Economics of Energy Effective Lighting for Offices

Energy Effective Lighting accomplishes the dual objectives of being efficient while meeting the needs of the space occupants. The USDOE Federal Energy Management Program is committed to saving energy and improving workspaces for Federal workers at the same time.

In recent years there has been a steadily increasing tide of concern about lighting quality in addition to energy efficiency. Conscientious Federal energy managers, energy services companies, and utility providers have learned from experience that lighting is a double-edged sword. It represents the most significant energy savings opportunity of all the building energy systems, and also has a profound and direct impact on the occupants of the buildings, for better or for worse.

For Better

Energy-efficient lighting can also be energy *effective*, but only if thoughtful and careful decisions are made. From a conceptual perspective, it stands to reason that reducing glare and gloom are likely to have positive impacts on occupant satisfaction and performance. It is the challenge and responsibility of those who make lighting decisions in Federal buildings to optimize the well-being and performance of the Federal workforce where possible as well as to save energy and money.

For Worse

The most common lighting fixture in Federal office buildings is the lensed 2x4, which is the least appropriate lighting technology for most modern open plan office environments. Additionally, some of the most frequent energy-efficient lighting installations can result in problems. In some cases specular reflector retrofits can reduce the visual comfort of the workers and decrease brightness at the walls.

Economic Impact of Lighting on Federal Productivity

If energy effective relighting were accomplished in Federal office buildings, the benefit would extend above and beyond the energy savings. The mean value of improved productivity from effective relighting in the Federal sector has been estimated at $1.64/SF per year, with a total annual value of $640 million. While productivity improvements are not typically introduced into a payback scenario, these tremendous potential benefits indicate that all reasonable effort should be made to provide Energy Effective Lighting using Federal life cycle cost guidelines.[1]

[1] See inside center column.

Brightness on the room surfaces is one of the top three priorities for office lighting in the new standards. Indirect lighting is one way to accomplish this. Alternatively, when using recessed fixtures, be sure to locate them close to the walls, or use a wall washing system as well.

Sun Microsystems, Mountain View, CA

The New Standard of Practice

Federal specifications are based on the standards and recommended practices of the Illuminating Engineering Society of North America. The year 2000 brings a new IESNA Lighting Handbook, 9th edition, that sets new standards and fundamentally changes lighting specification practices. The long-standing illuminance selection table has been replaced with a matrix that prioritizes design issues, and it has significant implications for Federal lighting projects. In offices the most important design characteristics are brightness (luminance) of the room surfaces, reflected glare, and direct glare. Notably, horizontal illuminance is no longer the highest priority. Federal lighting guidelines will be updated to meet the IESNA standard of practice.

Economics

Fortunately it is economically feasible to meet the dual objectives of new standards and energy efficiency at the same time. In fact, it is possible to actually improve the workplace environment for the Federal workforce and increase the value of the building stock as well. This brochure has been developed to help achieve the optimum balance between the factors discussed above. As with all energy conservation measures in the Federal sector, economics are at the core of how decisions will be made with respect to lighting energy effectiveness. In years past quality lighting equipment was out of reach because of higher costs, but the falling costs of new technologies has shifted the balance favorably. In most cases it will be cost-effective to use new equipment in a relighting design instead of simply retrofitting the components of aging and less appropriate lighting technologies. The design cases that follow show that it is now possible to provide Energy Effective Lighting using new and more appropriate technologies and with excellent payback scenarios.

Lighting System Options

The lensed troffer has been the workhorse of office lighting for over 60 years. Unfortunately the brightness of the plastic lens can create problems in the modern open plan office environment because of the prevalence of Visual Display Terminals (computer monitors). Even with the significant improvements in VDT screens, the lensed troffer does not meet the IESNA recommended practice for office lighting. This presents a significant challenge in Federal buildings because of the prevalence of this outdated technology. The designs below have been created to meet the following objectives:

- Meet the new standards of practice by avoiding reflected and overhead glare and creating brightness on the room surfaces.
- Wherever possible replace lensed troffers with lighting technologies such as parabolic troffers or semi-indirect fixtures.
- All proposed designs meet Federal life cycle cost requirements and have a Savings to Investment Ratio > 1.

Open Plan Designs

Base Case Design

Lensed 2x4s, (4) T12 lamps, magnetic ballast.

Until recently, the most common lighting system installed in office buildings employed four fluorescent lamps in a recessed troffer with an acrylic lens. A typical layout is shown here, with fixtures on 8′ by 8′ centers. Many installations will be found using 34 watt T-12 lamps and "energy saving" magnetic ballasts, operating at around 2.0 w/sf or more. Older installations may employ standard magnetic ballasts and 40-watt lamps, increasing power density to 2.6 w/sf or more.

	BASE CASE
Watts/Square Foot	1.97
Average Illuminance, footcandles	65
Total Initial Cost/SF	N/A
Annual Own and Optg Cost/SF	$0.69
Simple Payback (years)	N/A
Federal Savings to Investment Ratio	N/A

Base Case & Option 1

Option 1 • Retrofit

(2) T8 lamps, specular reflector, new lens, electronic ballasts, standard ballast factor.

The simplest improvement is to retrofit the existing troffers. In this case, the interior of the fixtures will be stripped of lamps, ballast, and sockets, and a specular reflector with sockets and ballast for two lamps will be installed. The lens should be replaced and the fixture cleaned. The resulting design will save at least 60% of the energy of the base system. While this will be the cheapest retrofit and will offer the fastest payback, unfortunately it fails to improve the quality of the overall lighting system, and **does not** meet the IESNA recommended practice. This system has a low Visual Comfort Probability of 50, indicating that one-half of the population is likely to experience discomfort from glare.

	OPTION 1
Watts/Square Foot	.77
Average Illuminance, footcandles	51
Total Initial Cost/SF	$1.12
Annual Own and Optg Cost/SF	$0.33
Simple Payback (years)	3.1
Federal Savings to Investment Ratio	5.6

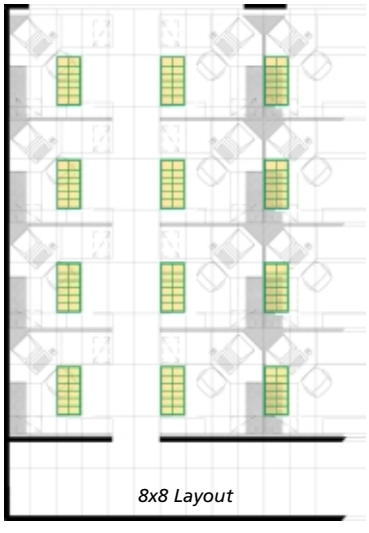
Option 2 • Retrofit

(2) T8 lamps, parabolic louver doorframe, white reflector, electronic ballasts, high ballast factor.

	OPTION 2
Watts/Square Foot	1.01
Average Illuminance, footcandles	51
Total Initial Cost/SF	$1.42
Annual Own and Optg Cost/SF	$0.41
Simple Payback (years)	5.0
Federal Savings to Investment Ratio	3.2

For an additional cost of about $25 per fixture, you can improve the retrofit by upgrading from a lens to a parabolic louver. The existing troffer is raised up, and the new louver doorframe is placed over the opening. The troffer then sits on top of the frame. In this case a high reflectance white reflector is recommended. The energy savings will be the same as for the basic retrofit, but now you will gain the shielding of the parabolic louver needed for open office areas. Because parabolic fixtures have a more downward distribution, it is important that the existing layout have the fixtures located within 3′ of the walls to avoid scallops and darkness at the tops of the walls. In a situation where new fixtures are prohibited because of asbestos or code wiring upgrade constraints, this retrofit can reduce glare without installation of new fixtures.

Option 2 & 3



Option 3 • Relighting

2x4 parabolic fixtures, (2) T8 lamps, 12-cell semi-specular louver, electronic ballasts, standard ballast factor.

This design replaces lensed fixtures with parabolic troffers using (2) T8 lamps in an existing 8x8 layout. The layout is advantageous because most workstations end up with a fixture overhead providing relatively even

	OPTION 3
Watts/Square Foot	.77
Average Illuminance, footcandles	46
Total Initial Cost/SF	$1.84
Annual Own and Optg Cost/SF	$0.32
Simple Payback (years)	4.9
Federal Savings to Investment Ratio	3.1

Important Co

- Because of long-term deterioration of lighting equipment, a fixture older than 15 years should almost always be replaced rather than retrofitted.
- Walls and ceilings should be light colored wherever possible to save energy and improve lighting quality.
- Direct glare from overly bright lamps and reflectors can cause significant visual discomfort. T5 lamps are best used in indirect wall washing fixtures rather than open downlights so the lamps are not exposed directly to the eyes.
- When there are high partitions in the open plan office, problematic shadows can occur and a tighter spacing layout

Deep Energy Savings

It is not advisable to perform *only* lighting energy conservation measures in a building. Since lighting usually offers the most cost-effective energy savings, it is important to address other efficiency improvements at the same time. Building analyses should consider performing energy conservation measures of the other building systems at the same time as the lighting. Often HVAC impacts of reduced lighting energy use can result in additional savings. If expensive equipment such as chillers are not replaced when savings are available from a relighting project, it can make it difficult to cost justify the measures alone at a later time.

When Relighting

The economic information included in this brochure is based on typical conditions. There are some conditions that change the economics enough that it becomes less feasible to obtain new fixtures, and component retrofit becomes the best option. If your project has one or more of the following constraints, you should re-evaluate the payback considering the additional costs:

What are Semi-In

Semi-indirect fixtures have a primarily uplight distribution, but they have a small amount of downlight usually through a luminous element in the housing such as perforated metal. The brightness in the housing reduces their contrast against the bright ceiling and makes them an excellent solution for visual comfort and aesthetics. Other features include:

Federal offices constitute 36% of t
but house a disproportionate 6
The high density of workers in F
any effects that the physical enviro

[1, 2] "Potential Productivity Benefits from High Qua
Proceedings of 1998 ACEEE Summer Study on E
for an Energy-Efficient Economy, Washington, D

ONSIDERATIONS

may be required. If direct fixtures are used, is it especially important to ensure that fixtures are located directly over the workstations.

- If your general lighting level is less than 40 footcandles in the task areas, task lighting should be used. In addition to undercabinet task lighting, compact fluorescent desk and table lamps may be used.
- Use controls to reduce hours of operation and adjust lighting levels. Depending on the space usage and technologies, the use of controls could save significant energy over time.

"With each lighting project, we have a crucial opportunity to improve lighting conditions for the Federal workforce. Attention to lighting quality is clearly a win-win approach that has the potential to raise morale and productivity while simultaneously reducing operating costs and meeting our energy efficiency goals."

Lisa Heschong,
Instructor FEMP Lights Web Course,
Partner, Heschong-Mahone Group

G DOESN'T WORK

- Asbestos in the ceiling
- Very low labor costs
- Wiring upgrade required by code
- Certain seismic considerations
- Prior retrofit to T8 with electronic ballasts.

NDIRECT FIXTURES?

1 recent trends in lighting equipment costs have made these fixtures surprisingly affordable with the use of steel housing,

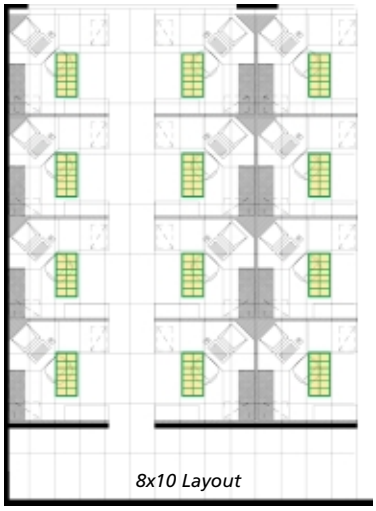
2 they are inexpensive to install because they are pendant mounted and they require a feed only at one end of the run. Ceilings must be at least 8'-6" to allow for an indirect lighting solution.

he Federal building square footage 66% of the Federal employees. ederal office buildings magnifies onment has on labor productivity.[2]

lity Lighting in Federal Buildings," L. Harris et.al, nergy Efficiency in Buildings. American Council D.C.

illumination. This design has the advantage of providing an all new lighting system that meets quality recommendations. The system has a high Visual Comfort Probability of 85, indicating that 85% of the population is likely to find the lighting system visually comfortable.

OPTION 4



8x10 Layout

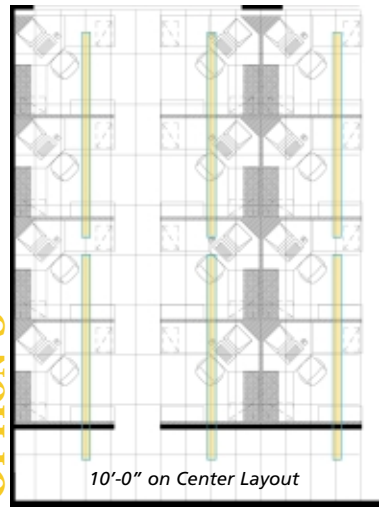
Option 4 • Relighting

New 2x4 parabolic fixtures, (2) T8 lamps, 12-cell semi-specular louver, electronic ballasts, standard ballast factor.

It is also possible to employ parabolic fixtures on 8'x10' centers. With a new fixture layout it becomes possible to ensure adequate wall brightness. This design should not be used if high partitions are in the space. If the original layout is 8x10, this design will have a better payback than what is estimated below because rewiring costs will be reduced. The system has a high Visual Comfort Probability of 85, indicating that 85% of the population is likely to find the lighting system visually comfortable.

	OPTION 4
Watts/Square Foot	.99
Average Illuminance, footcandles	56
Total Initial Cost/SF	$1.85
Annual Own and Optg Cost/SF	$0.39
Simple Payback (years)	6.2
Federal Savings to Investment Ratio	2.5

OPTION 5



10'-0" on Center Layout

Option 5 • Relighting

10'-0" on center layout, 3-lamp semi-indirect pendant mounted fixtures, electronic ballasts, low ballast factor.

Modern sheet-metal indirect and semi-indirect fixtures using T-8 lamps can be suspended from ceilings that are 8'-6" high or greater. The typical row spacing is 10'-0" on center. A low ballast factor (.75-.80) keeps the power density low while still providing adequate light levels. Using (2) T8 lamps per fixture and rows combining three or more fixtures, it is possible to implement high quality, modern office lighting within Federal payback criteria. The additional benefits of worker satisfaction and overall workplace improvements will generally make this an excellent choice.

	OPTION 5
Watts/Square Foot	.85
Average Illuminance, footcandles	47
Total Initial Cost/SF	$2.16
Annual Own and Optg Cost/SF	$0.36
Simple Payback (years)	6.5
Federal Savings to Investment Ratio	2.3

PRIVATE OFFICE DESIGNS

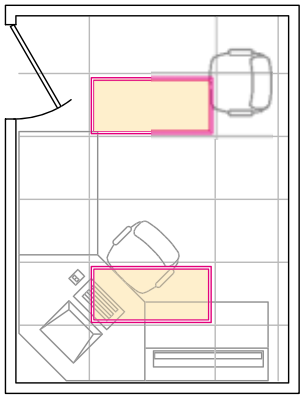
Base Case

Two 2x4 lensed troffers, (4) T12 lamps, magnetic ballasts

This illustrates typical baseline conditions. Two lensed troffers in an 8'x12' private office will provide adequate brightness on the walls and desktop, but can create an uncomfortable sensation of overhead glare for the occupants. Some offices may only have one 2x4 troffer which is inadequate with respect to uniformity and wall brightness.

	BASE CASE
Watts/Square Foot	2.85
Average Illuminance, footcandles	60
Total Initial Cost/SF	N/A
Annual Own and Optg Cost/SF	$0.82
Simple Payback (years)	N/A
Federal Savings to Investment Ratio	N/A

BASE CASE & 1



Lensed 2x4

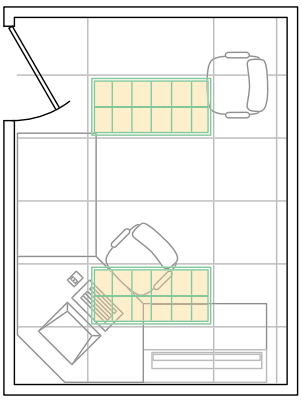
Option 1 • Retrofit

(2) T8 lamps, specular reflector, new lens, electronic ballast, low ballast factor.

Similar to the Open Plan Office Option 1, retrofitting the lensed fixtures with new components is the most common solution. A low ballast factor (.75-.80) keeps the power density low while still providing adequate light levels. In private offices, lensed fixtures do not create reflected glare in VDT screens, but the overhead glare can create discomfort and reduce satisfaction.

	OPTION 1
Watts/Square Foot	.98
Average Illuminance, footcandles	44
Total Initial Cost/SF	$1.62
Annual Own and Optg Cost/SF	$0.33
Simple Payback (years)	3.3
Federal Savings to Investment Ratio	6.0

OPTION 2 & 3



Parabolic 2x4s

Option 2 • Retrofit

(2) T8 lamps, white reflector, parabolic louver door frame, electronic ballast, standard ballast factor.

This design is also a retrofit design, but with the use of a parabolic louver door frame (see Open Office Option 2). In order to have acceptable lighting quality using retrofit parabolic louvers, the existing layout must have the fixtures located close to the walls to avoid the gloomy "cave effect." Because the louver door frame is not designed for the original optics of the existing troffer, the efficiency is reduced and task lighting may be necessary.

	OPTION 2
Watts/Square Foot	1.12
Average Illuminance, footcandles	37
Total Initial Cost/SF	$2.05
Annual Own and Optg Cost/SF	$0.36
Simple Payback (years)	4.4
Federal Savings to Investment Ratio	4.0

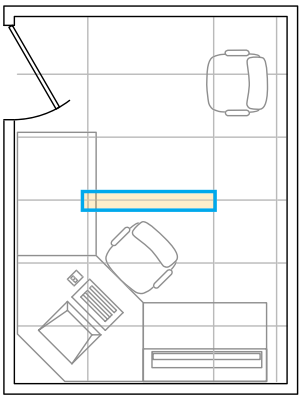
Option 3 • Relighting

2x4 parabolic fixtures, (2) T8 lamps, 12-cell semi-specular louver, electronic ballasts, standard ballast factor.

If installing new fixtures, parabolic troffers produce light of acceptable quality and improved appearance. However, it is important to use more than one fixture and spread them so as to illuminate the walls.

	OPTION 3
Watts/Square Foot	1.12
Average Illuminance, footcandles	42
Total Initial Cost/SF	$2.66
Annual Own and Optg Cost/SF	$0.34
Simple Payback (years)	5.5
Federal Savings to Investment Ratio	3.0

OPTION 4



4'-0" Semi-Indirect

Option 4 • Relighting

4'-0"semi-indirect pendant mounted fixture, (3) T8 lamps, high ballast factor (1.1-1.2)

This is the only private office design in which one fixture is acceptable. A single 3-lamp uplight provides extremely uniform and comfortable light. Because general light levels tend to be about 35 footcandles, a task light is suggested. This solution works well when conditions prohibit recessed fixture options and can be used to replace wraparounds, strip lights, and other surface-mounted low quality lighting solutions. Even when a task light is included in the energy consumption calculation, the payback (2.7 years) and SIR (7.9) are better than the component retrofit of the existing lensed fixtures. This is an excellent solution from both an efficiency and quality perspective.

	OPTION 4
Watts/Square Foot	.98
Average Illuminance, footcandles	36
Total Initial Cost/SF	$1.36
Annual Own and Optg Cost/SF	$0.28
Simple Payback (years)	2.5
Federal Savings to Investment Ratio	8.6

Weighing The Options

One of the things that makes lighting especially challenging and rewarding at the same time is that every application is different. Generalizations are useful, but should always be viewed in the context of the particular application. Based on the typical assumptions made for this analysis, Option 3 is a good open plan choice. The payback is less than 5 years, the fixtures are new, glare is reduced, and the power density is very low at .77 W/SF. When using the existing layout, the fixtures may not be close enough to the walls to avoid scallops and the cave effect. In this situation, adding a wall washing system can solve the problem. Wall washing fixtures are available in all types — such as a linear fluorescent system, compact fluorescent wall washers (cans), and 2'-0" wide fixtures using T5 lamps. The addition of wall washers to the design may make the parabolic design economically comparable to the indirect solution.

For private offices the clear winner is Option 4, which has a lower payback than the retrofit solutions at 2.5 years. This low payback is achieved because of the reduction from two fixtures to one, which is acceptable because of the diffuse distribution that is characteristic of indirect lighting. If there is a high concentration of private offices in your lighting project, it may be economical to expand the indirect solution into the open plan and conference room areas as well.

In some cases project constraints make it impossible to obtain new fixtures and retrofit becomes the only option. For the best retrofits, make an effort to reduce glare with the use of white reflectors or by using lenses that are thicker or designed to reduce lamp image. Also consider adding dimming ballasts and controls in the perimeter zones to take advantage of the daylight.

Caveats

The design guidance provided here is suitable for most conditions. However, the application of lighting technologies varies depending on the occupants of the space and the tasks to be performed. Following are some important caveats regarding the proposed designs:

- As eyes age they need more light. Occupants over the age of 45 should be offered a task light to supplement the general lighting levels. For those who need more light, the undercabinet task lights are not always sufficient. Consider the use of a compact fluorescent task lamp that sits on the desktop with an adjustable arm.
- Visually demanding tasks require more light. If the visual task is one with very small font size or low contrast conditions, then the footcandle allowances should increase.
- Use lighting design professionals for challenging or unusual relighting projects. Look for professionals who have credentials indicating a specialty in lighting. People with an "LC" credential have demonstrated an ability to apply fundamental lighting principles and techniques in the NCQLP Lighting Certification exam. People with an "IALD" credential are lighting design specialists who have been recognized for their experience and design expertise by the peer review of the International Association of Lighting Designers.

More Information

For additional information on Federal Lighting, visit the DOE FEMP web site at **www.eren.doe.gov/femp** to find additional FEMP Lights products such as:

- Federal Lighting Guide
- Energy Effective Lighting Checklist
- Energy Effective Lighting Video
- Web-based FEMP Lights training course

Additional lighting resource information can be found at the following web sites:

Illuminating Engineering Society of North America:
www.iesna.org

International Association of Lighting Designers:
www.iald.org

National Council on Qualifying the Lighting Professions:
www.ncqlp.org

Lighting Research Center at Rensselaer Polytechnic Institute:
www.lrc.rpi.edu

Inter.Light, Inc.:
www.lightsearch.com

Lighting.Com:
www.lighting.com

National Lighting Bureau:
www.nlb.org

TECHNICAL QUESTIONS?
Send email to Carol.Jones@pnl.gov