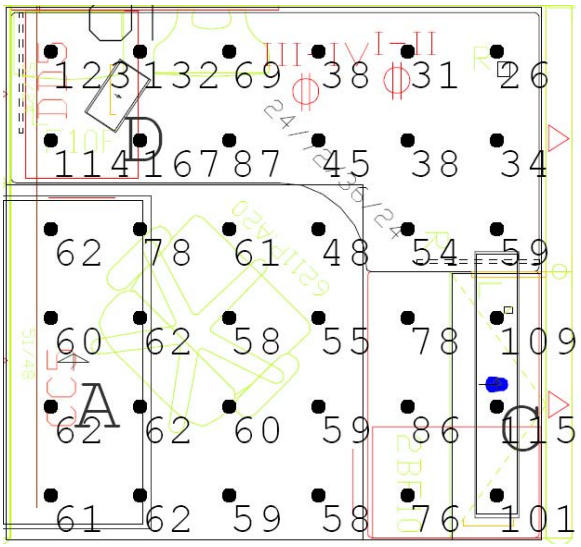
e. The desk in a simulated cubicle is illuminated with 28-68 footcandles, with an average of 44 footcandles on the workplane. (IESNA recommended target is 30 footcandles, with range of 21-40 footcandles). The desk in a private office is illuminated with 25-86 footcandles with an average of 46 footcandles (IESNA recommended target is 50 footcandles, with range of 35-68) (Figure 22, right).

The IOLS approach achieves a 53% energy savings with a payback of 1 year. Although the average illumination levels are reduced in the IOLS approach, the resulting illumination levels are within IESNA recommended target ranges and balanced lighting distribution with less glare provides improved light quality for high user satisfaction. The task / ambient approach also allows for enhanced flexibility in task lighting placement and intensity, allowing users to put higher levels of illumination in areas of need.

		Overhead Lighting Only ($/sf)	+ FLR Undercab and Desk ($/sf)		+ PLS Undercab and Desk ($/sf)	
			FLR Cost	Total Cost	PLS Cost	Total Cost
Baseline	Installation Cost	$2.05	$2.11	$4.16	$2.14	$4.19
	Annual Energy Cost[1]	$0.44	$0.13	$0.57	$0.04	$0.48
	Annual Maintenance Cost	$0.11	$0.04	$0.15	$0.00	$0.11
	Life Cycle Cost over PLS 20 Life	$12.97	$5.51	$18.48	$2.94	$15.91
IOLS	Installation Cost	$2.33			$2.14	$4.47
	Annual Energy Cost[1]	$0.21			$0.04	$0.25
	Annual Maintenance Cost	$0.06			$0.00	$0.06
	Life Cycle Cost over PLS 20 Life	$7.76			$2.94	$10.70
				Simple Payback (years)		1.0

Table 4. Comparison of life cycle costs of traditional overhead lighting with fluorescent task lighting to low ambient overhead lighting and PLS task lighting.

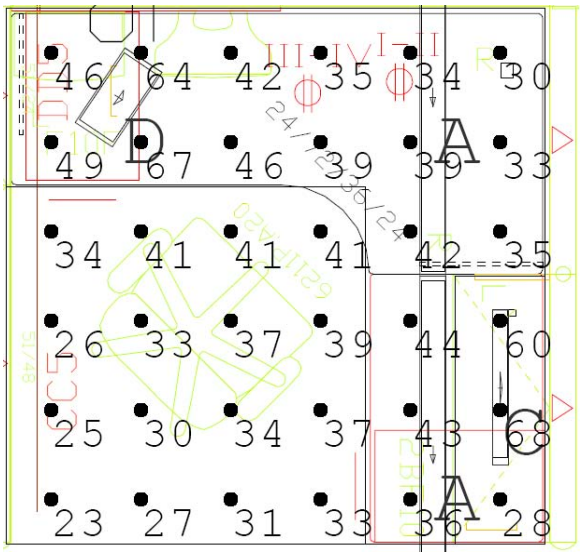
Refer to Appendix C for additional sample IOLS layouts compared to new construction and retrofit base cases.



Cubicle – Troffers + Fluorescent Task

Illuminance (Fc)
Average =70.81
Maximum =167
Minimum =26.0

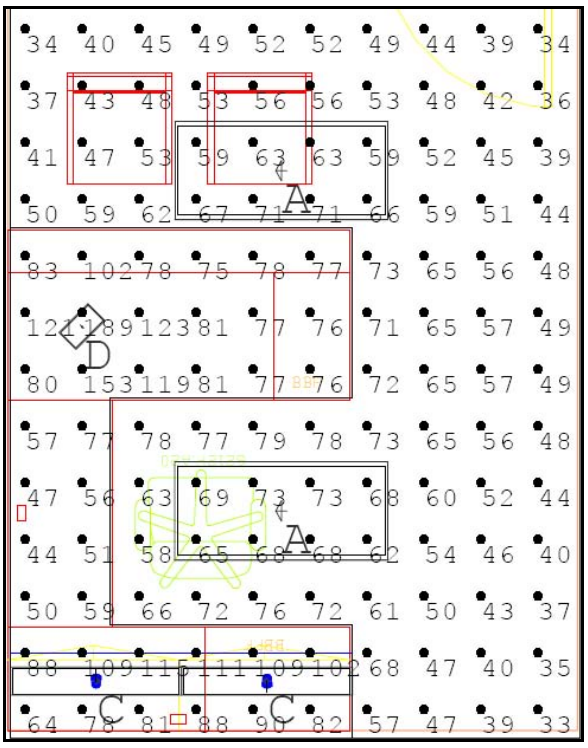
Illuminance (Desk Only) (Fc)
Average =79.10
Maximum =167
Minimum =26.0



Cubicle – Low Ambient + PLS Task

Illuminance (Fc)
Average =39.22
Maximum =68.0
Minimum =23.0

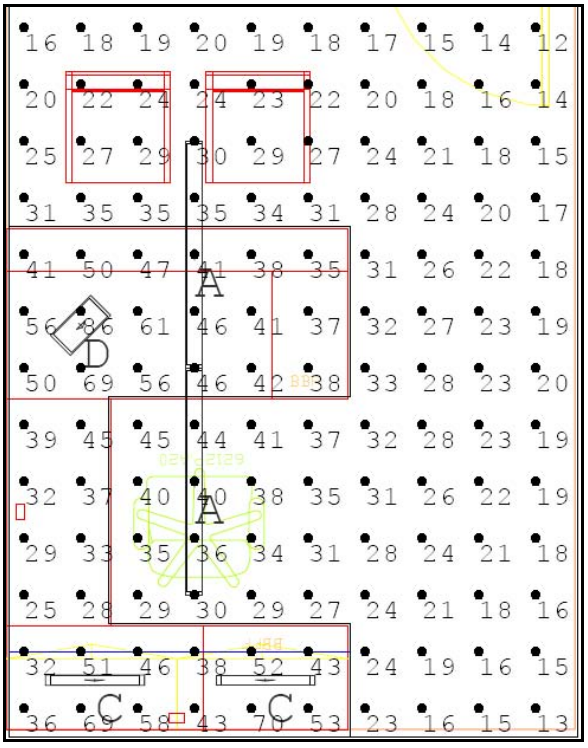
Illuminance (Desk Only) (Fc)
Average =44.00
Maximum =68.0
Minimum =28.0



Private Office – Troffers + Fluorescent Task

Illuminance (Fc)
Average =63.16
Maximum =189
Minimum =32.0

Illuminance (Desk Only) (Fc)
Average =86.95
Maximum =189
Minimum =44.0



Private Office – Low Ambient + PLS Task

Illuminance (Fc)
Average =29.81
Maximum =86.0
Minimum =11.0

Illuminance (Desk Only) (Fc)
Average =45.76
Maximum =86.0
Minimum =25.0

Figure 22. Comparison of simulated illuminance values for traditional overhead lighting with fluorescent task lighting to low ambient overhead lighting and PLS task lighting.

4.2.4. User Satisfaction

CLTC surveyed employees who participated in an IOLS demonstration using a web-based survey program. Surveys were returned by employees of United Stationers, the Department of Mental Health, the Department of Motor Vehicles, and Gexpro. In addition, survey results are included from a Sacramento Municipal Utility District demonstration of PLS units at Breathe California. The results comprise 50 respondents rating the PLS and a subset of 28 respondents also rating a reduced overhead lighting system.

To assess task lighting, survey participants rated the following categories on a scale of very negative, negative, neutral, positive, and very positive:

1. How would you assess the performance of the previous lighting at your workstation?
    a. Overall Functionality
    b. Amount of light provided at task level
    c. Quality of light provided (color)
    d. Ease of control (on/off switch; other control)and flexibility
    e. Size of the fixture/compactness/visibility
    f. Look & feel/compatibility with furniture
2. How would you assess the performance of the new task lighting at your workstation?
    a. Same categories repeated from question 1.
3. What was your initial reaction to the new task lighting installed at your workstation?
4. How would you assess the performance of the previous overhead ("ambient") lighting in your office?
    a. Overall Lighting
    b. Lighting Uniformity (ceiling, walls, desks)
    c. Quality of light provided (color, warmth, etc.)
    d. Energy Efficiency
5. How would you assess the performance of the new ambient lighting in your office?
    a. Same categories repeated from question 4.

For each question, the ratio of positive to negative responses was calculated to provide a simple metric to measure user satisfaction (a higher number corresponds to greater satisfaction). Neutral responses are not included in this ratio. For previous task lighting, this ratio ranged from 1:1-5:1, depending on category (Figure 23, blue series). After installation of the new PLS task lighting, the ratio was overwhelmingly positive. The satisfaction ratio exceeded 10:1 in all categories (Figure 23, green series). The PLS task lighting rated most highly for quality and color of light, flexibility of the system, size of the fixture and look and feel of the system.

Overall, the initial reaction to the PLS was positive (67%) with few negative reactions (8%) reported. The remaining employees (25%) initially felt indifferent about the new task lighting (Figure 24).

The ratio of positive to negative responses was also calculated to gauge satisfaction of the previously installed ambient lighting. This ratio ranged from 1:1-5:1, depending on category (Figure 25, blue series). The satisfaction ratio increased after adoption of reduced overhead lighting levels. The ratio increased to greater than 10:1 for perceived energy efficiency, quality/color of light and overall performance (Figure 25, green series). Satisfaction of lighting uniformity also increased from 3:1 to 6:1.

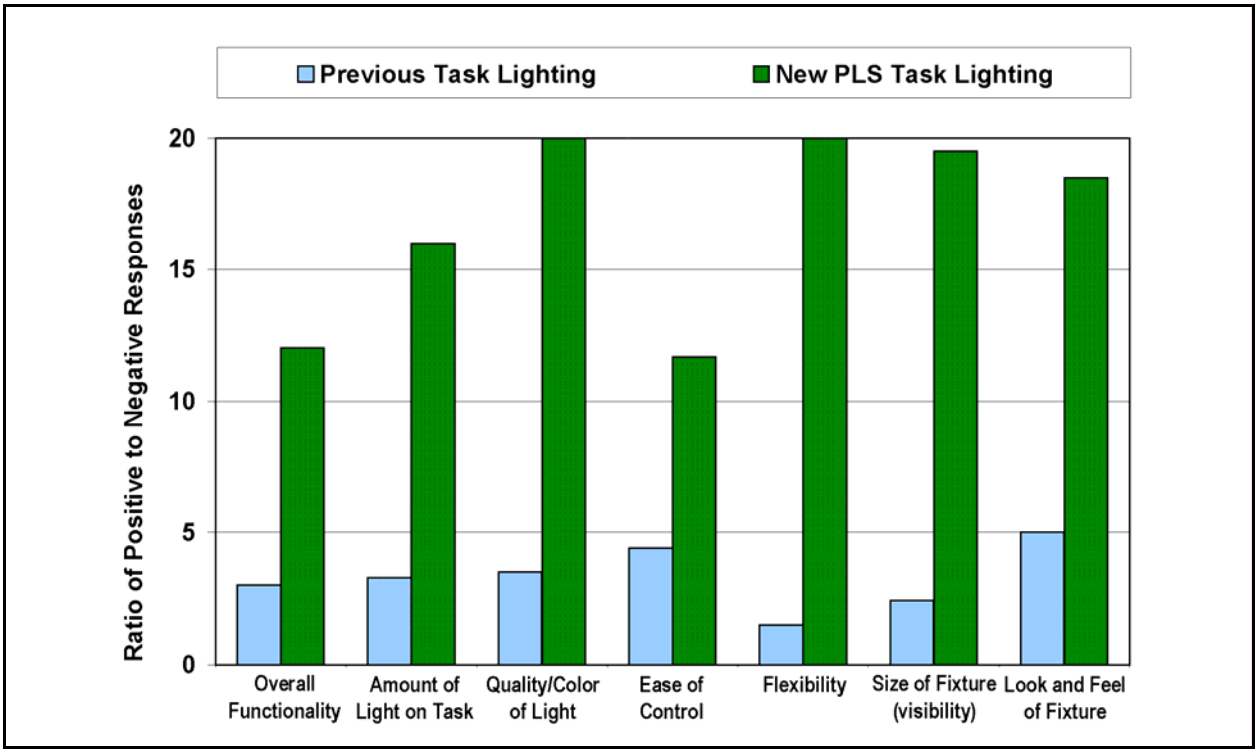


Figure 23. The PLS rated significantly higher than previous task lighting in all seven categories surveyed, especially for quality/color of light, flexibility, size of the fixture, and aesthetics.

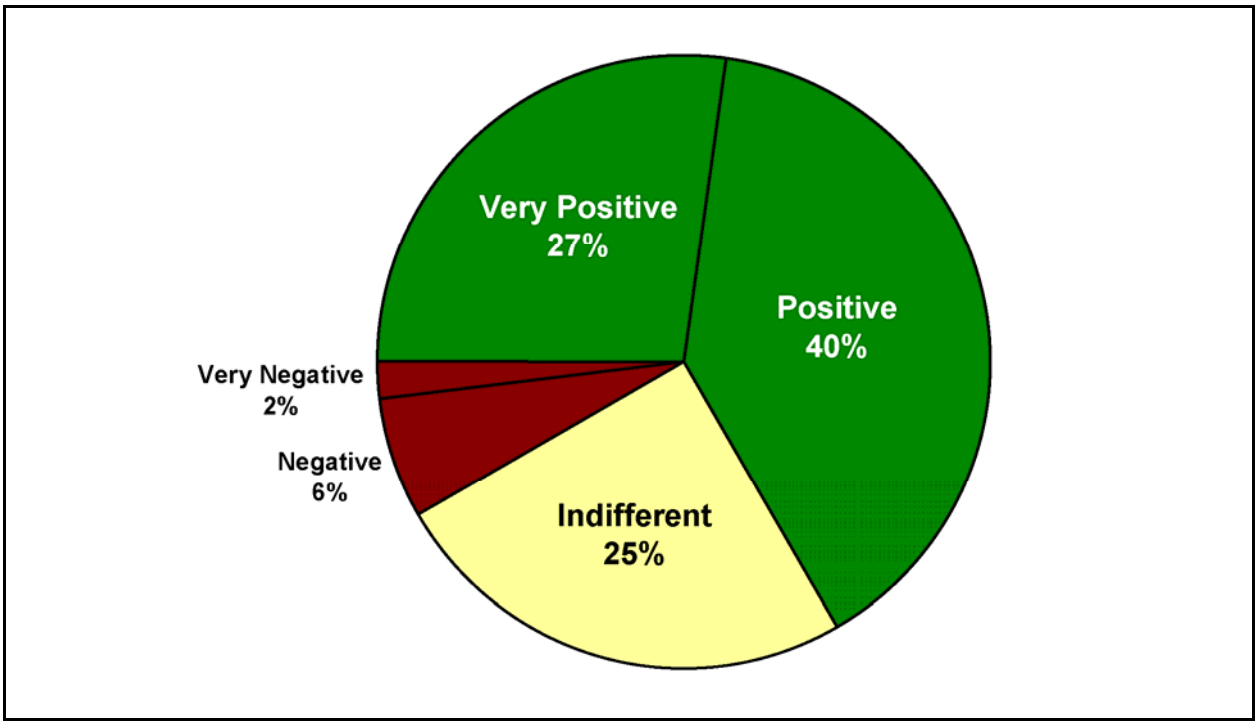


Figure 24. The majority initial reaction to the PLS was positive with few negative reactions reported.

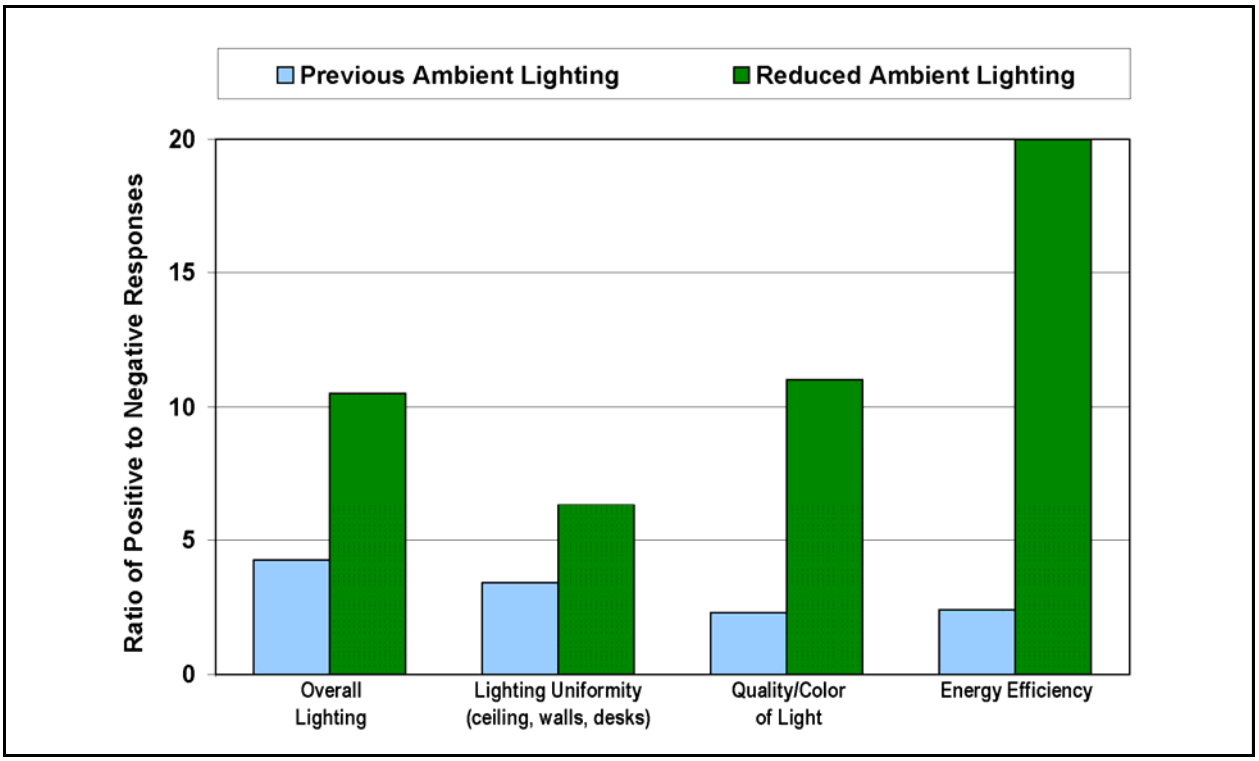


Figure 25. The reduced ambient lighting rated significantly higher than previously installed lighting, particularly for perceived energy efficiency, the quality/color of light, and overall performance.

In addition to completing the quantitative ratings, many users also provided useful comments and opinions regarding their new lighting. A sampling of the positive comments includes:

1. "My newly installed lighting system has brought the light to my work. Instead of having to position myself out of the way of the overhead light to avoid shadows, my new task lighting system provides me light for my work at work level. This makes seeing my work easier." – *United Stationers Employee*
2. "The new lighting has allowed me to work with only half of the old fixtures on. The lighting itself has improved as a result of the new LED fixture locations above my work area." – *United Stationers Employee*
3. "The newly installed lighting system is a much softer and warmer light and the sensor is fantastic!" – *Department of Mental Health Employee*
4. "This light is soft, efficient and inviting. I don't squint or stare. My eyes don't get tired, and I don't feel I am in a hospital environment with washed out brightness." – *Department of Mental Health Employee*
5. "The new lighting is very easy to use. I love it that I don't have to worry about turning off so many switches after I leave my office for a long time. It is very efficient and I love it that it conserves energy." – *Breathe California Employee*
6. "I believe I receive much better and more light from a task standpoint then before. And at the same time I believe I'm getting all of that in exchange for a much more efficient and energy saving system." – *Gexpro Employee*
7. "There was no task level lighting previously. I can read documents set on my desk much easier now and I feel less strain on my eyes. I really appreciate the extra light!" – *Gexpro Employee*

Although the large majority of comments were positive, survey comments also yielded some criticism and provided insight into potential problems. These responses include:

1. "The new lighting is too low and has been giving me headaches. I work in an office with no windows and since the task lighting is not bright enough, I still need to use my overhead lights." – *Breathe California Employee*
2. "The light is focused on my work station which is good when I am working directly underneath the light, but when I work several feet away from the light it does not provide adequate lighting for me. I would benefit from a larger efficient light in the room as well as the task light." – *Breathe California Employee*
3. "I think it would be beneficial to have at least one fixture in one area at the desk top that has the capability of increasing light levels for design tasks such as blue print preparation. The new 22" LED fixture could be increased in length allowing more spread of light across the work surface, or a two position switch that allow another set of LEDs to be energized." – *Department of Motor Vehicles Employee*

4. "Great improvement. Only problem that I have is that my radio can only pickup am stations. Can't get fm stations anymore. This is regarding the under cabinet lighting." – *Gexpro Employee*

Some of these comments were related to engineering issues that were unique to the pre-commercial systems used in the field studies (such as the RFI interference that was causing radio interference) and were solved in subsequent design modifications prior to full PLS commercialization. Other comments were more general in nature and provided insight that could be considered in future design reviews.

Concerns about low light levels were mainly reported by Breathe California Employees, which is a SMUD demonstration site and not funded by this project. However, the results are shown to illustrate that low lighting power densities are acceptable with limitations. At Breathe California, employees were encouraged to use the task lighting and severely cut the use of any overhead lighting. The task lighting is not intended to completely replace overhead lighting and attempts to do so clearly result in dissatisfaction. Several Breathe California employees reported that they now operate with half of their overhead lighting. Approaching the overhead and task lighting as a complete and integrated LED-task / low ambient system is paramount to achieving low power densities and user satisfaction.

A Department of Motor Vehicles employee requested a fixture with an adjustable lighting level. Finelite is investigating incorporating dimming into future project lines. A Gexpro employee reported interference with FM radio bands. Finelite has fixed this interference problem in the commercialized product.

4.3. Product Commercialization

Integrated office lighting components, including the PLS and indirect/direct ambient lighting systems are available from Finelite. PLS was fully commercialized in July and formally introduced to the market in September 2007; product details are available at www.finelite.com.

Following the research and development stage of PLS, Finelite pioneered the commercialization of an LED-based task lighting system on several fronts. For a lighting fixture manufacturer, two of the largest commercialization challenges entering the solid-state lighting space are 1) becoming a self supplier of lamp and driver technologies and 2) resolving supply issues from the LED component manufacturer.

The lighting industry as a whole integrates technologies by others into their fixtures to meet some specialized demand or performance requirement. However, for the most part, solid state lighting components did not exist that could be readily integrated into the PLS luminaire design. For this project, the lamp module and driver were developed from scratch since a suitably designed existing module was not available. The key driver component was one of the few commercially available when the project was started, and the supplier of the component was surprised by the performance issues uncovered during the development. Designing, testing, and manufacturing the driver system required an array of different skills that were

outside the realm of a typical lighting manufacturer at the onset of this project's commercialization stage.

Another new challenge was working with the LED component supplier to the system. Although general illumination is the fastest growing segment for LED manufacturers, it is still the smallest while at the same time being the most demanding in terms of performance and color temperature. The acceptable color temperature range, controlled by a process called "binning", for a consumer electronics manufacturer is far wider than is considered acceptable to the lighting community. It took considerable negotiation with the LED supplier partner to agree upon the need for tighter color temperature specifications in purchasing agreements, unlike those that were in place for non-lighting applications with companies such as Sony and Apple.

Beyond these major technical hurdles, the PLS luminaire design underwent nearly a year-long refinement process to streamline production for large-scale manufacturing. Because PLS is proximate to the end user and thus finish details are significantly visible, quality control is of the utmost importance with very tight tolerances.

Finelite began shipping its first commercial units in July of 2007 to the New York Times (NYT) Headquarters Building in New York City. The NYT purchased 500 9W Desk Lamps for use in open office areas. Since that time, a total of over 4,000 Desk Lamps and nearly 3,000 Undercabinet units have shipped to commercial customers, such as Roche Molecular Systems, Citigroup, and Stanford University.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The Integrated Office Lighting System project furthered task / ambient lighting design by developing and demonstrating a new LED task lighting system, the PLS, in combination with reduced ambient lighting. The PLS and reduced ambient lighting systems are currently available from Finelite. In 2007, the PLS won the Department of Energy's solid state lighting competition, "Lighting for Tomorrow". Finelite has shipped over 7,000 units to commercial customers and the PLS is being included in several PIER demonstrations, including 124 workspaces at the California Energy Commission.

In addition to the development of the PLS, an important outcome of this project is the knowledge gained about LED-task / low ambient lighting design and users' ability to adapt to a energy-saving office lighting. A variety of products from other manufacturers may provide LED- task / low ambient solutions to achieve similar goals. These products are expected to increase as LED lighting evolves with improved efficiency and lower cost.

LED-task / low ambient lighting is a powerful design that can beat both current and proposed Title 24 requirements for lighting power densities in office spaces. The resulting lighting power densities for the three demonstrations in this project are from 0.59-1.31 Watts/ft². While all three demonstrations featured the PLS, the lowest power density was obtained by replacing overhead lighting with a low ambient design. Obtaining a total lighting power density of 0.59 W/ft² is a significant achievement, considering California's current Title 24 requirement for lighting new and retrofit office spaces is less than 1.2 W/ ft². Proposed changes to this requirement for 2008 reduce the allowable lighting power density to 1.1 W/ ft² for offices less than 250 ft² and to 0.9 W/ ft² for offices greater than 250 ft². LED-task / low ambient lighting is the clear path forward to meeting and exceeding these goals.

It is important to assure that the user of lighting does not suffer visual discomfort at the expense of energy savings. LED-task / low ambient design must be approached carefully and must consider the tasks and needs of the user. As shown in this project, LED-task / low ambient lighting has the potential to increase user satisfaction because the LED task lights are portable, adjustable, and produce high quality light with even distribution.

Finelite and CLTC continue to pursue LED-task / low ambient lighting design and recommend continued research in this area. CLTC is demonstrating LED-task / low ambient lighting design as part of the 2008-2010 PIER Demonstration project. Furthermore, if the cost of LED lighting technology decreases as projected, the economics of LED-task / low ambient as presented in this Integrated Office Lighting System project will improve.

Energy Analysis - Department of Mental Health

	Data Field	Units	Notes
Square Footage (Total)	2500	sq ft	Calculated from floor plan
Number of Workstations (Total)	22	Cubicles	
Square Footage (Effective - Demo)	2045	sq ft	
Number of Workstations (Demo)	18	Cubicles	

BASE CASE			
Ambient Lighting Load	1728	Watts	Estimate 32 Watts per lamp/ballast
Ambient Lighting (# Lamps)	54	# Lamps	
Ambient Lighting Density	0.84	Watts/sq ft	Using Total Sq. Footage
Energy Cost per Year*	$1,102		15 hrs a day, 250 days per year
Task Lighting Load	1523	Watts	Completed Lighting Audit
Task Lighting Load (per Cubicle)	85	Watts	Average
Task Lighting (# Lamps)	57	# Lamps	Completed Lighting Audit
Task Lighting Density	0.74	Watts/sq ft	
Task/Ambient Lighting Density	1.59	Watts/sq ft	
Task Lighting Hours per Day	8	Hours	Estimated (Not monitored)
Energy Cost per Year*	$518		250 days per year

PLS and LOW AMBIENT			
Ambient Lighting Load	1178	Watts	Estimate 32 Watts per lamp/ballast
Ambient Lighting (# Lamps)	37	# Lamps	
Ambient Lighting Density	0.58	Watts/sq ft	Using Total Sq. Footage
Energy Cost per Year*	$751		15 hrs a day, 250 days per year
Task Lighting Load	330	Watts	Completed Lighting Audit
Task Lighting Load (per Cubicle)	18	Watts	Average
Task Lighting Density	0.16	Watts/sq ft	
Task/Ambient Lighting Density	0.74	Watts/sq ft	
Task Lighting Hours per Day	5.30	Hours	Monitored
Energy Cost Per Year*	$74		250 days per year

SAVINGS			
Energy Savings (Ambient)	$351	32%	Per Year
Energy Savings (Task)	$443	86%	Per Year
Energy Savings (Total)	$794	49%	Per Year
Maintenance Savings (Ambient)	$52		Maintenance cost of $3 per year/per lamp
Maintenance Savings (Task)	$285		Maintenance cost of $5 per year/per lamp
Maintenance Savings (Total)	$337		
Savings per Year, Total	$1,131		
Savings per Year, per Cubicle	$63		
Savings per year, per sq ft	$0.55		

COSTS/PAYBACK			
Total Task Retrofit Cost	$6,505		
Average Task Cost per Cubicle	$361		
Average Ambient Cost per Cubicle	$0		no new system
Average Cost per Cubicle	$361		
Payback (Years)	5.8		
Estimated System Life**	20	years	
Lifecycle Savings per Cubicle	$895		

*Calculated at $0.17 per kWh

**Based on 45,000 hr rated LED life, 9 hrs of operation a day, 250 days/yr

Energy Analysis - Department of Motor Vehicles

	Data Field	Units	Notes
Square Footage (Total)	3299	sq ft	Calculated from floor plan
Number of Workstations (Total)	18	Cubicles	
Square Footage (Effective - Demo)	2016	sq ft	
Number of Workstations (Demo)	11	Cubicles	

BASE CASE			
Ambient Lighting Load	3051		Estimated from LPD calc
Ambient Lighting (# Lamps)	95	# Lamps	Estimated from LPD calc
Ambient Lighting Density	1.51	Watts/sq ft	Counted Lamps/Tiles in pictures
Energy Cost per Year*	$1,945		15 hrs a day, 250 days per year
Task Lighting Load	880	Watts	From DMV Case Study
Task Lighting Load (per Cubicle)	80	Watts	Average
Task Lighting (# Lamps)	33	# Lamps	Estimate 3 units per cubical
Task Lighting Density	0.44	Watts/sq ft	
Task/Ambient Lighting Density	1.95	Watts/sq ft	
Task Lighting Hours per Day	8	Hours	Estimated (Not monitored)
Energy Cost per Year*	$299		250 days per year

PLS and LOW AMBIENT			
Ambient Lighting Load	2444	Watts	32 Watts per lamp/ballast
Ambient Lighting (# Lamps)	76	# Lamps	
Ambient Lighting Density	1.21	Watts/sq ft	
Energy Cost per Year*	$1,558		15 hrs a day, 250 days per year
Task Lighting Load	198	Watts	Completed Lighting Audit
Task Lighting Load (per Cubicle)	18	Watts	Average
Task Lighting Density	0.10	Watts/sq ft	
Task/Ambient Lighting Density	1.31	Watts/sq ft	
Task Lighting Hours per Day	5.60	Hours	
Energy Cost per Year*	$47		250 days per year

SAVINGS			
Energy Savings (Ambient)	$386	20%	Per Year
Energy Savings (Task)	$252	84%	Per Year
Energy Savings (Total)	$639	28%	Per Year
Maintenance Savings (Ambient)	$57		Maintenance cost of $3 per year/per lamp
Maintenance Savings (Task)	$165		Maintenance cost of $5 per year/per lamp
Maintenance Savings (Total)	$222		
Savings per Year, Total	$860		
Savings per Year, per Cubicle	$78		
Savings per Year, per sq ft	$0.43		

COSTS/PAYBACK			
Total Task Retrofit Cost	$3,685		
Average Task Cost per Cubicle	$335		
Average Ambient Cost per Cubicle	$0		no new system
Average Cost per Cubicle	$335		
Payback (Years)	4.3		
Estimated System Life**	20	years	
Lifecycle Savings per Cubicle	$1,229		

*Calculated at $0.17 per kWh

**Based on 45,000 hr rated LED life, 9 hrs of operation a day, 250 days/yr

Energy Analysis - Gexpro

	Data Field	Units	Notes
Square Footage (Total)	6616	sq ft	Calculated from floor plan
Number of Workstations (Total)	54	Cubicles	
Square Footage (Effective - Demo)	6616	sq ft	
Number of Workstations (Demo)	54	Cubicles	

BASE CASE			
Ambient Lighting Load	7151		Measured
Ambient Lighting (# Lamps)	223	# Lamps	Estimated (32W per lamp)
Ambient Lighting Density	1.08	Watts/sq ft	
Energy Cost per Year*	$4,559		15 hrs a day, 250 days per year
Task Lighting Load	2040	Watts	
Task Lighting Load (per Cubicle)	38	Watts	Average
Task Lighting (# Lamps)	70	# Lamps	Audit from furniture layout
Task Lighting Density	0.31	Watts/sq ft	
Task/Ambient Lighting Density	1.39	Watts/sq ft	
Task Lighting Hours per Day	11	Hours	Monitored
Energy Cost per Year*	$954		250 days per year

PLS and LOW AMBIENT			
Ambient Lighting Load	3027	Watts	Estimate 32 Watts per lamp/ballast
Ambient Lighting (# Lamps)	95	# Lamps	
Ambient Lighting Density	0.46	Watts/sq ft	
Energy Cost per Year*	$1,930		15 hrs a day, 250 days per year
Task Lighting Load	858	Watts	Completed Lighting Audit
Task Lighting Load (per Cubicle)	16	Watts	Average
Task Lighting Density	0.13	Watts/sq ft	
Task/Ambient Lighting Density	0.59	Watts/sq ft	
Task Lighting Hours per Day	9	Hours	Monitored
Energy Cost per Year*	$328		250 days per year

SAVINGS			
Energy Savings (Ambient)	$2,629	58%	Per Year
Energy Savings (Task)	$626	66%	Per Year
Energy Savings (Total)	$3,255	59%	Per Year
Maintenance Savings (Ambient)	$387		Maintenance cost of $3 per year/per lamp
Maintenance Savings (Task)	$350		Maintenance cost of $5 per year/per lamp
Maintenance Savings (Total)	$737		
Savings per Year, Total	$3,991		
Savings per Year, per Cubicle	$74		
Savings per Year, per sq ft	$0.60		

COSTS/PAYBACK/LIFECYCLE SAVINGS			
Total Task Retrofit Cost	$14,242		
Total Ambient Retrofit Cost	$14,400		
Average Task Cost per Cubicle	$264		
Average Ambient Cost per Cubicle	$267		
Average Cost per Cubicle	$530		
Payback (Years)	7.2		
Estimated System Life**	20	years	PLS and ambinent
Lifecycle Savings per Cubicle	$948		

*Calculated at $0.17 per kWh

**Based on 45,000 hr rated LED life, 9 hrs of operation a day, 250 days/yr

Appendix B: Integrating a Low Ambient Design throughout the Office Environment

Introduction:

Low ambient design for open offices, private offices, and other spaces use the following five lighting components:

1. Task
2. Ambient
3. Vertical surface illumination
4. Accent
5. Access to view

For open offices and private offices, ambient and task lighting play primary roles and must be carefully integrated to achieve maximum user comfort and minimum energy use.

Ambient lighting should provide low level illuminance to light the space and enhance the architecture while being consistent with the overall interior design concepts. Through the use of high performance indirect/direct luminaires, a beautiful office space can be achieved with recommended light levels and overall lighting power density of 0.5 to 0.65 watts per square foot. (Figure 1) Other high performance lighting systems may also achieve similar results.

Figure 1. Uniformity and balance are key to achieving a low level ambient system at target levels of 0.5 to 0.65 watts per square foot.

Task lighting should provide higher illuminances required or desired at easily identified, specific task locations. Integrate task lighting so the ambient lighting serves to provide an appropriate background illuminance necessary for comfort and a sense of psychological well being, while the task lighting adds light only where needed. Rather than using a T8 fluorescent lamp 2' away from the task, it is more energy-efficient and visually pleasing to use LED-based task lighting. As a desk lamp or under cabinet light, the low power and directional LED light source puts the right amount of light right where

an individual needs it at their workstation. In fact, with this approach, task lighting may be designed as the primary illumination system, and the ambient lighting designed secondarily. With LED task lighting, the added lighting power density may be as little as 0.05 watts per square foot. (Figure 2)

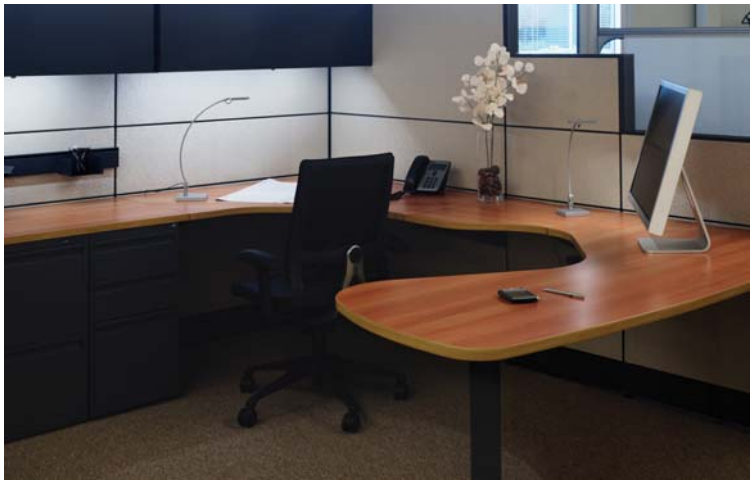


Figure 2. A combination of LED-based desk lamps and undercabinets provides balanced illumination while individual switching of units provides user flexibility and control.

Other elements can bring the office design together making it as visually interesting as it is energy efficient. Uniformly illuminating features on walls such as presentation materials or artwork using vertical surface lighting makes spaces feel brighter and larger. Using glass partitions rather than solid ones takes full advantage of views while potentially providing a modest amount of daylight in an open office space. (Figure 3)

Figure 3. Here, the glass partition separating the conference room from the adjacent open office allows workers access to views and the dynamic qualities of daylight.

Judiciously used accent lighting on a corridor wall or areas of visual interest can create an inviting feel (Figure 4). The key to being energy-efficient while providing the desired effect is to carefully balance the five components of light using the best technology available for each.

Figure 4. Accent lighting emphasizes artwork while simultaneously providing vertical surface illumination that makes the space feel brighter, more open, and inviting.

The Open Office:

People in open office space read a variety of printed material and use the computer throughout the day. The Illuminating Engineering Society of North America (IESNA) identifies this as Task D (requiring around 30fc plus or minus 1/3) and the indirect/direct illumination is generally preferred as it incorporates the right amount of downlight for reading tasks while minimizing glare on the computer screens.

In Figure 5, one-lamp high lumen T8 luminaires are spaced 12’ on center. T8 lamps are generally desirable when a luminaire has a direct lighting component as the lamp wall brightness is considered acceptable with appropriate shielding. White louvers, when used, increase the perception of brightness while creating a high-energy, fun space. Wall wash luminaires that accent a distant wall help enhance the perception of brightness.

Different department areas such as computer aided drafting and graphic design demand higher levels of illuminance within an open office layout since discrimination of fine detail is frequently required for extended periods of time. Likewise, older workers will require more light to perform the same visual tasks as younger workers. User-adjustable task lighting that the worker can position for performing critical tasks, or overcoming shadows and reflections, will provide optimal lighting.

Figure 5. Example of low ambient design using 1 lamp high lumen T8 luminaires spaced 12’ on center at an overall lighting power density of 0.5 w/sf.

The Private Office:

The control of overhead brightness may be less important for small private office spaces in terms of direct and reflected glare than for large spaces. Local task lighting, combined with low level ambient lighting, is also appropriate for private offices. However, the application of a task light may prove challenging because a task light built into a desk may not illuminate the primary work location and traditional desk lamps may not provide adequate quality or quantity of light. Therefore, finding a task lighting system with flexibility and user control is critical. Again, LED-based task lighting provides the basis for an ideal solution. In addition, while ambient and task lighting are as important in private offices as in open offices, the illumination of vertical surfaces plays an even more important role in making a private office comfortable. (Figure 6)

Conference Room(s):

Visual tasks in conference rooms range from simple to complex. Conference room spaces do not require task lighting, per se, but do often need flexible lighting systems to accommodate for different functions at different times.

Two or more lighting systems should be planned to provide flexibility including the following:

- A general lighting system, in which control is provided by switching or dimming to vary the illuminance.
- A supplementary downlighting system, with a dimmer control for image projection and other low-level illumination requirements. It is effective to incorporate dimming into a general florescent system.
- A perimeter wall wash system controlled with dimmers for better visual appeal, particularly where presentation materials may be wall mounted.

Controls that enhance the effectiveness for audiovisual presentations are a must. (Figure 7)

Figure 6. In this large private office primarily indirect lighting keeps vertical surfaces bright white. Task lighting mitigates shadows created by obstructions.

Figure 7. A streamlined approach for conference rooms using indirect/direct lighting for general and AV modes plus a separately controlled whiteboard luminaire provides ideal functionality for all uses of the room and low energy use

Copy and Server Rooms:

These functional spaces showcase ways to save money on every project. Totally indirect luminaires are affordable and provide an excellent means of achieving low ambient lighting for the tasks done in these rooms.

Break Room:

An office break room designed to be a bright, fun space encourages employees and guests to sit down together and enjoy lunch or a cup of coffee. Using daylighting in the break room, as in Figure 8, enables one row of luminaires to remain off during much of the day. Dimming and dual technology occupancy sensors improve energy savings potential.

Figure 8. Daylight responsive controls shed load at peak electricity-use periods without compromising the functionality of the space.

Training Room:

An office training room may be approached in a similar fashion to a standard school classroom size of 30’ x 32’. Using the best possible combination of indirect/direct luminaires along with independent switching, dimming, and an occupancy sensor, it is possible to reduce energy consumption to less than 0.9 W/ft²in such a space while simultaneously improving critical classroom communication. Instructors should have controls at the front of the classroom enabling them to change between general and audiovisual lighting modes. A whiteboard luminaire puts additional light on the teaching wall improving student retention. (Figure 9)

Figure 9. A high performance classroom lighting approach yields ideal results in a boardroom setting or training room equally well.

Entry Lobby / Reception Area:

Reception areas are designed for visitors. While waiting, they may want to check notes, scan magazines, or converse with each other. The lighting should be restful yet provide sufficient illuminance for reading. One way to provide a restful atmosphere without direct glare is to light one or more walls. Another method involves lighting the ceiling and part of the walls. Accent lighting on pictures or a corporate logo can attract attention and enliven the room's appearance.

Create a comfortable waiting space by blending natural light, electric light, pleasing finishes and inviting site lines. For example light from a hidden wall wash unit behind the receptionist will draw your eye into the space. The lighting should compliment the architecture, and carefully choosing the best surfaces to illuminate will result in the most visually pleasing and energy-efficient design.

Corridor:

Since many people move through corridors, lighting considerations should include safety requirements and luminance balance with respect to adjacent areas, as well as the appearance of the space. Public areas must remain illuminated for long, if not continuous periods of time. Therefore, serious consideration should be given to energy efficient lighting.

Using a corridor accent wall is an affordable way to use light and open space to add visual interest. Various shapes cut into a divider wall can allow a visual element to be dynamic when moving through the space. As in Figure 10, the brightness of the pendant luminaires seen from the corridor through the "windows" attracts the eye and invites people into the space beyond.

Figure 10. Illuminated windows become art themselves and add a playful element. When using fluorescent lighting for accent, great visual impact may be achieved efficiently.

Center Hallway and Restrooms: The use of color and light provides direction to a central hallway and provides guidance to a destination. (Figure 11) A vertically mounted luminaire is an affordable and energy efficient way to light a small area. Using as little as 25 watts can provide ample lighting in a decorative way, eliminating the need to light the space with other common strategies that could potentially consume twice the energy.

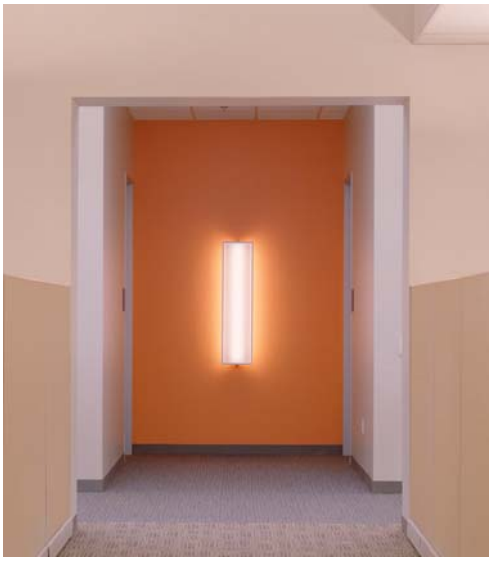


Figure 11. A bright luminaire element in contrast with saturated color provides a destination and aids in giving directions, demonstrating how light can be used as a tool to provide orientation in a space at low power consumption.

Summary:

Low ambient design for open offices, private offices, and other spaces can be both comfortable and energy-efficient when applying the five lighting components of task, ambient, vertical surfaces illumination, accent, and access to view. Through these techniques, a beautiful office space can be achieved with recommended light levels and overall lighting power density of 0.5 to 0.65 watts per square foot.

Appendix C: IOLS Lighting Pattern Book

The purpose of the IOLS Lighting Pattern Book is to demonstrate typical design templates that illustrate the application of IOLS using LED-Task / Low Ambient, resulting in office lighting that:

- Saves energy and reduces operating cost
- Meets LEED
- Uses reduced material
- Improves employee satisfaction
- Is affordable
- Creates high quality and aesthetically pleasing results

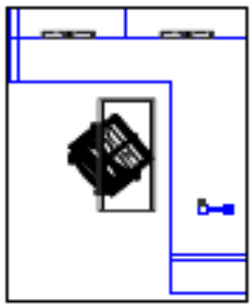
Specifically, the IOLS Lighting Pattern Book provides guidance for lighting:

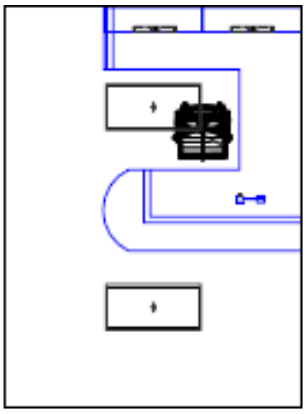
- Open Offices
  8', 9', & 10' ceiling heights

9400 sf open plan
with (36) 10'x12' workstations,
60" panel height and
binder bins along main spine

- Private Offices
  8', 9', & 10' ceiling heights

Typical 8'x10' Typical 12'x16'





- Individual Workstations
  Optimized for customized solutions using LED-Task lighting

The Five Components of Office Lighting

Well-executed lighting, for any space, uses a technique of layering light. In office spaces, ambient and task illumination provides the majority of the lighting. While this IOLS Lighting Pattern Book focuses on solutions for ambient and task, these solutions are presented with the understanding that additional lighting components would be desirable, if not critical, to providing the most visually effective, pleasantly illuminated, and energy-efficient environment for the benefit of project owners and occupants. The lighting components, and how they relate to offices, are:

1. Task

While a variety of tasks are performed within an office, lighting requirements are set by tasks that are predominant and visually demanding, which normally translates into some form of a reading task. Size and contrast determine the degree of difficulty of the reading task and the required illumination level. Complexity is determined by the variety of tasks, the task orientation (horizontal versus vertical), and the nature of how the task background reflects light. In most cases, office workers simultaneously perform horizontal paper-based tasks and vertical computer-based tasks. Balanced lighting between adjacent tasks is as important as the amount of illumination provided at the task for ideal seeing conditions. Balanced lighting is lighting that eliminates harsh contrast and glare, and when task lighting is optimized, the other lighting components may be designed the most efficiently and utilized to their greatest impact.

Optimizing task lighting is easy with the PLS LED-Task system. The right amount of light causes less glare, fewer headaches, and increases productivity. Individual control and ergonomic adjustment for each user provides higher levels of user satisfaction. Optional occupancy sensor provides automatic off function to further increase energy savings.

2. Ambient

Ambient illumination creates the sense of space and allows for free movement within the interior environment. Good ambient illumination provides soft, uniform lighting, at the lower levels needed for conducting less visually demanding tasks such as face-to-face meetings and way-finding. With today’s lighting technology, fluorescent-based systems achieve these goals efficiently and affordably using a Low Ambient design approach.

3. Vertical Surface Illumination

Whether circulating through the office, or seated at a desk performing a reading task, occupants are positioned with their eyes looking forward, at vertical surfaces. The perception of how much light is in the space is directly influenced by the amount of light that strikes vertical surfaces. Lighter, brighter vertical surfaces will make a space feel brighter and more open. Choosing ambient lighting systems that provide good vertical illumination, or specifically adding illumination to light vertical surfaces, will move the quality of the task and ambient illumination from good to excellent.

4. Accent

A key to providing comfortable lighting in the office is to encourage the eye to take frequent breaks from demanding visual tasks. Judicious, but not over-powering, points of brilliance will attract attention to avoid visual fatigue. Accent lighting

creates visual interest, defines an image, and paradoxically in the office, can enhance levels of concentration.

5. Access to View

Access to daylight and a view to the outdoor environment provide occupants with a connection to the outdoors. As a recognized design practice that enhances the interior environmental quality, LEED provides up to three points for achieving specific benchmarks of daylight penetration and direct line of sight to an exterior view. As with all other elements of lighting, avoiding excessive contrast and direct glare are critical. These goals are especially challenging to meet given the sheer potential quantity of daylight that might be introduced into the interior environment, as well as the dynamic nature of daylight based on the building orientation and changing weather conditions.

Specific Design Criteria for *LED-Task* and *Low Ambient* Elements

The target illumination level at the task is 30 footcandles for open plan offices and 50 footcandles for private offices. These targets are, for general purposes, to cover the majority of tasks typically performed within the office. Adjustments for specialized tasks or individual user requirements (such as the age of the occupant) may require either an upward or downward adjustment from these target levels. Assuming a 30 to 50 footcandle target illumination level at the task, the combined LED-Task / Low Ambient design benchmarks are:

From the *Low Ambient*: 10-20 footcandles
From the *LED-Task*: 20-40 footcandles
Combined *LED-Task / Low Ambient*: 30-60 footcandles
Combined Lighting Power Density: 0.50-0.65 watts per sf or less

The IOLS Lighting Pattern Book illustrates specific Integrated Office Lighting Systems showing the combined effect of excellence in *LED-Task / Low Ambient* design in an open office, a 12’ x 16’ private office, and an 8’ x 10’ private office. For the *Low Ambient* part of the design, the selection of luminaire spacing and needed optics and lumen packages are dictated primarily by ceiling height. Typical scenarios using both linear and recessed fluorescent systems are presented for 8’, 9’ and 10’ ceiling heights. One workstation size is depicted in each of the three office spaces illustrated, but additional Lighting Patterns for Individual Workstations illustrate how to customize the *LED-Task* portion of the design.

When reviewing the data, keep in mind that the presented information is based on a set of assumptions about the space. If actual conditions vary, then results may differ significantly. The basic assumptions are:

Illuminance levels are maintained, given in footcandles

Room reflectances: 80% ceiling; 50% walls; 20% floor
Workstation partition and furniture reflectances: 50%
Partition height: 60”

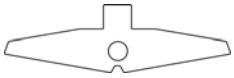
Low Ambient:	Input Watts based on High Efficiency Instant Start T8 ballasts
	Lamp lumens based on High Performance 3100 lumen T8 lamps

LED-Task:	Undercabinet: One 6W PLS UC under each binder bin (two per workstation) Desk Lamp: One 6W PLS DL per workstation (head 15” above desk surface)
Simple Payback:	Includes equipment and labor costs plus energy and maintenance savings
Base cases:	New Construction: 2’x4’ 3-lamp T8 Parabolic, 8’ x 10’ on center Retrofit: Ambient at 1.5 w/sf on average

Open Office-8' Ceiling

Linear Close-to-Ceiling Pendant

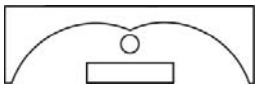
Fixture: Series 15-1T8, 1.20BF
Quantity: 592 lf
Spacing: 12' on center
Suspension Length From Bottom of Fixture: 6"



			Illuminance at 2.5' Workplane Height			Simple Payback	
LED-Task / Low Ambient	W/sf	No. of LEED CI Points	Overall	Workstation Group	Desk	New Construction	Retrofit
UC only	0.61	3	24	30	30	3 yrs	6 yrs
UC & DL	0.64	3	25	32	34	< 1 yr	7 yrs

Recessed

Fixture: 1x4-1T8, 1.20BF
Quantity:124
Spacing: 8' x 8'



			Illuminance at 2.5' Workplane Height			Simple Payback	
LED-Task / Low Ambient	W/sf	No. of LEED CI Points	Overall	Workstation Group	Desk	New Construction	Retrofit
UC only	0.55	3	29	33	25	4 yrs	7 yrs
UC & DL	0.58	3	30	35	29	2 yrs	7 yrs

Open Office – 9’ Ceiling

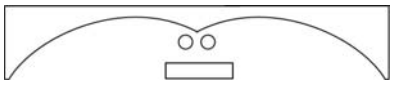
Linear Pendant

Fixture: Series 16-1T8, 1.00BF
Quantity: 592 lf
Spacing: 12’ on center
Suspension Length From Bottom of Fixture: 18”

			Illuminance at 2.5’ Workplane Height			Simple Payback	
LED-Task / Low Ambient	W/sf	No. of LEED CI Points	Overall	Workstation Group	Desk	New Construction	Retrofit
UC only	0.49	3	30	37	34	1 yr	5 yrs
UC & DL	0.52	3	31	39	38	Immediate	5 yrs

Recessed

Fixture: 2x4-2T8, 0.78BF
Quantity: 100
Spacing: 8’x 10’



			Illuminance at 2.5’ Workplane Height			Simple Payback	
LED-Task / Low Ambient	W/sf	No. of LEED CI Points	Overall	Workstation Group	Desk	New Construction	Retrofit
UC only	0.56	3	37	40	35	2 yrs	6 yrs
UC & DL	0.59	3	38	42	39	Immediate	6 yrs

Open Office – 10’ Ceiling

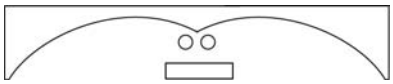
Linear Pendant

Fixture: Series 16-1T8, 1.20BF
Quantity: 484 lf
Spacing: 14’ on center
Suspension Length From Bottom of Fixture: 24”

			Illuminance at 2.5’ Workplane Height			Simple Payback	
LED-Task / Low Ambient	W/sf	No. of LEED CI Points	Overall	Workstation Group	Desk	New Construction	Retrofit
UC only	0.53	3	29	40	40	Immediate	4 yrs
UC & DL	0.56	3	30	42	44	Immediate	5 yrs

Recessed

Fixture: 2x4-2T8, 1.00BF
Quantity: 86
Spacing: 10’x 12’

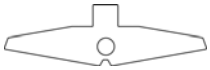


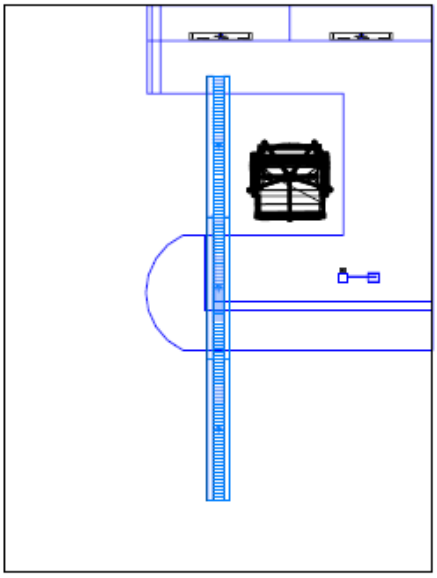
			Illuminance at 2.5’ Workplane Height			Simple Payback	
LED-Task / Low Ambient	W/sf	No. of LEED CI Points	Overall	Workstation Group	Desk	New Construction	Retrofit
UC only	0.62	3	41	44	29	1 yr	5 yrs
UC & DL	0.65	3	42	46	33	Immediate	6 yrs

12’ x 16’ Private Office – 8’ Ceiling

Linear Close-to-Ceiling Pendant

Fixture: Series 15-1T8, 1.20BF
Quantity: 12 lf
Spacing: centered
Suspension Length From Bottom of Fixture: 6”

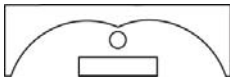


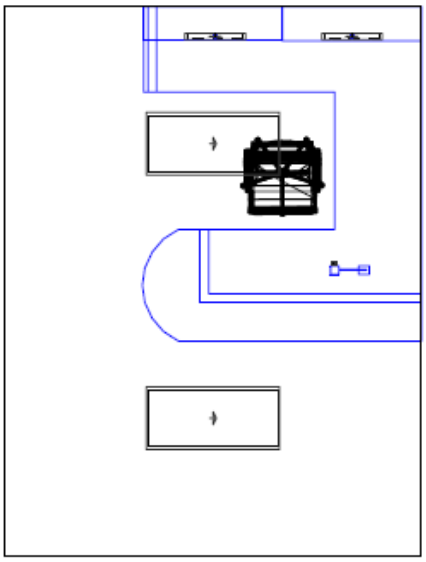


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.65**	**3**	**20**	**24**	**4 yrs**	**7 yrs**
UC & DL	**0.68**	**3**	**21**	**27**	**3 yrs**	**7 yrs**

Recessed

Fixture: 1x4-1T8, 1.20BF
Quantity:124
Spacing: 8’ x 8’



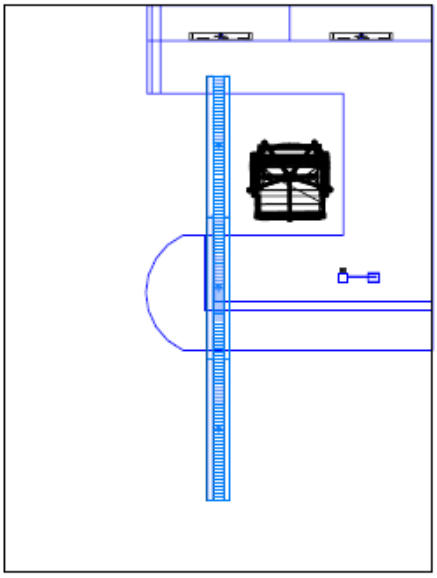


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.64**	**3**	**39**	**40**	**Immediate**	**5 yrs**
UC & DL	**0.67**	**3**	**40**	**43**	**Immediate**	**5 yrs**

12’ x 16’ Open Office – 9’ Ceiling

Linear Pendant

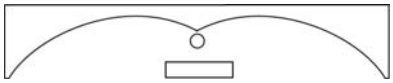
Fixture: Series 16-1T8, 1.00BF
Quantity: 12 lf
Spacing: centered
Suspension Length From Bottom of Fixture: 18”

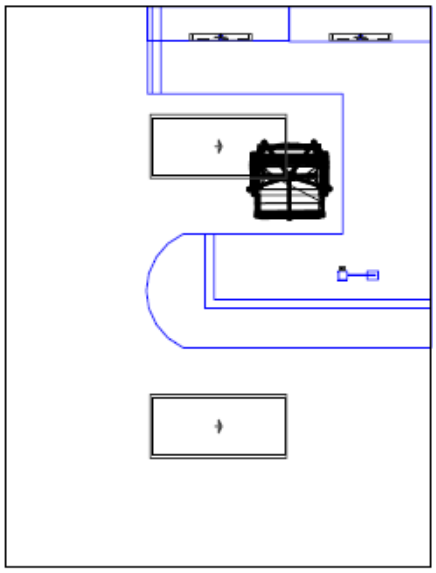


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.60**	**3**	**25**	**29**	**2 yrs**	**6 yrs**
UC & DL	**0.63**	**3**	**26**	**32**	**1 yr**	**6 yrs**

Recessed

Fixture: 2x4-2T8, 0.88BF
Quantity: 2
Spacing: 8’ on center



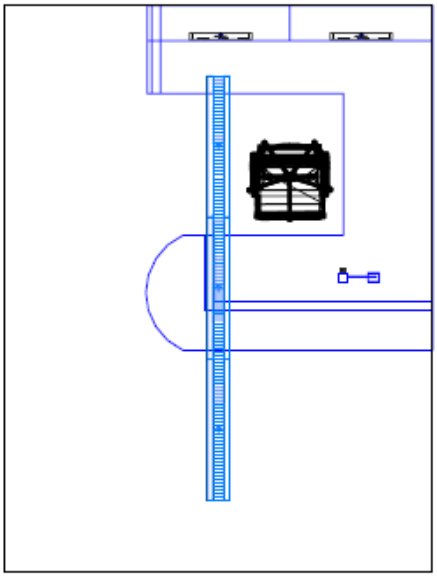


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.64**	**3**	**36**	**38**	**Immediate**	**5 yrs**
UC & DL	**0.67**	**3**	**37**	**41**	**Immediate**	**5 yrs**

12’ x 16’ Private Offline – 10’ Ceiling

Linear Pendant

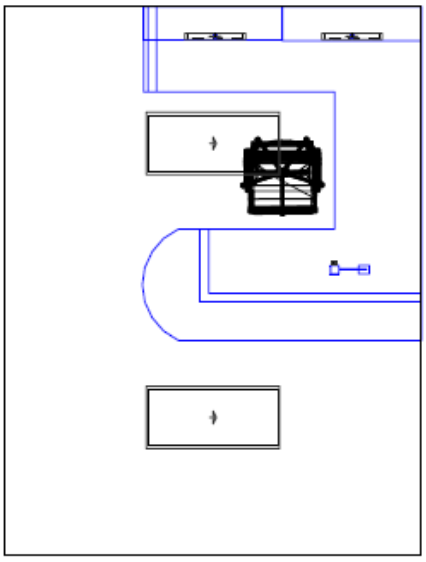
Fixture: Series 16-1T8, 1.20BF
Quantity: 12 lf
Spacing: centered
Suspension Length From Bottom of Fixture: 24”



			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.65**	**3**	**28**	**31**	**2 yrs**	**6 yrs**
UC & DL	**0.68**	**3**	**29**	**34**	**1 yr**	**7 yrs**

Recessed

Fixture: 2x4-2T8, 1.00BF
Quantity:2
Spacing: 8’ on center

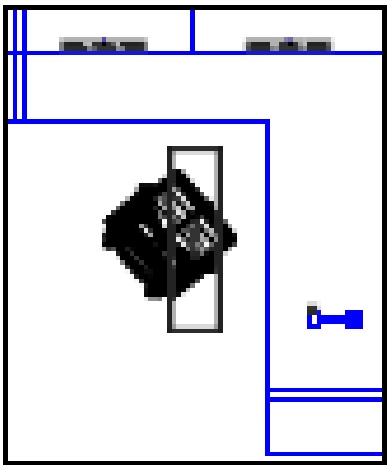


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.72**	**2**	**37**	**40**	**Immediate**	**5 yrs**
UC & DL	**0.75**	**2**	**38**	**43**	**Immediate**	**6 yrs**

8’ x 10’ Private Office-8’ Ceiling

Linear Close-to-Ceiling Pendant

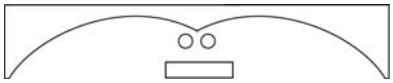
Fixture: Series 15-2T8, 1.20BF
Quantity: 4 lf
Spacing: centered
Suspension Length From Bottom of Fixture: 6”

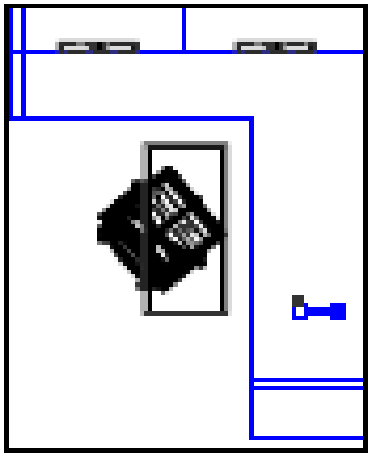


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**1.09**	**na**	**20**	**20**	**< 1 yr**	**10 yrs**
UC & DL	**1.17**	**na**	**22**	**24**	**Immediate**	**11 yrs**

Recessed

Fixture: 2x4-2T8, 0.78BF
Quantity:1
Spacing: centered



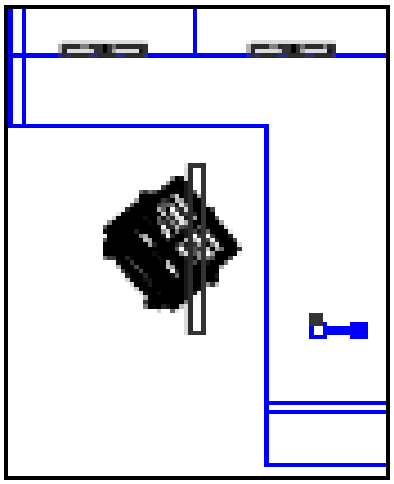


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.76**	**2**	**36**	**35**	**Immediate**	**7 yrs**
UC & DL	**0.84**	**1**	**38**	**39**	**Immediate**	**8 yrs**

8’ x 10’ Private Office – 9’ Ceiling

Linear Pendant

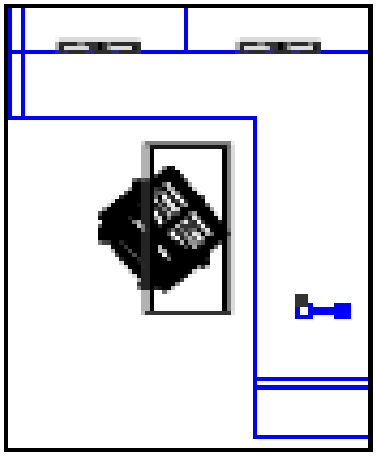
Fixture: Series 16-2T8, 1.00BF
Quantity: 4 lf
Spacing: centered
Suspension Length From Bottom of Fixture: 18”



			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.94**	**1**	**30**	**30**	**Immediate**	**8 yrs**
UC & DL	**1.02**	**na**	**32**	**34**	**Immediate**	**10 yrs**

Recessed

Fixture: 2x4-2T8, 0.88BF
Quantity: 1
Spacing: centered

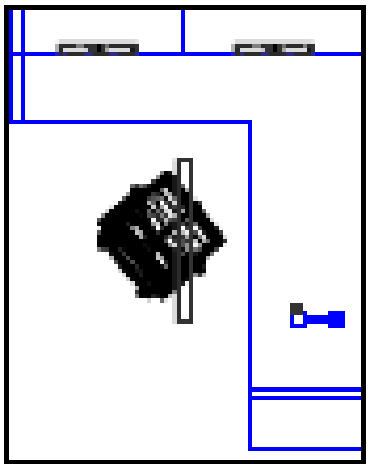


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**1.17**	**1**	**35**	**35**	**Immediate**	**8 yrs**
UC & DL	**1.02**	**1**	**37**	**39**	**Immediate**	**10 yrs**

8’ x 10’ Private Offline – 10’ Ceiling

Linear Pendant

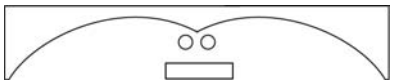
Fixture: Series 16-2T8, 1.20BF
Quantity: 4 lf
Spacing: centered
Suspension Length From Bottom of Fixture: 24”

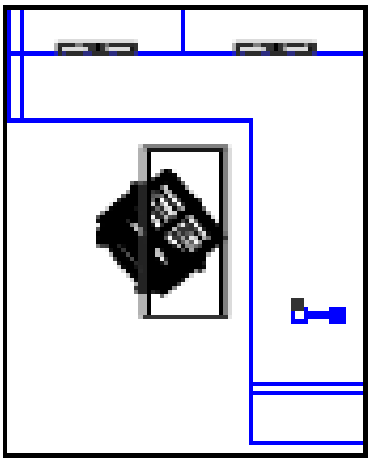


			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**1.09**	**na**	**32**	**32**	**Immediate**	**9 yrs**
UC & DL	**1.17**	**na**	**34**	**36**	**Immediate**	**11 yrs**

Recessed

Fixture: 2x4-2T8, 1.00BF
Quantity: 1
Spacing: centered

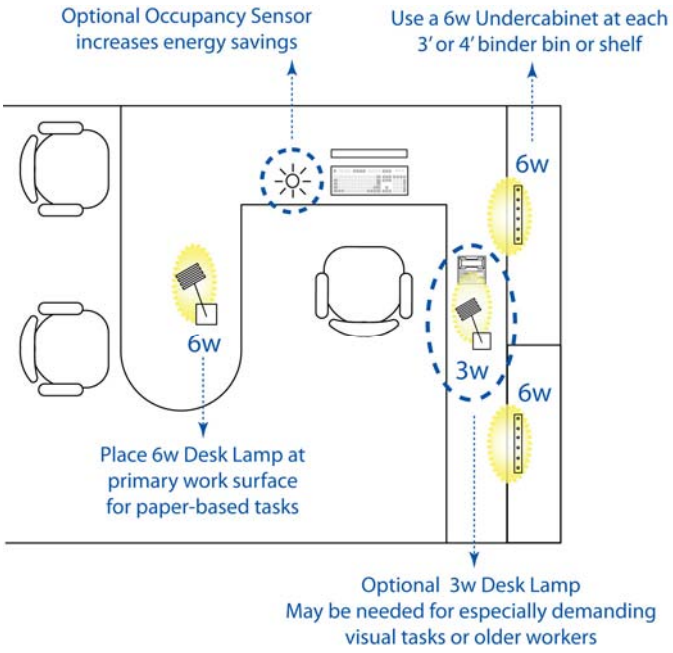




			Illuminance at 2.5’ Workplane Height		Simple Payback	
LED-Task / Low Ambient	**W/sf**	**No. of LEED CI Points**	**Overall**	**Desk**	**New Construction**	**Retrofit**
UC only	**0.94**	**na**	**35**	**35**	**Immediate**	**8 yrs**
UC & DL	**1.02**	**na**	**36**	**39**	**Immediate**	**10 yrs**

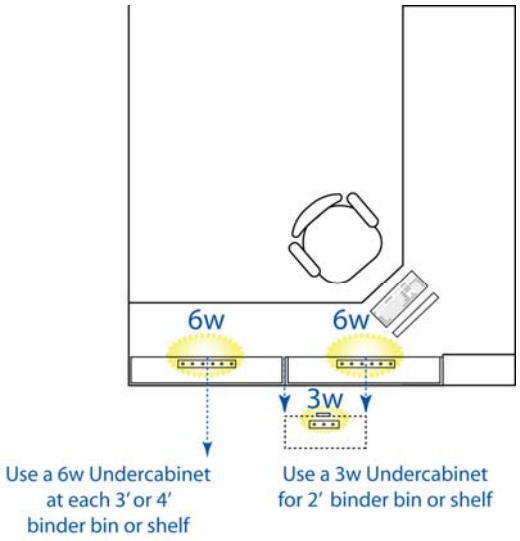
LED -Task Rules of Thumb for Individual Workstation

Executive Office – Discrete Tasks at Multiple Locations



Higher wattage fixtures may be appropriate for very tall or dark partition finishes.

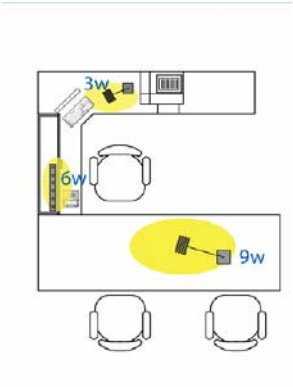
Standard Office with Binder Bins



For low or light partitions, a Desk Lamp may be used instead of Undercabinet fixtures.

Sample *LED-Task* Layouts for Individual Workstations

Executive Office / Discrete and Multiple Tasks



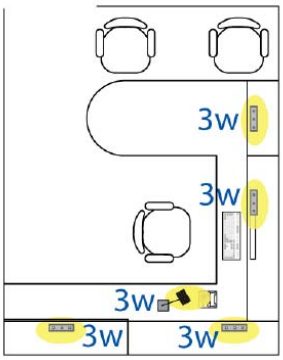
Personal Lighting System
(1) 6W UC = 6W
(1) 9W DL = 9W
(1) 3W DL = 3W
_____
Total = 18W

8'x12' Workstation = 96 sf

0.18 w/sf
LED-Task 0.09 *
Low Ambient 0.50**
_____
LED-Task + Ambient = 0.59w/sf

- **6W Undercabinet unit provides light under shelf**
- **3W Desk Lamp by computer balances luminances between adjacent tasks**
- **9W Desk lamp on conferring work surface when needed for review of large layouts**

Executive Office / Continuous Overhead Shelves



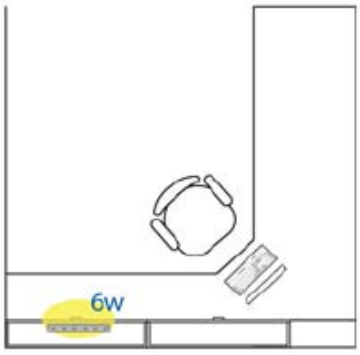
Personal Lighting System
(4) 3W UC = 12W
(1) 3W DL = 3W
_____
Total = 15W

9'x12' Workstation = 108 sf

0.14 w/sf
LED-Task 0.07 *
Low Ambient 0.50**
_____
LED-Task + Ambient = 0.57w/sf

- **3W Undercabinet units provide uniform vertical illumination**
- **3W Desk lamp at location of detailed paper-based note-taking task**
- **Additional lighting not needed for return when used for conferring only**

Typical Office / Computer-based Tasks



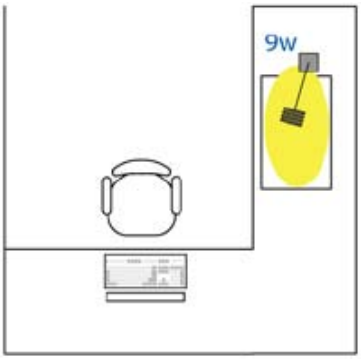
Personal Lighting System
(1) 3W UC = 3W
(1) 6W UC = 6W
_____
Total = 9W

8'x8' Workstation = 64 sf

0.14 w/sf
LED-Task 0.07 *
Low Ambient 0.50**
_____
LED-Task + Ambient = 0.57w/sf

- **6W Undercabinet unit lights under shelf to provide vertical illumination**
- **3W Undercabinet may be added to maintain balanced luminances between computer screen and adjacent vertical surface**

Typical Office / Paper-based Large Layouts



Personal Lighting System
(1) 9W DL = 9W
_____
Total = 9W

8'x8' Workstation = 64 sf

0.14 w/sf
LED-Task 0.07 *
Low Ambient 0.50**
_____
LED-Task + Ambient = 0.57 w/sf

- **9W Desk lamp provides added light on layout task**
- **No additional task lighting needed since there are no binder bins or shelves**

* Average Task LPD, including circulation area in open plan office.
** Target Low Ambient LPD at 0.5 w/sf.