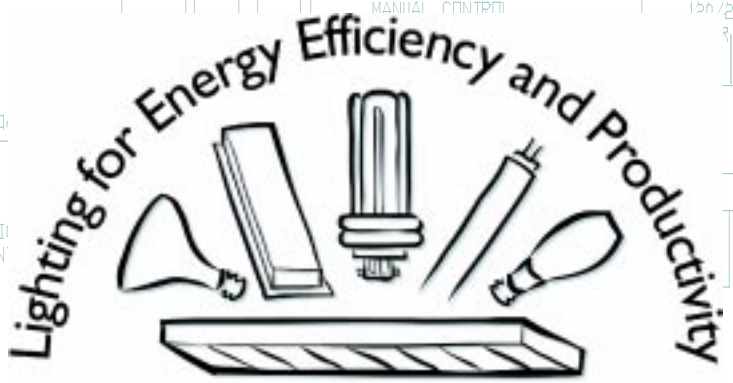


# Federal Lighting Guide

## A Resource for Federal Lighting Improvement Projects

**June 1998**

FEMP Lights is...

...part of the Technical Assistance team, within the United States Department of Energy's Federal Energy Management Program (FEMP). The Technical Assistance program provides the technical and training foundation for all of FEMP's efforts to identify and implement technically sound and cost-effective energy efficiency, water, and renewable projects at Federal facilities. The mission of the FEMP Lights program is to: Provide support to Federal Energy Managers to significantly increase the quantity as well as quality of energy-efficient Federal lighting projects through the use of systematic outreach, targeted education, appropriate tools and effective technical resources.

Comments and suggestions are welcome for future updates of this binder. FEMP recognizes the significant potential of lighting energy savings and ancillary benefits in Federal buildings. The Federal Lighting Guide is provided as partial fulfillment of the FEMP Lights mission, as support to the Federal Energy Managers in the field who are making Energy Conservation Measures a reality.

Dean McCauley,
USDOE, FEMP Lights Program Manager

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Contributors: Thank you to Hayden McKay, Hayden McKay Lighting Design, for contributing graphics on 'Overhead Glare,' 'Room Reflectance,' and original sketches on 'Spacing Criteria.'

Thank you to Lisa Heschong, Heschong-Mahone Group, for contributing graphics on 'Color Quality,' 'Balancing Quality and Efficiency,' and 'Tube Size Matters.'

USDOE FEMP expresses its appreciation to other contributors who are acknowledged in the body of the document.

Lighting for Energy Efficiency and Productivity
FEMP Lights

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# Federal Lighting Guide

## For Federal Energy Managers

# Federal Energy Manager's Lighting Guide: A Resource for Federal Lighting Improvement Projects

## Chapter 1: Overview

### Introduction

Improving lighting systems in Federal facilities can result in cost savings, occupant comfort, improved productivity, and environmental accountability. This guide is a wayfinding tool for Federal energy managers, providing general information on how to implement Federal lighting improvement projects as well as references for more specific information. Rather than attempting to answer technical questions in great depth, the objective here is to provide a "one-stop-shopping" resource which provides direction on a broad range of topics that typically arise on Federal lighting projects.

Chapters 1-7 address various phases of a Federal lighting project. Where more detail is considered important to Federal Energy Managers and is not readily available elsewhere, the Appendices have been developed to provide relevant supplementary material.

### Project Process

Federal facility managers must assume ultimate responsibility for any lighting improvement project. The lighting assessment and project planning process defined in this guide is a structured way for Federal facility managers to effectively identify, design/plan, implement, commission and maintain lighting improvement projects for maximum benefit. The process includes the following steps:

- Evaluate existing lighting system
- Identify potential lighting projects
- Identify funding options
- Analyze and prioritize potential projects
- Determine energy use and cost baseline
- Prepare Energy Effective Lighting design and specifications

- Procurement and installation.
- Commission completed lighting improvements; develop Operations & Maintenance Plan
- Verify benefits.

Before beginning a project, consider how each lighting improvement will affect potential savings from other improvements for the same building and facility. A deeper level of energy savings is possible through whole- building/whole-facility analysis.

## Evaluate Existing Lighting System

To evaluate an existing lighting system, one must perform a lighting audit, which is an accounting of current lighting equipment and controls. The lighting audit may be part of an overall facility audit. The lighting audit may require that the auditor:

- count fixtures, lamps, and ballasts
- characterize lighting controls and operation
- identify environmental concerns (PCBs, mercury volume)
- evaluate operations and maintenance (O&M) schedules
- identify unsafe conditions
- consider occupant satisfaction/special concerns; characterize lighting quality
- evaluate electrical/fixture support conditions.

Subcontracted engineers or design professionals can perform lighting audits if this expertise does not exist in-house or additional support is considered important. For additional information, refer to Appendices A& C for references and lighting analysis software tools related to evaluating existing lighting systems.

## Identify Potential Lighting Projects

Identify all potential lighting projects or areas that need improvement or may yield energy or resource savings. Consider how well potential lighting improvements will meet organization or workplace objectives.

Consider the following factors when identifying potential lighting projects:

- security and safety requirements
- codes and standards requirements for new Federal buildings (see Chapter 4)
- organizational restrictions
- mission requirements
- other construction activities, building occupancy changes
- need for relighting (redesign) instead of, or in addition to component process
- incorporation of available daylight
- need for complete system improvement
- control strategies/operation schedule
- future use of space
- energy/labor costs
- life-cycle cost
- facility access

A variety of software products are available to assist in identification of potential lighting projects. Some products were developed by Federal agencies specifically for Federal use and others by private industry for general commercial use. Appendix C contains a list of lighting analysis and design software tools. Many lighting-related manufacturers and retailers also provide useful decision-making software.

## Identify Funding Options

Existing operational budgets often do not support lighting improvement projects, so alternative funding is usually required. Several funding sources are available for financing Federal lighting and other energy-related projects including:

- internal O&M or utility budgets
- direct appropriations

- utility incentive programs
- energy savings performance contracts

Chapter 2 provides additional information on alternative financing.

## Analyze and Prioritize Potential Projects

After determining potential projects and funding options, conduct a more detailed analysis to determine the cost effectiveness and benefits of each option. This analysis should measure potential project benefits throughout the building and should also and consider other potential projects in the same facility. Tangible benefits should include energy use, disposal costs, and maintenance costs in a life-cycle cost calculation, as return on investment, or as simple payback. Also consider other less-tangible benefits such as increased worker productivity and improved comfort and space appearance.

When prioritizing potential projects, consider all lighting and nonlighting projects in a facility to effectively use financial resources. The following factors are generally used to prioritize projects based on facility needs.

- initial cost
- life-cycle cost
- potential savings (include less-tangible benefits)
- facility access
- organizational needs
- effect on other projects

Refer to Appendix C for a list of lighting analysis and design software tools.

## Determine Energy Use and Cost Baseline

Before initiating any projects, identify current lighting energy use and other related costs to establish a baseline for evaluating potential savings opportunities and assessing other project benefits. This information may also be valuable in future proposals for additional improvements. To determine energy use and related costs, evaluate:

- historical energy use or other resource consumption
- real-time data to characterize current energy use (if available)
- energy, O&M, and equipment disposal rate structures
- connected load (fixtures x input watts)

Historical data can include energy consumption, O&M costs, facility supply costs, and more elusive items such as morale and occupant comfort. Appendix A contains information on FEMP publications related to baseline monitoring. Consider administering an occupant survey in order to assess lighting quality improvements with a Post Occupancy Evaluation (POE) after the project is installed.

## Prepare Energy Effective Lighting Design

Energy Effective Lighting provides both energy-efficient and high-quality lighting, contributing to an improved work environment. Lighting has a direct and powerful impact on building occupants, affecting health, safety, mood, and the speed and accuracy of task performance. Therefore, using Energy Effective Lighting in Federal buildings is important to ensure energy savings and possibly even improve productivity. Lighting system elements that impact humans include:

- room surface brightness
- glare
- task illuminance
- light distribution
- color quality

- visual interest
- flicker
- controls
- daylighting

These elements affect visual performance, psychological needs, lighting preference, and circadian rhythms. Flicker from some types of fluorescent ballasts (usually not seen by the human eye); glare from fixtures; the absence of daylight; and dim, gloomy spaces can adversely affect worker morale, motivation, and performance. Excessive brightness contrast ratios can cause disturbing reflections on visual display terminal (VDT) screens, impeding computer task performance.

The cost of Federal workers greatly exceeds the cost of energy. For this reason, all changes to the lighting system must consider the impact on the occupants. If lighting quality is improved thereby positively affecting Federal workers, then the new lighting system can add significant value in addition to creating energy savings. When designing lighting systems, consider both functional and aesthetic elements. For simple spaces, a variety of design tools are available (see Appendix C for a list of available design tools).

Lighting design professionals can help define effective lighting designs that not only reduce energy consumption and provide adequate lighting distribution but also improve lighting quality. Existing facilities often require the expertise of an independent lighting designer or illuminating engineer familiar with daylighting design, visual comfort, visibility, glare control, and VDT reflection control.

FEMP offers assistance in procuring professional lighting design services, including general procurement guidance and lighting-specific boiler plate language to ensure that you contract a qualified lighting professional.

See Appendix A for information on FEMP materials, other publications, training and certification programs, and lighting societies and professional associations for design professionals. Much of the FEMP Lights information can be obtained off of the web site, at http://www.eren.doe.gov/femp, under Technical Assistance. More information on Energy Effective Lighting can be found in Chapter 3, and Appendices D & E. The FEMP Lights Distance Learning Course is strongly recommended to all Federal Energy Managers and interested subcontractors as a means to become fully prepared to manage Federal lighting projects. New and up-to-date, the FEMP Lights Course is delivered via email to your desktop and only requires a few hours per week to complete at times which are convenient to each registrant.

## Specifications

Once a conceptual design has been developed, it becomes necessary to develop contract language and specifications. Tight specifications are the backbone of a successful project; without a solid specification the best ideas and intentions often fall by the wayside. The FEMP Master Specification for Lighting and the associated Technical Notes provide the technical back-up needed to help implement a conceptual design. New language is being developed which is tailored for use under an ESPC.

## Procurement and Installation

Once the specifications and project details have been prepared, it becomes time to start the implementation phase of the project:

- solicit proposals
- evaluate proposals
- select contractor
- schedule the work

It is critical to identify the person in charge who will carefully watch over the procurement and installation phase. Very often substitutions will be offered which may not

meet the original design intent. It is important to be mindful of this and insist that all products meet the contract specifications and Energy Effective Lighting guidelines (see Chapter 3).

## Commission Completed Lighting Improvements

Commissioning building systems is necessary to ensure the equipment has been installed according to specifications, operates in the manner for which it was designed, and meets facility needs. Commissioning must be done before the responsible contractor leaves the site and/or the equipment is turned over to on-site facilities control.

To complete the commissioning process:

- verify work is completed and meets specifications
- perform operational checks
- prepare an Operation &Maintenance (O&M) plan

See Chapter 6 for guidance on commissioning completed lighting improvements and Chapter 7 for information on preparing an O&M plan.

## Verify Benefits

Verifying net energy savings, reductions in disposal quantities and costs, avoided environmental hazards, improved occupant comfort, and increased productivity is an important part of lighting improvements. Documenting benefits provides valuable information on the effects and experience gained from the completed work to apply to future projects. The party in charge of verifying benefits, and the exact protocol to follow will vary by project. The general steps include:

- collect time-of-use and one-time resource use data (if possible; metering required)
- complete use and satisfaction surveys (Post Occupancy Evaluations)
- monitor actual resource billings
- document activities, savings, and benefits

The "North American Energy Measurement and Verification Protocol" includes valuable information on this topic and is available from the FEMP website.

## Marketing

Once everything is completed and verified, do not forget to claim victory. Publicity for the energy savings and completed improvements will strengthen morale in your facility and educate others on potential benefits as a result of these efforts.

# Chapter 2: Financing

The following funding sources are available for financing Federal lighting and other energy-related projects.

## Internal O&M Budget

The internal O&M budget is often the easiest way to get project funding but is frequently inadequate. If planned early in budget process, these funds can be used to replace some lighting systems as part of general facility maintenance. However, using these funds may prevent the completion of major cost-effective projects, resulting in a loss of potential cost savings.

## Direct Federal Appropriations

Historically, direct Federal appropriations (directly through Congress or agency-based) have provided most of the energy efficiency financing for government agencies. Direct appropriations do not incur interest charges and allow the Federal government to retain all savings from cost-effective renovations.

Because the government's appropriated funds come from tax revenues or bonds, the cost to appropriate these funds is lower than the cost to borrow money from a bank or a financial institution. This approach also enables the agency to implement an energy efficiency project with minimal contractual obligations. However, with current emphasis on reducing Federal government appropriations, energy- and facility-related projects not directly related to an agency's mission may not be fully funded or funding may be delayed. Due to funding limits selection is based on those projects with the shortest payback period.

## Utility Incentive Programs

Utilities often offer programs to their customers thay may include rebates and/or energy services. Large facilities, such as universities, government installations, and military sites, have been successful in tailoring utility programs to their needs.

These programs include financial or other incentives to customers to install energy-efficient equipment in existing buildings. Incentive programs provide a technical resource or funding source that can be leveraged to help an agency implement an energy project. Utilities may pay the capital costs of new lighting in consideration of the energy savings the retrofits will produce. In most cases, utilities arrange some other form of third-party financing. The net cost to the Federal agency acquiring the new technology remains minimal and the agency benefits from the "one-stop shopping" provided by a utility partnership.

## Energy Savings Performance Contract (ESPC)

Under ESPC contracts, energy service companies (ESCOs) assume the capital costs to install new energy-efficient equipment. The ESCO guarantees a fixed amount of energy cost savings over the life of the contract (up to 25 years). Energy cost savings are any reduction in the cost of energy used in federally owned buildings. The ESPC contract specifies the percentage of energy cost savings as their fee and the method for determining the value of such savings, which may vary from year to year. The ESCO is paid directly from the energy cost savings and the agency retains any remaining savings. ESCOs are most interested in funding projects with immediate savings potential.

To make it easier for Federal agencies to use ESPC's, FEMP has developed a Super ESPC based on the Indefinite Delivery/Indefinite Quantity provision of the Federal Acquisition Regulation (FAR). Super ESPCs are broad-area contracts (base-wide, agency-wide, regional) that allow agencies to establish site-specific ESPCs with the winning ESCO's without having to start the contracting process from the beginning.

## Federal Agency Financing Contacts

The following Federal agency contacts can provide information on available agency funding, product procurement, and application procedures. The listed names and phone numbers are for current agency building/property management representatives.

U.S. Department of Agriculture
David Dunn
(202) 720-5993

U.S. Department of Commerce
Jim Woods
(202) 482-0885

U.S. Department of Defense
Kevin Gross
(703) 697-6195

U.S. Department of Health and Human Services
Glen Phillips
(301) 443-6340

U.S. Department of Housing and Urban Development (BUD)
(see General Services Administration)

U.S. Department of Interior
John Moresko
(202) 208-5704

U.S. Department of State
Tim Arthurs
(202) 647-6001

U.S. Department of Transportation
Dennis Sullivan
(617) 494-2300

# Chapter 3: Energy Effective Design and Specification

Energy efficient technologies such as T8 fluorescent lamps, compact fluorescent lamps, improved reflector technologies, efficient ballasts and the use of controls provides great promise of a reduced energy load by a lighting system. However, in our quest for energy savings we often sacrifice proper lighting through the misapplication of efficient technologies.

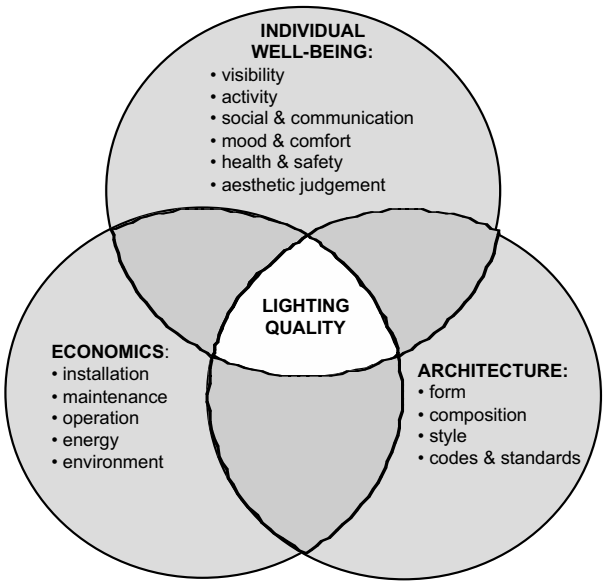
Next to temperature, no other building system has as profound an effect on occupant comfort and productivity as lighting. Too little light causes eyestrain and an unhealthy work environment, whereas too much light can cause glare, heat and can also reduce a persons ability to optimally function in the work place. Increased understanding of the impact of lighting on worker productivity and well-being by architects, engineers, facility managers and Federal agency management is part of a new philosophy of treating lighting as an ergonomic issue. The lighting projects that we now embark upon should be energy efficient and support workers in being effective on the job.

## Why should the Federal Energy Manager care about Energy Effective Lighting?

The increased awareness of lighting quality and its impact on worker productivity has caused the lighting industry to attempt to find a balance between energy efficient and comfortable lighting. The newest findings of the Illuminating Engineering Society of North America (IESNA) indicate that many of the most common lighting strategies used to save energy in facilities today can be detrimental to the comfort, mood and possibly the performance of workers. Conversely, following a recipe for Energy Effective Lighting is likely to actually improve the lighted environment for Federal workers. Because the cost of labor dramatically exceeds that of energy, quality relighting has the potential of benefiting both the environment and the economy. Recent estimates place a potential value ranging between $220 million/per year and $1.3 billion dollars per year from improved lighting conditions (based on Federal salaries).

## What is Energy Effective Lighting?

Energy Effective Lighting is light that not only helps us see and be comfortable, but also provides our work environments with a sense of pleasure and psychological warmth– and does so in an energy-efficient way. Energy Effective Lighting accomplishes the dual objectives of being energy efficient while also meeting the needs of the space occupants. Effective lighting varies with each type of application and must consider the short term and long-term performance of the occupants of the space.




***Graphic courtesy of Jennifer Veitch, Ph.D., National Research Council of Canada. Presented at the 1st CIE Symposium on Lighting Quality in Ottawa, Canada, May 1998.***

The design of an energy effective lighting system is less of an engineering practice and more of a marriage of architectural design,

space planning, engineering and lighting system design. An energy effective lighting design is site specific and will be derived from a collection of factors which include the purpose for a workspace, budget, architectural limitations, and other criteria.

In order to achieve an Energy Effective lighting design address the following eight areas as discussed in the following pages. These points apply to most work environments.* Use the following to achieve a well-lit environment:

**1. Room surface brightness**

**2. Reduction of glare**

**3. Adequate task illuminance**

**4. Uniform light distribution**

**5. Good color lamps**

**6. Visual interest**

**7. Electronic ballasts****

**8. Controls & Daylighting**

* For the purpose of explanation, office spaces are used most often to illustrate the points discussed.

** Except in cases of technical incompatibility, see below.

## 1. Room Surface Brightness

Quality lighting is a function of the proper balance of brightnesses in a space. A space with dark walls or ceiling, or with harsh patterns, will never provide adequate visual comfort for the workers.

Traditional lighting designs have focused on providing sufficient foot-candles (fc) on the horizontal workplane (i.e.the desktop) and have generally ignored illumination of the ceilings, walls, partitions and vertical tasks.

One of the fundamental principles of energy effective design is the lighting of all of a room's surfaces, with a heavy emphasis on illuminating its vertical surfaces. Illumination of the horizontal workspace is critical, however, it is the vertical surfaces in a room that the occupant sees most often and have the greatest potential to influence an occupants perception of his or her work environment.

### *Wall washing*

Wall washing is the use of fixtures designed to distribute their most of their light in one direction and onto a vertical surface. This can be accomplished with several kinds of fixtures, including open compact fluorescent wallwashers, lensed compact fluorescent wallwashers, and linear fluorescent wallwashers.

**Wallwashing**

***Photo courtesy of Lisa Heschong, Heschong-Mahone-Group. Instructor, FEMP Lights distance learning course.***

To maximize the efficiency of a wall washing system, it is important to use paint and or wall treatments that are white or light in color.

### *Indirect Lighting*

The use of an indirect component allows wide spacing of the fixtures, reduces shadows, and creates a sense of openness and spaciousness in the space.

**Indirect Furniture-Mounted Lighting**

***Proctor & Gamble Headquarters, Cincinnati, OH***
***Photograph courtesy of JoAnne Lindsley, Lighting Designer. KPF, Architect. Peter Aaron, Photography.***

### *Direct/Indirect Lighting*

Direct/Indirect lighting is the use of luminaires which have both uplight and downlight and are suspended from the ceiling. This solution puts the fixtures closer to the working plane in the space and is very energy efficient. Because it provides better uniformity and fewer shadows, it allows greater flexibility with respect to space planning, making it easier if the furniture should need to movein the future.

### *Cove Lighting*

Another strategy for the lighting of walls and ceilings is the use of coves, either as a slot or valance at the corner of the wall and ceiling, to wash the walls, or as an uplight cove to light the ceiling. The role of a wall wash cove lighting system is to reduce shadows at upper wall surfaces, which eliminates harsh shadow patterns, and increases the perception of "openness."

### *Clerestory Windows*

Clerestory windows are a passive design feature that visually provides openness in a room, and allows for the transfer of light between internal office spaces. Clerestory windows are generally located high on a wall near a light source, but limit the field of view for occupants thus providing the necessary privacy between office spaces. Glass adjacent to private offices offers another opportunity to borrow light between spaces and increase a sense of openness.

### *Cave Effect*

One of the most typical and problematic design solutions in modern offices is the use of downlight troffers with specular parabolic or paracube louvers in offices without adequate wallwashing.

**The Cave Effect**

***Photo courtesy of Jim Benya, Pacific Lightworks, Portland, OR. Co-instructor, FEMP Lights Distance Learning Course.***

Because these fixtures focus most of their light in a downward pattern they do not put enough light on the walls, creating a gloomy appearance and harsh scallops.

The solution to this problem is to use semi-specular or white louvers, and to locate fixtures very close to the walls, so there is sufficient brightness on the vertical surfaces.

**Wall Brightness**

***NYS Department of Labor, Syracuse, NY. Photograph courtesy of Naomi Miller, Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY. Demonstration and Evaluation of Lighting Technologies and Applications (DELTA). Quinnlivan Pierik & Krause, Designer and Architect. William Clifford E.E., Fraser and Fassler, M.E. Cindy Foor, Photography.***

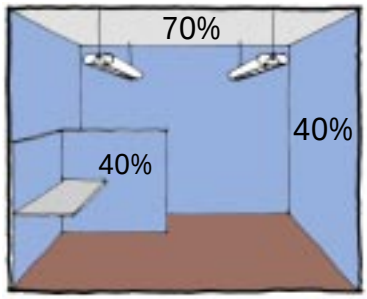
The photograph above is a good example of adequate brightness on the walls. Alternately, the troffers could be located further away from the walls if a supplementary wallwashing system is used.

### *Surface Reflectances*

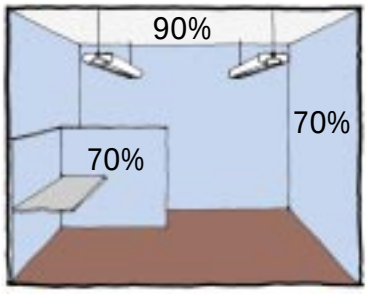
The entire room is an integral part of the lighting system, and perhaps no other factor in room design is as critical to the lighting as the reflectances of the room surface. The most desirable reflectances are those which are light in color with a matte finish. Shiny materials create mirror images and can cause glare. Dark-colored materials absorb the light, requiring much more energy to achieve the desired brightness of walls, ceilings and workstation surfaces.

It is important to light the surfaces of a room to create proper visual comfort and avoid high contrasts and glare.

A room with middle-range reflectances (Room A) typically reflects only 40% of the light which hits the walls and 70% of the light which hits the ceiling. Overall, this room absorbs 53% of the light that hits these important surfaces. Darker colored rooms will perform much worse. By using lighter finishes in Room B, the absorption has been reduced by half. The balance of light will be much easier to achieve in this room. More impressive is the 70% of energy saved in the room with lighter colored walls and ceiling while achieving the desired level of brightness on the walls, and 55% more light on the task. The use of higher reflectance materials is a no-cost strategy which has a tremendous impact on the "effective" utilization of energy, as well as providing greater lighting quality and comfort.




**Room A**




**Room B**

## 2. Reduce Glare

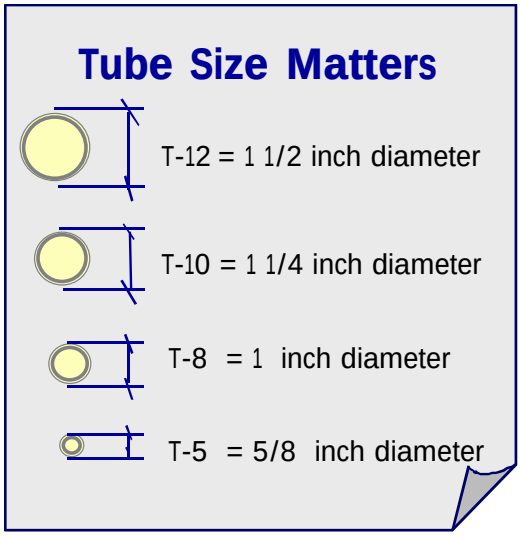
One of the most common criticisms of a lighting application is glare. Glare can come from numerous sources including overhead lights, windows or reflections in a computer monitor. Lighting glare is commonly cited as the source of visual discomfort in open plan office workplace as well as industrial workplaces.

Because glare prevents people from being their most effective, it is an important issue to address in an energy effective lighting design. Glare generated from a lighting system is most often associated with the

misapplication of lamps, reflectors and louvers, or improperly shielded windows.

### *Glare From Lamps*

In commonly used fluorescent lamp technologies, smaller lamp diameters have a greater surface brightness. The consequence of this is that some of the most efficient lamps are also the highest intensity and can be very uncomfortable to the naked eye.

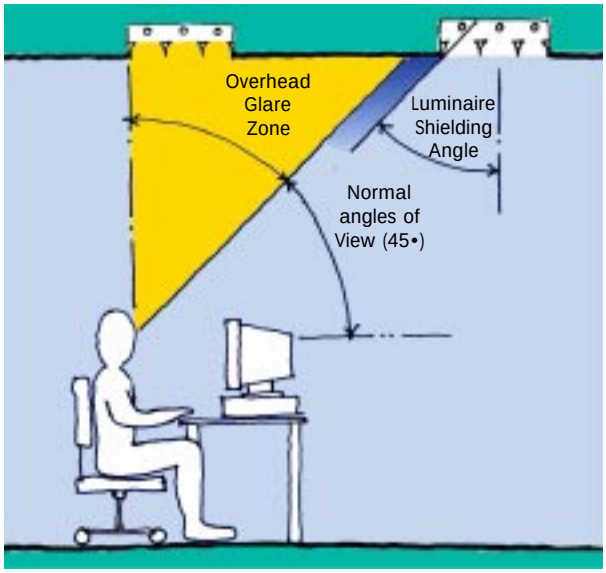



Therefore, great care should be taken when choosing both lamps and fixtures.

T5 lamps (compact fluorescent) offer excellent energy efficiency as compared to incandescent. However, use of this high intensity light should be limited to applications where the actual lamp is not visible to the worker eyes. Because T5 lamps provide extremely intense light from a small diameter lamp, they are excellent technologies for use with reflectors for indirect lighting and wall washing systems.

### *Luminaires and Shielding*

Louvers and shielding techniques are generally only effective for fixtures in front of a worker. However, the excessive glare from fixtures directly overhead of a worker can actually decrease visual acuity, especially when a vertical task such as computer work is involved.




**Overhead Glare Zone**

Open plan office layouts make it difficult to avoid locating luminaires outside of worker's overhead glare zone. The use of luminaires with open bottoms is particularly problematic, because the worker is exposed to the bare lamp in this zone. The goal is to reduce the brightness of the source, or reduce the contrast.

***It is critical that lamps and luminaires be selected to mitigate the problem of discomfort glare.***

Specular reflectors or specular louvers should not be used in open-celled luminaires above workers, because they reflect the bright image of the lamp into the eyes of the occupants. This can cause intense visual discomfort, inhibiting worker performance, causing headaches and occupant dissatisfaction.

When using compact fluorescent downlights, pay attention to where they are located with respect to workers in the space. Compact fluorescent downlights located near people who will be working for ex-

tended periods of time should have excellent shielding and semi-specular cones. Consider the use of cross baffles in downlights located near workstations.

Use the following strategies to reduce contrast and create a more comfortable environment for the occupant:

- Appropriate lamps for the given application, considering tasks and locations of workers
- Fixtures with adequate shielding media
- Semi-specular or white louvers
- Use a cove to put light onto the ceiling, or use furniture-mounted or wall-mounted indirect fixtures
- Use more fixtures with lower output.

### *Visual Display Terminal (VDT) Glare*

While glare in computer screens continues to be a problem, we are coming to understand that it is not the only area of significant concern with respect to lighting quality. If low brightness parabolic louvers are used, care should be taken to create enough room surface brightness at the walls, ceilings and partitions.

**VDT Glare**

***Photo Courtesy of Mark Rea,Ph.D. Director, Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY.***

The problem of glare in VDT screens is at its worst when lensed fixtures are used and the VDT screen is dark. It is much more common to have a lighter background on modern computer screens, which has lessened but not eliminated the problem. Glare in screens from windows continues to be a problem (see Windows section).

The simplest way to correct these reflections is to position computers so that they are at angles that do not promote reflections of windows or lights. For those workspace designs where the computer screen can not be positioned properly or harsh reflections cannot be otherwise reduced, commercially available anti-glare screens can be attached to the computer monitor. This generally eliminates the reflection problem or reduces it to an insignificant level. Providing a uniform wash of light on the ceiling also significantly reduces reflected images.

### *Glare in Industrial Spaces*

Because of the common use of High Intensity Discharge (HID) sources in industrial spaces, glare can often be a problem.

The closer the fixtures are to the working plane, the less energy is necessary to achieve the desired light levels. However, the intensity of the fixtures suspended too close to the workers can create discomfort.

***The solution must be a balance between energy efficiency and the comfort and effectiveness of the workers.***


Of great importance in industrial lighting is having adequate task illuminance, to facilitate accuracy and safety. With adequate task lighting, sometimes the general level of illumination can be reduced.

One way to mitigate the experience of glare is to reduce the contrast of the bright lights

against a dark ceiling. Wherever possible, work with the maintenance and operations personnel to paint the walls and ceilings a lighter reflectance.

Consider these two photographs, which illustrate the difference between bright and dark ceilings in industrial spaces.

**Bright fixtures against a dark ceiling.**

***Photgraph courtesy of Naomi Miller, Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY, and Daybrite fixtures, Thomas Lighting Industries.***

**High reflectance ceiling.**

***Hewlett-Packard building in B4 Camas, Washington. Photograph courtesy of Naomi Miller, Lighting Research Center, Rensselaer Polytechnic Institute. PAE Consulting Engineers, Portland, OR. Naomi Miller, Lighting Designer. Boucher Mouchka Larson, Architect. Strode-Eckart, Photography.***

### *Windows*

Part of providing an even surface brightness is the reduction of high contrast on vertical surfaces. A standard wall should be illuminated so that it does not exceed a ratio of 3:1 between lightest and darkest areas. On walls where windows are present, there is a very high contrast between light and dark areas. To counteract this is it important to include wall washers between the windows to illuminate the columns.

The use of daylight is critical to the design of an energy effective workspace. To control glare from a window blinds should be used. The use of venetian blinds allows occupants to make adjustments for their comfort as needed throughout the day. Also, the use of window glazing has the added benefit of significantly reducing unwanted heat gain and loss, and the damaging ultraviolet (UV) light rays that cause eye damage.

## 3. Adequate Task Illuminance

The ultimate goal of lighting within an office space is to provide the quality and quantity of illumination necessary for the worker to perform their necessary tasks. While ceiling mounted luminaires and direct/indirect lights provide general lighting requirements, most workspaces require additional illumination on the work surface. Unlike some of the lighting mentioned earlier, the major purpose of the task light is to provide footcandles on the task, whether that be the horizontal desktop, the vertical typing stand, or the industrial benchtop.

Although an undercabinet light is frequently provided as part of the furniture package in offices, it is not particularly effective for lighting tasks. It generally provides too much light from the wrong direction. If the worker is facing the toward the light, veiling reflections will occur in the task. However, undercabinet lighting is effective if it reaches the task from the side, and is important for reducing shadows under the overhead cabinets.

One efficient option is to specify the undercabinet lights with low-output ballasts, which reduces the output and energy consumption by about 50% and still accom-

plishes the objective of reducing undercabinet shadows and providing additional task lighting.

**A workstation without undercabinet task lighting results in harsh shadows and inadequate illumination.**

***Photograph courtesy of Peter Boyce, Ph.D., Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY.***

Articulated (adjustable) task lights are fixtures which allow physical adjustments in three planes. These allow the user to manipulate the light in their workspace and focus it on the task being performed. Articulated lamps can also be moved either closer or farther away depending on the lighting needs of the occupant and can light vertical, horizontal or tilted tasks.

Articulated task lights are usually preferred by the occupant for two reasons: 1) they give the occupant the satisfaction of having some personal control over their environment and 2) they are significantly more effective in accomplishing task lighting. Both the articulated compact fluorescent task lights and undercabinet shadow reducers are available in a wide assortment of styles and energy efficient versions while being inexpensive and can be easily purchased from the GSA schedule.

## 4. Uniform Light Distribution

The uniformity of light distribution within a space is dependant on several factors, the most important being the distribution characteristics of the specific light fixtures, (e.g.: direct, indirect, wide, narrow) and the geometry of the space, including the presence of partial height partitions so commonly used in open plan furniture layouts. Determining the average illuminance in a room is not enough. The balance of light from one workstation to another should be relatively uniform.

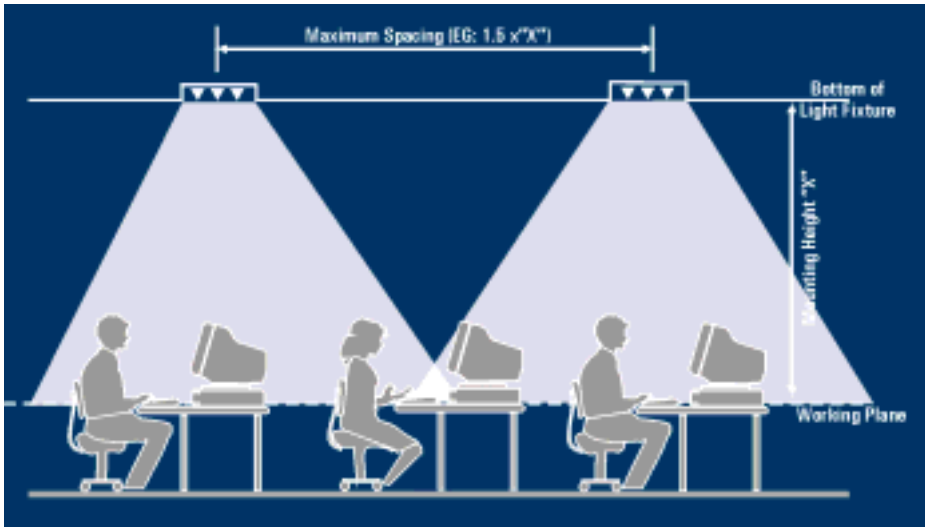
Many projects are not viable candidates for lighting retrofits (component changeout) because the existing fixtures are spaced too widely to achieve uniform distribution. The determination of whether a project is appropriate for a retrofit or will require a redesign should be done at the earliest stages of project feasibililty assessment. The Spacing Criteria is a valuable tool in this determination.

The Spacing Criteria is a number supplied by the lighting fixture manufacturer on each individual fixture catalog cut sheet. It identifies the spacing between fixtures as it relates to their location above the work surface. Multiplying this number by the height of the fixture off the desk will determine the maximum spacing between fixtures that will still yield uniform lighting on the desk.

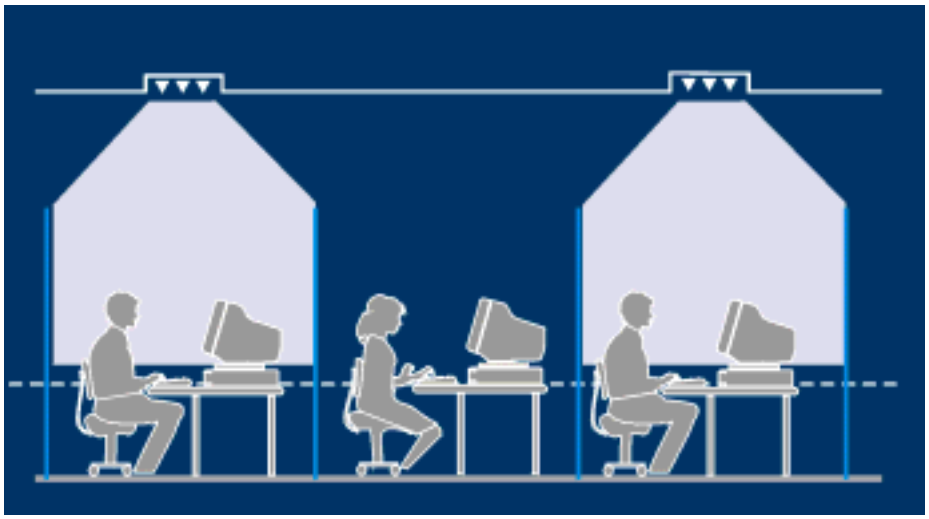
**Spacing Criteria x Height = Spacing**

Fixtures that have a wide distribution, or an indirect component, can be spaced more widely. Fixtures that have a narrow distribution must be spaced more closely. Retrofit strategies such as retrofit reflectors, or changes in lamp positions or louvers frequently narrows the distribution from the original. In these cases, a closer spacing will be required, as well as the addition of more lighting on the walls.

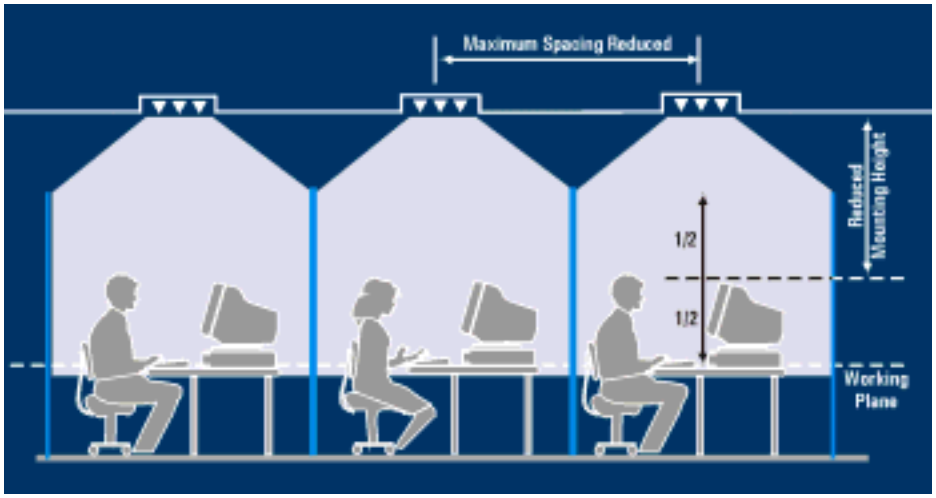
Unfortunately, the Spacing Criteria does not account for rooms with obstructions, such as high file cabinets or furniture partitions. Many existing lighting installations are inadequate due to the addition of tall partitions, and should be redesigned to incorporate more fixtures, at a lower output. To do this, modify the height measurement for use in multiplying by the Spacing Criteria.




An old style office, without modern partitions.



After adding partitions to the room, the spacing between fixtures becomes too wide.




This room would require a redesign rather than a simple retrofit, in order to provide adequate light levels and uniformity.

## To use the Spacing Criteria Method in rooms with partitions:

**1)** Determine the height from desktop to top of partition, and divide it in half.

**2)** Add the result to the height from the top of the partition to the underside of the fixtures.

**3)** Use this "reduced mounting height" number in multiplying times the manufacturers Spacing Criteria.

**4)** The resulting number is the maximum on-center spacing that should be used to achieve adequate uniformity.

## 5. Good Color Lamps

Beyond just providing illumination in a workspace, differences in lamp color can drastically affect a person's perception of their environment. "Cooler" lamp colors (4100 Kelvin) are very good in applications where high intensity light is needed (>100fc), such as laboratories, medical areas, and some assembly areas. Warm lamp colors (<3000 Kelvin) are very good in "hospitality" spaces such as residential housing, restaurants, and lounges.


In most office spaces intermediate temperature lamps are an appropriate choice (approximately 3500 K). These intermediate temperatures in the lamps provide a balance between the perceived warmth and "friendliness" of the warm lights while still providing the clarity and crispness of a cool light. 3500 Kelvin also provides a good compromise for daylighted and interior spaces.

The visual perception of color is dependent on the light source which is striking an object. True white light is balanced between all of the colors of the visual spectrum, and thus provides a correct rendering of the true color of an object. Almost all artificial and natural light sources are not evenly balanced, and thus provide an altered perception, or shift of an objects true color.

A lamp's ability to provide the proper color rendition and minimal color shift is measured as the Color Rendering Index (CRI) which is based on a scale of 1 to 100. Fluorescent lamps with a CRI above 70 are acceptable in most environments.

## 6. Visual Interest

In most workplaces there are spaces which are not exclusively workstations, such as transition spaces (corridors), cafeterias, lobbies, etc. In these areas, the creative use of light and decorative lighting technologies can break-up a boring wall or can accentuate certain architectural features.

A good way to do this is with sconces using compact fluorescent lamps. It can make a very significant difference between a space being boring or interesting, and has been shown to be preferred in research studies. Light levels in transition and lounge areas do not need to be as high as the workstations, nor do reflectances need to be as high. In fact, the variety in light and color is preferred.

## 7. Electronic Ballasts

The fluorescent ballast is designed to provide the necessary burst of energy to start a fluorescent lamp and then limits the electricity flow to provide an even discharge of current to sustain an even generation of light. Electronic ballasts are significantly more efficient than the old electromagnetic ballasts and are a staple ingredient in lighting energy conservation measures.

Electronic ballasts should always be used except in the case of technical incompatibility. **For example, electronic ballasts should not be used in areas where sensitive electronic equipment can be found. There has been a concern that the use of instant start ballasts with occupancy sensors can reduce lamp life, but recent research has shown that this is not necessarily the case. As a preventative measure occupancy sensors should be set for a 15 minute or

greater time delay, to avoid frequent cycling of the lamps. Instant start ballasts are slightly more efficient than rapid start ballasts. Manufacturer's guidelines should be followed at all times when installing lamps to ensure proper lamp efficacy and life. The industry is currently developing standards that will provide additional guidance on this topic.

### 8. Lighting Controls & Daylighting

**Lighting Control Technologies**

*Photo courtesy of Electric Power Research Institute*

Automatic lighting controls should be seriously considered for most Energy Effective designs due to their ability to save energy over time. Many different controls are available to suit every kind of need.

Lighting controls enable the use of daylight as a means of reducing energy consumption. Daylighting is perceived as an important part of lighting quality by building occupants, but daylighting design and the use of daylighting controls requires significant expertise; be sure to obtain technical assistance or at least experienced advice, depending on the complexity of the application.

Lighting controls enable the building energy manager, and in some case the worker, to exert greater control over the lighting system. Research has shown that lighting controls have the potential to reduce lighting energy use by up to 35% compared to conventional lighting systems without controls. Both quality and efficiency should increase through the use of strategies such as:

1. occupancy sensors
2. daylight harvesting
3. lumen maintenance and tuning controls
4. sweep off lighting scheduling with overrides
5. on-demand personal dimming
6. load shedding

Decisions about which controls should be used should be made on a project-by-project basis after careful consideration of issues including the use of the space, hours of operation, ability to properly commission and maintain the system, and life-cycle costs.

## Design Assistance

For simple spaces, a variety of design guides and software programs are available to an agency in-house designer or facility engineer with basic lighting knowledge to help design a lighting system. However, designing effective lighting in even the simplest of spaces requires human thought and consideration that comes from experience and training. Therefore, do not rely on software alone to provide an energy effective lighting design. In larger spaces or areas with special needs, a lighting design professional can achieve the desired effect while maintaining high efficiency.

As more and more federal facilities undergo lighting retrofits and lighting designs, facility managers need to be cautious of lighting technology applications which are commonly applied incorrectly. If it appears difficult to apply the principles laid out in this document, then it may be helpful to get technical assistance from a lighting design professional. FEMP has developed boiler plate language for use when it becomes

necessary to obtain additional assistance through a subcontract. The language is available electronically from the FEMP web site (http://www.eren.doe.gov/femp, under Technical Assistance) and includes a recommended Scope of Work, Evaluation Criteria, and general guidance on hiring design professionals.

# Specifications

Boilerplate specifications are an essential part of any project which includes the acquisition of lighting equipment for federal buildings. Over the past 15 years there has been such a profusion of new lighting technologies that even experts in the field are hard pressed to keep abreast of new developments. The lighting specifications developed by FEMP help federal energy managers take advantage of these new technologies when they are appropriate, and establish quality baselines for all projects. The specifications are distilled from the practical experience of a number of lighting professionals, and are regularly updated to incorporate new technologies and standards.

### *Master Specification for Lighting*

***For use on projects with appropriated funds.***

The Master Specifications (and the Technical Notes which accompany them) are intended for use on projects where the lighting systems are designed by outside consultants, but provided and installed by electrical contractors who have been hired through a traditional bidding process. It is in CSI format, and must be edited on a project-by-project basis by the consultant. Providing this specification to subcontractors will not only give them an effective tool for ensuring that their designs are properly executed, but it will also be an effective way of conveying to the consultants the quality of equipment they are expected to specify.

### *Delivery Order Lighting Requirements*

***(Draft Under Review)***

Since the contractors on ESPC projects are responsible for both design and installation of lighting systems, the lighting requirements built into the Delivery Order Request for Proposal will contain both design and equipment standards. Language is under review for use within the Super ESPC process and the resulting Delivery Orders. This language (similar in many ways to the Master Specification) will provide a basis for implementing Energy Effective Lighting in Federal buildings.

# Chapter 4: Codes and Standards Requirements

The Energy Policy Act of 1992 (EPAct, Public Law 102-486) requires the head of each Federal agency to adopt procedures necessary to ensure new Federal buildings meet or exceed the Federal building energy standards established by the U.S. Department of Energy (DOE). Further, Executive Order 12902 requires that new Federal facilities be designed to minimize the life-cycle cost of the facility, including energy-efficient technologies. In addition to the requirements for product efficiency called out in EPAct, Federal building codes and standards provide the requirements for energy efficiency in new Federal building construction.

## Federal Residential Lighting Codes

Federal residential lighting codes or standards only apply to common areas in multifamily dwellings three stories or less. Lighting requirements for common areas in multifamily dwellings less than three stories are in Section 505, "Electrical Power and Lighting," in the Council of American Building Officials Model Energy Code (MEC). For information on purchasing the MEC, contact:

The Council of American Building Officials
5203 Leesburg Pike
Falls Church,VA 22041
(703) 931-4533

## Federal Commercial Lighting Codes

The intention of the Federal commercial lighting standard is to provide a set of guidelines for designing energy-efficient buildings and building systems. These guidelines are designed to promote the application of cost-effective design practices and technologies that minimize energy consumption and maximize the use of nondepletable energy sources without sacrificing either the comfort or productivity of building occupants.

The Federal standard is extremely broad in scope, encompassing almost all new construction (except low-rise residential) in all climates across the United States. The requirements of the Federal standard are both general and conservative and thus do not represent the most cost-effective level of energy conservation for each and every project. Designers should consider these requirements as a starting point and are encouraged to consider the interrelationships of different building elements and systems and to seek designs that exceed the Federal standard. Therefore, the Federal standard presents recommendations in addition to its requirements.

The requirements of the Federal standard are mandatory for all new Federal buildings constructed after January 1989 that use energy primarily to provide "occupant comfort and sanitation." These buildings include new buildings that are constructed or leased by any agency or branch of the Federal government, including all branches of the military. The standard does not apply to all buildings. The Federal lighting standard accepts certain visual tasks and lighting in certain space types. The Federal commercial lighting standards can be found in the Code of Federal Regulations, Title 10, Part 435, Section 103. For information on obtaining The Code of Federal Regulations, contact:

Superintendent of Documents
Attn: New Orders
P.O. Box 371954
Pittsburgh, PA 15250-7954
http://www.access.gpo.gov/nara/cfr/index.html (search for "10cfr435")

Charge orders may be obtained by phone at the Government Printing Office order desk on (202) 783-3238.

A Federal User's Manual explains the requirements of the Code of Federal Regula-

tions and recommends procedures and documentation on how to comply with, implement, and enforce the code. The manual is available through the:

DOE Building Standards and Guidelines
Program Hotline
(800) 270-CODE (800-270-2633).

# Chapter 5: Procurement

### *Lighting Services*

It is critical to identify the Federal person in charge who will carefully watch over the procurement and installation phase. Very often substitutions will be offered which may not meet the original design intent. It is important to be mindful of this and insist that all products meet the contract specifications and Energy Effective Lighting guidelines (see Chapter 3).

If lighting design assistance becomes necessary, FEMP has developed boiler plate language to obtain additional assistance through a subcontract. The language is available electronically from the FEMP web site (http://www.eren.doe.gov/femp, under technical assistance) and includes a recommended Scope of Work, Evaluation Criteria, and general guidance on hiring design professionals.

For information on ESPC financing and Delivery Orders visit the FEMP web site (address above) under Financial Assistance.

### *Lighting Products*

The Federal government administrates a central supply source for procuring energy-efficient lighting products that save taxpayer dollars by improving the availability of these products and lowering their costs. Two Federal supply agencies, the General Services Administration (GSA) and Defense Logistics Agency (DLA), collaborate with FEMP to provide energy-efficient products that meet operational needs and are cost-effective. FEMP helps buyers purchase efficient products by:

- identifying Federal supply sources that offer efficient products
- suggesting ways for buyers to identify efficient products when buying from commercial sources
- presenting a cost-effectiveness example, in order to help buyers judge whether a price premium is really "worth it"
- offering tips to help buyers and users save energy without sacrificing comfort or performance
- providing leads to other useful sources of information on product energy effiicency

Three central reasons for the initiative are:

- energy and money savings
- pollution reduction
- market leadership

Using products that consume less energy and thereby have lower operating costs (and often, lower maintenance costs) overall results in energy and money savings, even if their initial purchase price may be slightly higher than less energy-efficient products. By reducing energy consumption, these products can contribute to the lowering ower air and water pollution and greenhouse gas emission, such as carbon dioxide, into the environment. Finally, as a matter of public policy, the Federal government aims to set a precedent of energy-efficient and cost-effective practices for other government, corporate, and institutional purchasers.

Federal policies mandate the purchase of energy-efficient and cost-effective products, as expressed in the following decisions:

- **Energy Policy Act of 1992 (EPAct, Public Law 102-486)** requires the U.S. Department of Energy, in association with other agencies, to "identify and designate those energy-efficient products that offer significant potential savings." Guidelines to "encourage the acquisition and use [of these products] by all Federal agencies" are also sanctioned.
- **Executive Order 12902 (1994)** directs each agency to "purchase products listed as energy-efficient in the [EPAct] guide

lines whenever they meet the agency's specific performance requirements and are cost-effective." Furthermore, agencies are to purchase "products that are in the upper 25 percent of energy efficiency for all similar products."

- **Federal Procurement Challenge (1995)** commits 22 Federal agencies, which represent 95% of Federal purchasing, to purchase products in the upper quartile (top 25%) of energy efficiency within a comparable class of products.
- **Federal Acquisition Regulations (FAR, sec. 23.704) (1997)** implements Executive Order 12902 in directing agencies to effectuate "cost-effective contracting preference programs favoring the acquisition of...products that are in the upper 25 percent of energy efficiency for all similar products."

The Defense General Supply Center is headquartered in Richmond, Virginia (1-800-DLA BULB). For more information on Federal energy-efficient procurement, see the FEMP web site at http://www.eren.doe.gov/femp under Technical Assistance or Federal Procurement.

# Chapter 6: Commissioning Completed Lighting Improvements

Before a facility is accepted into the Federal facility inventory, Executive Order 12902, Section 306 (3) requires that each Federal agency establish and implement a facility-commissioning program to ensure that new facility construction meets the requirements outlined in the order. While this mandate generally applies to new facilities, the same important principles should also apply to retrofit projects.

When testing is required as part of the commissioning process, consider using specific lighting tests that may not be part of the standard commissioning test. These tests may involve:

- light level measurements on work surfaces
- lighting panel energy measurements
- relative lighting quality measurements (light distribution, color, reflectance from surfaces, visual comfort probability)
- lighting control operational measurements including daylight control sensitivity, occupant sensor sensitivity, and occupant sensor timer.

See References (Appendix A) for information on technical publications on how to perform these measurements. A lighting design professional can provide expert assistance in determining where these tests will be important and cost-effective.

Commissioning lighting systems and equipment involves the same principles and activities presented in the FEMP Building Commissioning Guide (Version 2.2, April 1998) that is available through their web site at http://www.eren.doe.gov/femp under Technical Assistance. This guide provides information on how to set up and successfully administer a commissioning program.

# Chapter 7: Operations and Maintenance Plan

A lighting Operations and Maintenance (O&M) plan helps guarantee efficient energy use and cost savings and superior system performance. If necessary, consider using subcontractors to help prepare the O&M plan. To prepare the plan, create a file that includes all documentation and equipment manuals and establish a routine preventive maintenance schedule. All best attemps should be made to ensure that adequate funding is allocated toward preventive maintenance.

Maintenance is the only way to continue achieving lighting quality with all its associated ancillary benefits. Effective lighting maintenance ensures minimum O&M costs and efficient energy use while keeping the output of a lighting system as near to its initial level as is practical. Trained maintenance personnel are needed to implement systematic maintenance plans. Some facilities have adequate funds to equip and train personnel, although it is often an advantage to use off-site maintenance specialists.

An effective maintenance plan includes replacing and cleaning lamps and maintaining and repairing lighting components. To develop an effective maintenance plan, the following information is provided on relamping and cleaning lamps; appropriate operating programs, methods, materials, and equipment; and remedies for mechanical and electrical difficulties that can develop in lighting systems.

Replacing and cleaning lamps can prevent loss of light. Several factors contribute to loss of light, including luminaire dirt depreciation, luminaire surface depreciation, room surface dirt depreciation, burnouts, and lamp lumen depreciation. These factors can be controlled through maintenance procedures by:

- periodically cleaning fixture surfaces
- using proper cleaning materials and techniques
- regularly cleaning and painting room surfaces
- including a lamp-replacement program in the maintenance plan.

## Light Loss Factors

### *Luminaire Dirt Depreciation*

A significant amount of light loss can be attributed to dirt accumulation on luminaire surfaces. Ventilated lighting units tend to collect dirt less rapidly than those with closed tops. Periodically cleaning fixture surfaces will eliminate this loss of light.

### *Luminaire Surface Depreciation*

Materials used in luminaires will deteriorate over time from exposure to ultraviolet radiation and heat, changing the reflectance and transmittance of light and color. Using improper cleaning materials and/or techniques can cause chemical reactions and scratch the surface, resulting in additional changes in transmittance. The luminaire components are usually not replaced until new luminaires are installed as part of a major retrofit. Replacing some lenses can improve lighting quality at a minimal cost.

### *Room Surface Dirt Depreciation*

Collections of dirt on room surfaces tend to reduce the amount of light reflected around a room, reducing the overall lighting level in the space. Although walls and ceilings are periodically cleaned and painted in all installations, surfaces reflecting a larger percent of light should be cleaned and painted more often.

### *Lamp Lumen Depreciation*

Light output from lamps decreases over time. To reduce this loss of light, include a lamp replacement program, such as planned relamping, in the maintenance plan.

## Burnouts

Burned out lamps cause loss of light and sometimes a change in the electrical supply to other lamps. In some instances, more than just the faulty lamp may be lost. For example, when one lamp burns out in a sequence of fluorescent ballasts, all lamps go out.

## Relamping and Cleaning

Periodic planned group relamping and cleaning will reduce the effect of lamp lumen depreciation and prevent many burnouts, thereby improving and maintaining illuminance levels. Group relamping is when all the lamps are changed out at one time, based on a statistical average of when burnouts will become so numerous as to render spot replacements uneconomical. A relamping plan should include procedures to:

- reduce burnouts to save time and money in spot burnout replacement
- install lower-wattage lamps when appropriate to reduce energy use
- clean luminaires and room surfaces to provide more delivered light per luminaire.

The relamping and cleaning schedule should be in accordance with the lighting system designer's plans. If intervals between operations are too long, excessive loss of light results. If intervals are too short, labor, equipment, and lamps are wasted.

Lighting systems are becoming more complex, resulting in increased labor and equipment requirements for relamping and cleaning. It is impractical to purchase or use specialized equipment and specially trained personnel to clean a small number of luminaires. As the number of luminaires increases, the value of using specialized equipment and employee training also increases. An analysis of labor rates, lamp life, access to spaces, location of lamps, and lamp and energy costs can help determine the best approach for replacing and cleaning lamps.

The sequence of maintenance steps will vary with luminaire type and location. For example, one person with a ladder, sponge, and pail can maintain open strip units ten feet from the floor. On the other hand, a sizeable crew with an elaborate scaffolding assembly may be required to maintain a transilluminated ceiling 30 feet above the floor. The following procedure outlines the sequence of steps for a typical two-person team:

- ***Remove shielding material and lamps.*** One person use a ladder to remove louvers or plastic/glass panels and lamps from the luminaire and hand them to the person on the floor.

- ***Make luminaire shock-free***. Turn off electrical circuit or cover sockets (e.g., with tape, dummy lamp bases) to prevent shock when working around electric sockets.

- ***Clean basic unit***. If required, first remove heavy deposits of dirt from top surfaces of channel, reflector, etc., by vacuuming, wiping, or brushing. Then wash the entire unit with a suitable solution, using brushes, sponges, or cloths, and rinse to remove any residue.

- ***Clean shielding material and lamps***. While the person on the ladder cleans the unit, the person at the floor takes the shielding material and lamps to a cleaning station or cleans them at the ladder. Allow plastic materials to drip dry after rinsing or damp dry with toweling or some other material. Dry-wiping can cause the formation of electrostatic charges. Dry-wipe new lamps before installation.

- ***Replace lamps and shielding material***. After cleaning the unit, install clean shielding and new or cleaned lamps. Incandescent and high-intensity discharge luminaires usually do not require as many cleaning steps as fluorescent units; use this method to clean all lighting equipment.

## Appropriate Cleaning Compounds

Appropriate cleaning compounds, when properly used, save time and money. The types of cleaners appropriate for the most common luminaire finishes are as follows:

- ***Aluminum.*** **Very mild soaps and cleaners** do not harm an aluminum finish if the surface is thoroughly rinsed with clean water immediately after cleaning. Never use strong alkaline cleaners on an aluminum finish.

- ***Porcelain Enamel.*** **Nonabrasive cleaners** will not affect a porcelain finish. Detergents and most automobile and glass cleaners do a good job under average conditions.

- ***Synthetic Enamel.*** **Detergents** do not harm synthetic enamel finishes. However, some strong cleaners may harm a synthetic finish, particularly when the enamel is left to soak in the solution. Never use alcohol or abrasive cleaners on a synthetic enamel finish.

- ***Glass.*** **Nonabrasive cleaners and most detergents** generally do not harm glass. Dry cleaners are usually preferred on clear glass panels, but not on etched or sandblasted surfaces.

- ***Plastics***. Dust is often attracted by a static charge developing on plastic. Most common detergents do not provide permanent antistatic protection. In most areas, however, cleaning plastic at least twice a year with a detergent usually reduces static dirt. Destaticizers are available that remove static dirt more permanently than common detergents. Never wipe plastic dry after applying a rinse solution.

## Maintaining and Repairing Lighting Components

Lighting maintenance includes repairs to lighting components. While the operation of fluorescent and high-intensity discharge lamps is more complex than incandescent filament lamps, problems can generally be diagnosed and corrected quickly with simple test equipment.

### *Preheat-Starting Fluorescent Lamp Circuits*

- Ensure lamps can be used on preheat circuits. Use only lamp types marked on ballast labels.

- Check luminaire wiring for incorrect connections, loose connections, or broken wires.

- Check ballast to see if the label agrees with the application in terms of temperature limitations and lamps that can be used. Replace ballast if it is faulty or does not fit applications requirements.

- Replace deactivated lamps as quickly as possible. Blinking lamps cause abnormal currents to flow in the ballast, causing ballast heating and thereby reducing ballast life. Blinking lamps will also reduce starter life.

- Do not use energy-saving 30- and 40-watt, rapid-start lamps on preheat starting fluorescent circuits; replace with standard lamps.

### *Rapid-Starting Fluorescent Lamp Circuits*

- If a lamp requires 5 to 6 seconds to start, one cathode is probably not receiving the cathode heating current. Excessive darkening of the end not receiving cathode heat usually occurs after a short period of operation. Check heater voltages after removing lamps. To check voltage, use a tester that has a flashlight lamp mounted on a fluorescent lamp base. If you use a voltmeter, insert a 10-ohm, 10-watt resistor in parallel with the meter. The meter should measure at least 3 volts. If proper voltage is available, check for poor contact between lamp-holder and base pins or contacts on the lamp. If no volt-

age is measured, check for an open circuit (poor or improper connections, broken or grounded wires, open heater circuit on the ballast). Check for proper spacing of lampholders.

- If one lamp is out and the other lamp is operating at low brightness or if both lamps are out, only one lamp may be deactivated.

- Determine input voltage to the ballast and replace the ballast if wrong or no voltage is supplied to the lamps.

- Replace deactivated lamps as quickly as possible. The 800 mA and 1500 mA lamps require both heater current and operating current for proper operation. If either current is missing, poor starting or short 2-lamp life will result. In the lamp series circuit, one lamp can fail and the second lamp will operate at reduced current. This condition will reduce the life of the second lamp.

- Keep lamps reasonably clean. The bulbs of all rapid-start lamps are coated with silicone to provide reliable starting in high humidity. Dirt can collect on the lamp surface that may absorb moisture in high-humidity atmospheres, which could nullify the silicone coating and prevent starting or cause erratic starting.

### *Instant-Starting Fluorescent Lamp Circuits*

- Check lampholders for broken or burned contacts or discolored plastic in the holders, indicating high temperature.

- Measuring ballast voltages in the luminaire is difficult because the primary circuit of the ballast is automatically disconnected when a lamp is removed.

- Replace deactivated lamps as soon as possible. In the 2-lamp series circuit, one lamp can fail and the second lamp will operate at low brightness. This condition reduces the life of the second lamp and causes an abnormal current to flow in the ballast, raising ballast heating and reducing ballast life.

### *Incandescent Lamps*

- Ensure lamp ratings correspond with actual circuit operating conditions. Overvoltage or over-current operation may shorten lamp life drastically. For example, a 120-volt lamp operated on a 125-volt circuit suffers a 40 percent loss in life.

- Use vibration service or rough-service lamps under shock and vibration conditions. Using general service lamps under these conditions results in short lamp life.

- Use only lamps designed for the luminaire. Violent lamp failure may result if any metal part of a luminaire comes in contact with a hot lamp.

- Do not use a wet cloth to clean a hot lamp because violent lamp failure may occur.

- Use a clean cloth or tissue to handle tungsten-halogen lamps to avoid placing fingerprints on the bulb. Fingerprints may cause bulb discoloration and a subsequent reduction in light output. Follow lamp manufacturer instructions on the carton of each lamp.

### *High-Intensity Discharge Lamps (Mercury, Self-Ballasted Mercury, Metal Halide, High- and Low-Pressure Sodium)*

**Caution:** Always follow lamp manufacturer recommendations for allowed use of metal halide lamps in open or enclosed luminaires.

**Caution:** To prevent electric shock, always turn power off before removing or installing lamps, especially when removing lamps that may have cracked or broken outer envelopes. Unless power is turned off, the exposed metal parts of the internal lamp structure will be connected and touching them may cause an electric shock.

- Check ballast nameplate. Make sure that ballast and lamp designations match.

- Check supply circuit wiring for open circuit or incorrect connections.

- Replace ballast if no output voltage can be obtained and line voltage is properly connected to ballast input terminals.

- If a lamp fails prematurely or if lamps continue to fail prematurely in a similar failure mode in the same luminaire, check for the following:

  a) lamp breakage - Outer envelope cracks or breakage will allow air to enter the lamp and cause arc tube seal failure. Cracks or breakage can be caused by rough handling, contact with metal surfaces, a bulb changer or metal parts of the luminaire, or water droplets falling on an operating lamp.

  b) black or swollen arc tubes - Excessively black or swollen arc tubes may indicate excessive lamp current and over-wattage operation or the ballast may have failed due to a component failure, such as a capacitor or sorted core wiring.

- If tapped ballasts are used, ensure the tap matches the supply voltage to which the ballast tap is connected. Connecting a given line voltage to a higher marked tap will give low-light output due to under-wattage operation. Connecting a given line voltage to a lower marked tap will cause poor lumen maintenance and short life due to over-wattage operation.

- Ensure the line voltage is reasonably free of voltage fluctuations. A variety of ballast types are available that provide a desired percentage lamp wattage regulation with respect to percentage line voltage variation.

- Ensure electrical characteristics of lamp and ballast combinations match by following the system of lamp and ballast designations developed by the lamp industry and ANSI. Incorrect lamp and ballast matching may result in short life and equipment damage.

- Handle lamps carefully. Rough handling can cause scratches or cracks in outer glass envelopes resulting in short lamp life and possible injury.

- Self-ballasted mercury lamps are rated by voltage and should be used in installations in which available socket voltages correspond to the allowed voltage range recommended by the manufacturer for the particular lamp.

- Ensure starting temperature limits for self-ballasted mercury lamps published by the manufacturers are carefully followed. Because these lamps operate directly from the available line voltage, no "step-up" voltage can be introduced unlike mercury, metal halide, and high-pressure sodium lamps where ballasts must be used and step-up transformers can be incorporated.

- Because self-ballasted mercury lamps will probably be replaced into existing incandescent sockets, lamps will be installed in old luminaires. Ensure socket rating is not exceeded and water falling on bulb is prevented. Follow manufacturers' recommendations for indoor and outdoor burning positions in open and closed luminaires.

- Many metal halide lamps are to be used only in identified operating positions. Short life and improper light and color output will result if lamps are not used in their recommended burning positions.

- Metal halide lamps may have a short delay between the time the circuit is energized and the lamp starts.

- Metal halide lamps generally have a slight source color shift from lamp to lamp. These lamps may have to burn one to two days before lamp color will stabilize.

- Only operate metal halide lamps in allowed operating positions.

- Excessive discoloration of the arc tube of high-pressure sodium lamps or a metallic deposit on the inside walls of the outer envelope may indicate over-wattage operation.

- An igniter is required to start high-pressure sodium lamps. If several lamps do not start, determine if the igniter or ballast or perhaps both are defective. First, ensure the proper line voltage is connected correctly to the ballast input. Obtain a ballast tester from a ballast manufacturer and follow instructions on the tester to determine the defect.

- High-pressure sodium lamps have a vacuum in the space between the ceramic arc tube and the outer envelope. Handle these lamps carefully because vacuum lamps make a loud noise if dropped and the glass breaks.

- If low-pressure sodium lamps fail prematurely, check for the following:

  a) lamp breakage - Check lamps for cracks or scratches in the outer bulb, which can be caused by rough handling, contact with metal surfaces in bulb changer or luminaire, or moisture falling on over heated bulb.

  b) excessive current - Check if ballast is shorted. Check for possible voltage surges or transients on the supply line.

# Appendix A: References

**The Federal Energy Management Program (FEMP)** provides lighting related information to Federal Energy Managers through publications such as this Federal Lighting Guide, and in certain instances provides technical assistance on a project-by-project basis. Products include:

- *Federal Lighting Guide, including Energy Effective Lighting Recommendations*
- *Master Specification for Lighting* (for projects with a subcontracted lighting designer)
- *Delivery Order Lighting Requirements* (under review)
- *Lighting Design Services Solicitation Language*
- *Product Energy Efficiency Recommendations, Lighting Products* (under Federal Procurement on the web site)

For additional information, contact

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Federal Energy Management Program, EE-90
1000 Independence Avenue, SW
Washington DC 20585-0121
FEMP Help desk: (800) DOE-EREC
FEMP Help desk fax: (703) 893-0400
FEMP HQ fax: (202) 586-3000
http://www.eren.doe.gov/femp

**The National Lighting Product Information Program** publishes a series of Specifier Reports, Lighting Answers bulletins, and guides on lighting products and issues including

Specifier Reports:

- *Electronic Ballasts*
- *Screwbase Compact Fluorescent Lamp Products*
- *CFL Downlights*
- *Specular Reflectors*
- *Occupancy Sensors*
- *Reflector Lamps*
- *Exit Signs*

Lighting Answers:

- *T8 Fluorescent Lamps*
- *Multilayer Polarizing Panels*
- *Task Lighting for Offices*
- *Dimming Systems for HID Lamps*
- *EMI Involving Fluorescent Lighting Systems Power Quality*
- *Thermal Effects in 2 ft. x4 ft. Fluorescent Lighting Systems*
- *Controlling Lighting With Building Automation Systems*

Guides:

- *Fluorescent Lamp-Ballast Compatibility*
- *Specifying High-Frequency Electronic Ballasts*

To order these publications, contact

Lighting Research Center
Rensselaer Polytechnic Institute
Troy, NY 12180-350
(518) 276-2999 Fax

**The Illuminating Engineering Society of North America (IESNA)** produces a wide range of lighting information and training materials including handbooks, references, specifications, test and measurement guides, design guides, and practices and standards for both members and nonmembers. For additional information, contact:

IESNA
120 Wall Street
New York, NY 10005-4001
(212) 248-5000

**The Association of Energy Engineers (AEE)** offers many energy-related books. Several of the following books deal specifically with lighting.

*Applied Illumination Engineering, 2nd Edition* - This comprehensive reference provides a practical, fully illustrated guide to the design specification and application of state-of-the-art lighting from the fundamentals of illumination to hands-on application.

*Energy Effective Industrial Illuminating Systems* - This reference provides guidance to engineers and managers involved in improving lighting system performance and reducing lighting-related energy consumption in any type of manufacturing or industrial workspace.

*Lighting Management Handbook* - This straightforward, nontechnical handbook contains a complete spectrum of lighting management strategies for efficiency. This handbook is ideal for building owners and managers, facility managers, or anyone concerned with reducing lighting costs.

*Lighting Efficiency Applications, 2nd Edition* - This publication provides guidance on designing, specifying, and applying lighting systems that can potentially reduce building operating costs by as much as 50% compared to traditional or outdated systems. For more information, contact

The Association of Energy Engineers
4025 Pleasantdale Road, Suite 420
Atlanta, GA 30340

**The International Association for Energy-Efficient Lighting (IAEEL)** publishes a free newsletter quarterly on international lighting issues. For more information, contact:

NUTEK /EFF
S-117 86 Stockholm , Sweden
+46 8 681 9100 Phone
+46 8 681 9585 Fax
http://eff.nutek.se/iaeel/iaeel.html

## Lighting-Related Organizations

The **Lighting Research Center (LRC)** is the largest university-based research and educational institution dedicated to lighting with heavy emphasis on research. LRC offers lighting education courses, performs research, and publishes lighting-related information. For information, contact

Lighting Research Center
Rensselaer Polytechnic Institute
Troy, NY 12180-350
(518) 276-2999 Fax
www.rpi.edu/dept/lrc/LRC.html

**The International Association of Lighting Designers (IALD)** is a lighting design professional association dedicated to the advancement of lighting excellence in the building environment. The IALD serves the interests of professional lighting designers and communicates the benefits of designed lighting. For more information, contact

International Association of Lighting Designers
1133 Broadway, Suite 520
New York, NY 10010-7903
(212) 206-1281
(212) 206-1327 Fax
www.iald.org

**IESNA** is a professional lighting society whose mission is to advance knowledge and to disseminate information for improving the lighted environment. Additional information can be obtained at

IESNA
120 Wall Street
New York, NY 10005-4001
(212) 248-5000
www.iesna.org

**The Lighting Design Lab** is a working resource center combining the art of lighting and the science of energy efficiency. The lab is designed to meet the needs of commercial lighting designers, specifiers, architects, engineers, contractors, facility managers, and others interested in the latest, most efficient lighting applications. The lab has a flexible format to meet your needs, schedule, and interests.

Lab facilities are available free of charge to

any lighting designers working on commercial lighting projects. Make appointments to use the mock-up room and daylighting lab as far in advance as possible. Shorter notice is required to consult with staff, to use the resource library or computer lab, or simply to visit the lab. For more information, contact:

Lighting Design Lab
400 E. Pine St., Suite 100
Seattle, WA 98122
(206) 325-9711
(800) 345-38864 in WA, OR, ID, BC

**The EPRI Lighting Research Office** has a comprehensive research agenda and numerous research projects underway that are of significant relevance to the lighting community. For a packet of information on LRO please contact:

Al Gough
EPRI Lighting Research Office
(704) 692-7388
(704) 692-6820, fax
www.epri.com

**EPA Green Lights** is now part of the **EPA Energy Star Buildings Program**. Its goal is to promote energy-efficient lighting throughout the commercial sector. For more information, contact:

EPA Green Lights (6202J)
401 M Street, SW
Washington, DC 20460
(202) 775-6650
www.epa.gov/energystar.html

**The Energy Technology Resource Center (ETRC)** is a Tampa Electric Company facility with the goal of bringing energy-efficient technologies to Florida's businesses. ETRC is a showcase and interactive demonstration center for existing and emerging technologies. It is a resource for west central Florida-area businesses, schools, and other institutions, as well as organizations considering relocation to the area. For more information, see the ETRC web site at http://www.teco.net/etrc/ETLighting.html.

# Appendix B: Training and Certification Programs

## Training Programs

Many training programs on lighting efficiency and project implementation are available to help Federal facility managers successfully complete lighting projects. FEMP maintains a locator for energy efficiency training that includes lighting-related courses, seminars, and workshops. For additional information, contact FEMP at 1-800-DOE-EREC or on the FEMP web site at http://www.eren.doe.gov/femp under Technical Assistance. A partial listing of lighting-related training offered through various agencies, schools, and organizations are summarized below.

**FEMP** offers a distance-based learning course entitled, **"Basic Lighting Training."** This course is an excellent way to become fully prepared to manage Federal lighting projects. A new and up-to-date course, the training is delivered to your desktop via email and only requires a few hours per week to complete at times which are convienient to each registrant.

The course covers 1) technical lighting knowledge and design, 2) procedural aspects of lighting efficiency projects, 3) ESPCs and evaluation of delivery orders, and 4) a life-cycle cost analysis. For additional information, contact:

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Federal Energy Management Program, EE-90
1000 Independence Avenue, SW
Washington DC 20585-0121
FEMP Help Desk: (800)DOE-EREC
FEMP Help Desk Fax: (703) 893-0400
FEMP HQ Fax: (202) 586-3000
Home Page: http://www.eren.doe.gov/femp

**The University of Wisconsin at Madison** offers a course entitled, "Basic Lighting Design." For additional information, contact:

Department of Engineering
Professional Development
432 North Lake Street
Madison, WI 53791-8898
(800) 462-0876
(800) 442-4214 Fax
Course ID 329

**The Electric Power Research Institute** offers a course entitled, "Commercial Lighting Training." For more information, contact:

EPRI HVAC+R Center
150 East Gilman Street, Suite 2200
Madison, WI 53703
(800) 858-6209
(608) 262-6209 Fax
Available on an as-needed basis.

**The North Carolina State University** offers a course entitled, "Energy Savings In Cost-Effective Lighting." For more information, contact:

Industrial Extension Services
College of Engineering
Box 7902
Raleigh, NC 27695-7902
(919) 515-5438
(919) 515-6159 Fax

**The Lighting Research Center (LRC)** is the world's largest university-based research and educational institution dedicated to lighting with heavy emphasis on research. LRC offers a 48-credit, two-year curriculum leading to a Master of Science in Lighting degree. Courses are offered in lighting technology, lighting design, optics, research methods, human factors, and the human visual system. For additional information, contact:

Lighting Research Center
School of Architecture, RPI
877 25th Street, Room 2215
Watervliet, NY 12189
phone (518) 276-8717
fax (518) 276-4835
http://www.lrc.rpi.edu

The **Illuminating Engineering Society of North America (IESNA)** is an organization of lighting professionals. IESNA offers a wide range of lighting information and training materials for both members and nonmembers. For more information, contact:

Illuminating Engineering Society of North America
120 Wall Street
New York, NY 10005-4001
(212) 248-5000
http://www.iesna.org

The **Lighting Design Lab** is a lighting resource designed to meet the needs of commercial lighting designers, specifiers, architects, engineers, contractors, facilities managers, and others interested in the latest, most efficient lighting applications. The lab offers a wide range of lighting classes, most of which are offered at no charge. Classes typically offered during the year include:

- Lighting Audit and Survey Training
- Retail Lighting Workshop
- Utility Programs Update
- Multifamily Exterior Lighting Workshop
- Dimming Ballast PKD
- Residential Light Sources

For more information, contact:

Lighting Design Lab
400 E. Pine Street, Suite 100
Seattle, WA 98122
(800) 354-3864
http://www.light-link.com/ldl/

The **Association of Energy Engineers (AEE)** offers a variety of seminars and training courses and maintains the Certified Lighting Efficiency Professional (CLEP) certification program (see below).

In addition to their certification preparatory course, AEE also offers the following courses and seminars:

- Effective Lighting Retrofit Solutions
- Energy Auditing: Improving Efficiency in Existing Facilities
- Energy Accounting: Practical Tools for Managing Energy Information
- Performance Contracting for Energy and Environmental Systems
- Energy Management in Federal, State, and Local Government Buildings
- Industrial Energy Conservation: Strategies That Work
- Measurement and Verification for Performance Contracts

For further information contact:

The Association of Energy Engineers
4025 Pleasantdale Road, Suite 420
Registrar, AEE Energy Seminars
P.O. Box 1026, Department 339
Lilburn, GA 30226
(770) 925-9533
(770) 381-9865 Fax
Atlanta, GA 30340
http://www.aeecenter.org

The **EPA Green Lights** program is now part of the **EPA Energy Star Buildings** program. As part of their educational workshops on buildings, they do cover lighting. For additional information and registration, contact:

EPA Green Lights (6202J)
401 M Street, SW
Washington, DC 20460
(202) 775-6650
http://www.epa.gov/greenlights.html/

Several lighting companies, offer training courses for staff and the public. Although these courses may include manufacturer-specific product references, they can also provide valuable generic lighting information and expertise. This is by no means a comprehensive list; additional surfing is encouraged. For more information, contact:

**General Electric Lighting Institute**
http://www.ge.com/lighting/gel.htm

**Hubbell Lighting, Inc.**
(504) 381-2580
(504) 382-1526 Fax

**Lightpoint, Sylvania Lighting**
www.sylvania.com

**Lithonia Lighting Center**
http://www.lithonia.com/train00.htm

**Philips Energy Center**
www.lighting.philips.com

**Thomas Lighting Idea Center**
(213) 724-4392 Fax

## Certification Programs

The **National Council for Qualifying the Lighting Professions (NCQLP)** is a nonprofit organization founded in 1992 and sponsored by major lighting societies and organizations, government agencies, and other industry trade groups.

FEMP holds a seat on the NCQLP board and is supportive of this broad-based effort. The LC credential will help Federal Energy Managers identify qualified lighting professionals when it is appropriate to seek additional subcontractor services.

Through a peer-review process, the NCQLP establishes the education, experience, and examination requirements for certification in the lighting industry.

Those who pass the NCQLP Lighting Certification Examination will have demonstrated an understanding of basic lighting principles and their application and will be entitled to use the appellation LC (Lighting Certified) after their name. Lighting associations will offer preparation review courses in early fall. For a listing of courses, contact:

National Council for Qualifying the Lighting Professions
4401 East-West Highway, Suite 305
Bethesda, MD 20814
phone (301) 654-2121
fax (301) 654-4273
info@ncqlp.org

The **Association for Energy Engineers** maintains the Certified Lighting Efficiency Professional (CLEP) certification program. The CLEP was developed to identify specialists in lighting efficiency. This program is recognized as meeting the certification requirements of the EPA Green Lights Lighting Management Company Ally Program. A 2-day seminar is available to prepare for the exam, entitled “Fundamentals of Lighting Efficiency - A Preparatory Course for the CLEP Examination.” This course is designed to prepare professionals to take the CLEP exam and serves as a broad-based instructional program to “brush up on the basics” of efficient lighting design, retrofit, and application. For further information on certification see AEE contact information, above.

# Appendix C: Lighting Analysis and Design Tools

Many lighting analysis and design software tools are available both from FEMP and commercial or non-FEMP sources. A list follows with brief descriptions of each product.

## FEMP Tools

The following tools are available free through FEMP for use by Federal facility managers in evaluating and assessing potential energy projects. The tools compare potential energy conservation measures by performing complex energy consumption analyses and modeling, as well as comparative life-cycle costing analyses. They are designed to help project designers choose the most cost-effective and environmentally friendly conservation measures.

For additional information on these tools and others, as well as downloadable program files, see the FEMP web site at http://www.eren.doe.gov/femp under Technical Assistance.

***Building Life-Cycle Cost (BLCC)*** is the main program in a set of five National Institute of Standards and Technology (NIST) computer programs that provide computational support for analyzing capital investments in buildings. BLCC conducts economic analyses by evaluating the relative cost effectiveness of alternative buildings and building-related systems or components. BLCC compares the life-cycle costs of two or more alternatives to determine which has the lowest life-cycle cost and is therefore more economical. BLCC calculates comparative economic measures including net savings, savings-to-investment ratio, adjusted internal rate of return, and years to payback.

***Quick BLCC*** provides a convenient way to set up and solve relatively simple life-cycle costing problems. Quick BLCC can generate input data files for a full BLCC analysis if a more detailed analysis is required.

***EMISS*** is a special-purpose computer program to assess $CO_2$, $SO_2$, and NOx emissions related to energy usage in buildings. BLCC can access the resulting data files to calculate reductions in air pollution emissions from energy conservation investments in buildings and building systems. BLCC does not place an explicit dollar value on these reduced emissions, but the additional information on emission reductions may help in selecting alternative building systems.

***ERATES*** (Electricity Rates) is used to calculate the monthly and annual electricity costs for a facility, building, or system under a wide range of electric utility rate schedules. ERATES is intended to provide more accurate estimates of annual electricity costs (or savings) for specific design and operating conditions than can be calculated using average unit rates (e.g., $0.07/kWh) and annual kWh usage data.

The ***Facility Energy Decision System (FEDS)*** is a comprehensive fuel-neutral, technology-independent, integrated (energy) resource planning approach. For example, when considering a lighting retrofit, the model evaluates the change in energy consumption in all building energy systems rather than just the change in lighting energy. In determining the optimal retrofit for each technology, the interactions at the installation level are considered by determining the impact on the installation's electric energy and demand cost, as well as the interactive effects among end-uses.

## Commercial and Non-FEMP Tools

The following analysis and design tools are available commercially or through other non-FEMP sources. These products are typically used at more advanced stages of design by design professionals or users with some lighting design knowledge.

***EnLightN Lighting Software*** is a decision-making tool that can run multiple scenarios with unlimited options. System requirements are IBM Compatible; 640 K; Hard Disk; VGA; DOS 3.1 or higher. The cost is $495 and can be ordered:

United Energy Associates, Inc.
140 North Orlando Avenue, Suite #150
Winter Park, FL 32789
(407) 740-0178
(407) 740-0169 Fax

***AGI (Advanced Graphical Interface)*** for Lighting is a 3-D graphical software program capable of computing point-by-point illuminance (and more) for both interior and exterior environments using a single interface and command structure. Interior environments can be complex including rooms of any shape, partitions, and sloped ceilings. AGI also imports and exports CAD files in DXF format for easy data exchange with your project drawings. AGI is designed to model demanding lighting projects. Contact AGI by E-mail at info@Lighting Analysts.com.

***Superlite 2.0*** is a DOS-based lighting analysis program designed to accurately predict interior illuminance in complex building spaces from daylight and electric lighting systems. It enables the user to model interior daylight levels for any sun and sky condition in spaces having windows, skylights, or other standard fenestration systems. An Intel-compatible 80 x 87 math coprocessor is required for program execution. Minimum RAM is 600 KB. This software can be downloaded from the web at http://eande.lbl.gov//btp/superlite2.html.

***RADIANCE*** is a suite of programs for analyzing and visualizing lighting design. Input files specify the scene geometry, materials, luminaires, time, date, and sky conditions (for daylight calculations). Calculated values include spectral radiance (i.e., luminance + color), irradiance (illuminance + color), and glare indices. Simulation results may be displayed as color images, numerical values, or contour plots. RADIANCE is used by architects and engineers to predict illumination, visual quality, and appearance of innovative design spaces and by researchers to evaluate new lighting and daylighting technologies. RADIANCE is UNIX software and can be downloaded from the web at: http://radsite.lbl.gov/radiance/radiance_short.html.

***ADELINE 2.0*** is an integrated lighting design computer tool developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Program. It provides architects and engineers with accurate information about the behavior and performance of indoor-lighting systems. Both natural and electrical lighting problems can be solved in simple rooms or the most complex spaces. ADELINE produces innovative and reliable lighting design results by processing a variety of data including geometric, photometric, climatic, optic, and human response to perform light simulations and to produce comprehensive numeric and graphic information. ADELINE 2.0 can be ordered on-line at http://radsite.lbl.gov/adeline/HOME/html

***Lumen Micro*** is a 16-bit or 32-bit application for the Microsoft Windows environment. It is a flexible indoor and outdoor lighting design, specification, and analysis tool that analyzes everything from simple zonal cavity calculations, to point-by-point footcandle analyses, to complex architectural space renderings. Lumen Micro incorporates daylighting, wall and ceiling exitances, partitions, and object shadowing to provide the most accurate calculational data. Lumen Micro can be used to design and analyze both indoor and outdoor projects and provides complete CAD functionality. Additional details and ordering information is available on the web at http://www.lighting-technologies.com

# Appendix D

# ENERGY-EFFECTIVE LIGHTING:

## An Executive Summary of the Links Between Lighting, Productivity, and Well-Being

By Judith H. Heerwagen, Ph.D.
Staff Scientist
Pacific Northwest National Laboratory

## WHAT IS ENERGY-EFFECTIVE LIGHTING?

Energy-effective lighting is light that not only helps us to see, but also provides our work environments with a sense of pleasure and psychological warmth – and does so in an energy-efficient way.

High quality, energy-effective lighting has a number of general characteristics, including[1]:

- *Eliminates distractions.* High quality, energy-effective light eliminates problems with glare, shadows or excessive and annoying brightness. It allows people to work without constantly having to move to a better viewing angle.

- *Creates visual interest and a sense of place.* High quality, energy-effective lighting contributes to an aesthetically pleasing environment. This aspect of lighting is not a mere frill. There is evidence that the aesthetic appearance created by light has a special role in how people feel about their work environments and how they feel about coming to work every day.[2] Having an environment that looks nice makes people feel good, and feeling good contributes to motivation and work satisfaction.

- *Supports interactions and communication.* Lighting can have a negative effect on social interactions and judgments if the light distorts facial features. High quality, energy-effective lighting helps us "read" people's facial expressions, thereby providing a better context for communication and social interactions. It can also serve as a behavioral guide through variation in lighting levels.

- *Contributes to well being and reduces health problems*. High quality, energy-effective lighting reduces problems associated with poor lighting (headaches, muscular-skeletal strain, discomfort). It may also contribute positively to health and well-being by enhancing mood and motivation.

Unfortunately, many of us do not have quality light in our environments. Sure, we can see our computers and read written materials. But we often have to squint because we can't see all that well, or we get into all sorts of awkward positions to avoid seeing the overhead light in the computer screen. And while this wiggling and body adjusting may get rid of the reflections, it also can give us headaches and neck aches, not to mention put us in a bad mood.

Many common lighting installations in office settings inadvertently create a cave-like effect that make spaces look dim and gloomy at the periphery, even when there is enough light over the work surface. This happens because lighting installations frequently neglect the vertical spaces, such as walls or the exterior of partitions. Thus,

[1] Veitch, J. and Newsham, G. 1995. "Quantifying Lighting Quality Based on Experimental Investigations of End User Performance and Preference." Paper presented at the 3rd European Conference on Energy-efficient Lighting, Newcastle-upon-Tyne, U.K., June 1995.
[2] Heerwagen, J. et al, 1996. "A Tale of Two Buildings: Biophilia and the Benefits of Green Design". Paper presented at the U.S. Green Buildings Council Conference, San Diego, CA, Nov. 17-20.

as we move about the office environment, it feels gloomy because the walls are more dimly lighted than the work surfaces.

### *Who cares about quality lighting?*

Who cares about the quality of lighting? The American workforce does. In a nationwide study for Steelcase, Inc., pollster Lou Harris found that 80% of the workers questioned said lighting affects their performance, and that having good lighting was important to them[3] . Another study commissioned by Fortune Marketing found that corporate facility executives care also: 87% of the facilities execs believe that a high quality work environment increases worker productivity, morale, and safety. Furthermore, 93% believed that improved lighting could enhance worker productivity by 10% or more.[4]

## LIGHTING AND PRODUCTIVITY

### *What is Productivity?*

Before discussing links between lighting and productivity, it is useful to consider what productivity is and how it is measured. In the Industrial Age, productivity was relatively easy to measure. It was the number of widgets produced per unit of time or cost. This definition worked well when outputs were easy to track and people worked in well-defined jobs. However, as the unit of work becomes more information and serviced based, productivity becomes increasingly difficult to measure. In the new economy, customers value quality and service as well as variety and continuity of relationships. In this new climate, productivity has shifted from an input/ output model to a model based on adding value while reducing the costs of doing business.[5]

How does lighting affect this new bottom line? Several routes are possible. Light can *add value* by enhancing the quality of work life for employees, by improving the quality of products and services, by reducing impediments to work, and by increasing work efficiency. Light can also *reduce costs* through the use of energy-efficient equipment and by reducing health problems that may be associated with poor or inappropriate lighting.

### *Organizational Level Measures vs. Worker Level Measures*

In looking for links between lighting quality and productivity, it is important to distinguish between productivity measured at the *individual level* (usually referred to as human performance, not productivity) and productivity at the *organizational level*. In assessing the productivity impacts of lighting, it is important to evaluate both individual and organizational level outcomes.

*Organizational Productivity*

The potential measures of organizational "productivity" have expanded beyond the Industrial input/output model to include customer satisfaction, innovation, quality of products and services, timeliness of delivery, efficiency of resource use, and quality of work life. In addition, many organizations also track a number of more indirect measures of overall productivity such as quality of work life, absenteeism, health care costs, ability to attract high quality workers, and turnover rates. For any given
organization, a suite of outcomes is normally used to indicate overall performance.[6]

[3] *The Office Environment Index, Detailed Findings*,. 1988. Prepared by Louis Harris and Associates, Inc. for Steelcase Inc., Grand Rapids, MI.

[4] Custom Research, Inc. 1996. Facilities and Real Estate Strategies: Survey Findings. Commissioned for Fortune Marketing.

[5] Wise, J. 1997. "How Nature Nurtures: Buildings as Habitats and Their Benefits for People." HPAC, February, 48-51.

[6] Aranoff, S. and Kaplan, A.G. 1995. *Total Workplace Performance*. Ottawa, Canada: WDL Publications.

*Worker Performance*
At the individual level, performance is widely viewed as a function of two factors: ability and motivation. Ability deals with whether or not a person *can* do a task, while motivation is a measure of whether or not a person *wants to* do it. Lighting can affectperformance through its impacts on both ability and motivation. The quality of the light influences whether a person can see the task clearly (an ability issue) as well as whether they feel inspired or interested in their work (a motivation issue). Although there is increasing interest in the motivational and psychological impacts of lighting, most of the research has centered on task-related ability issues.

Performance measures generally focus on how light affects the visibility of tasks or on performance of the visual system itself. The vast majority of work has taken place in laboratory settings centered on experiments with countable outcomes, such as rate of work, numbers of errors, and number of reports/products completed in the specified time period.

Researchers and designers are increasingly interested, however, in assessing a broader range of outcomes, particularly nonvisual effects of light — such as the impact of lighting on motivation, mood, and team work. Although these outcomes are more challenging to measure, many experts believe that we will never have a full picture of the human dimensions of lighting if these psychological and social processes are neglected.

## *How do We Know It's the Lights, and Not Something Else?*

One of the critical problems faced by lighting researchers is how to separate out the effects of lighting from all of the other office influences that surround us daily and affect our work – such as temperature conditions, noise, work load, corporate policies and culture.[7]

*The Hawthorne Effect*
The problem of extraneous influences is known as the Hawthorne Effect. The term derives its name from a series of lighting studies conducted by Elton Mayo at the Hawthorne Plant of Western Electric from 1927-1932.[8] The studies were designed to assess the effect of environmental conditions on worker productivity. The research
involved a small group of workers who made telephone assemblies. For the research project, they were separated from the rest of the workers and studied in a special room that enabled researchers to change the illumination levels and track work performance resulting from the lighting variations.

The results of these studies have puzzled researchers for decades. No matter what the direction of the illumination changes, work performance continued to increase – even when illumination reached levels that was considered excessively bright or almost too dim to see. The researchers tested other manipulations, such as changes in rest breaks and payment method, with similar results. Productivity still increased. Finally, the researchers interviewed the women who attributed their continuously improving performance to:

- being in a small group
- being less supervised
- the novelty of the situation
- their own interest in the experiment
- the attention they received from management and the researchers.

The last three explanations are generally described as the "Hawthorne Effect." However, even 60 years after the studies psychologists are still arguing over what really happened at the Hawthorne plant.

[7] Baron, R.A. 1994. "The Physical Environment of Work Settings: Effects on Task Performance, Interpersonal Relations, and Job Satisfaction." *Research in Organizational Behavior*, Vol. 16: 1-46.
[8] For a good overview, see S. Aronoff and A. Kaplan, 1995. *Total Workplace Performance*, Ottawa, Canada: WDL Publications.

Explanations range from having performance feedback to the synergy of group process.

*Impacts of the Hawthorne Effect*
Whatever the true cause of the results, the Hawthorne research placed a significant damper on studies of the office environment in general, and lighting research in particular. The results seemed to mean that neither lighting nor other environmental factors could influence work productivity in any significant way. As long as workers could see (however poorly), they could do their work. For decades to follow, the organizational environment was viewed as superior to the physical environment in its influence on human functioning.

The Hawthorne studies have had far reaching effects, not only on environmental research, but also on field studies in general. Because of the difficulty of sorting out the many influences on task performance in real settings, researchers have shied away from the work world in favor of highly controlled laboratory work. The best way to isolate the influence of any stimulus, including light, is to control all other conditions.

However, the laboratory approach has a number of shortcomings. In most cases, research subjects carry out tasks only for short periods of time. If the lighting environment has cumulative impacts or effects that do not show up within the experimental time period, then the research will not capture the full range of outcomes. Also, when people know they are in a research project, they tend to work harder and thus may skew results in a positive way that is unlikely to occur in real work situations. These problems can be overcome to a large extent through simulation experiments with temporary workers whose real tasks and work settings are similar to the experimental one.

Even with the best experimental set ups, however, there are always nagging doubts about whether the same results would be attained in actual work environments. This is why it is important to conduct both field studies and experiments. Field studies are useful not only for a reality check, but for raising questions that can be studied in more detail in the laboratory. However, in order to provide satisfactory results, field work should include, to the extent possible, measurement of other environmental factors that affect work performance (such as noise, air quality, temperature conditions, privacy, distractions) as well as assessments of pertinent organizational policies and values.

## *The Office Environment and the Renewed Interest in Productivity*

In the last fifteen years researchers have once again turned their attentions to the office environment as a factor in work performance. In the 1980's interest in the physical environment of work stemmed, in part, from a growing national concern over declining productivity. Experts in a wide range of fields began to look at how to get the nation over its productivity slump, especially in the rapidly growing area of knowledge work which lagged far behind that of manufacturing productivity. Personal computer technologies promised new ways of working and new tools to increase worker output, yet there was no indication that this was actually happening. Simultaneous with the technological advances was growing evidence of widespread malaise among office workers, as indicated by:[9]

- declining job satisfaction
- worries about the health impacts of the office environment, especially indoor air quality
- a backlash against the dehumanizing aspects of office automation
- increasing numbers of employee rights lawsuits concerning safety, privacy, work stress, and safety.

[9] Brill, M., Margulis, S. and Konar, E. 1984. Using Office Design to Increase Productivity, Volume 1, Buffalo, NY: Workplace Design and Productivity, Inc. See also, Naisbitt, J., 1984. *Megatrends*. New York: Warner Books.

Within this milieu, designers and researchers began to seriously question whether the Hawthorne studies provided a true picture of the work environment, especially the high technology office of the future.[10] The advent of computer technology, more than any other factor, led to a re-examination of the physical setting at work. The computer created entirely new demands on the social and physical milieu and, especially, on lighting design.

One of the first attempts to link the office environment with productivity was the BOSTI study, headed by Michael Brill, in the 1980s.[11] The BOSTI research assessed both the physical environment and worker outcomes for approximately 6000 workstations in 70 organizations. In the report's executive summary, the researchers concluded that lighting quality affects environmental satisfaction and job satisfaction, and that it "probably" affects job performance. It is important to note, however, that the BOSTI studies were conducted before computers became a standard feature of office work. The conclusions about the relationship between light and performance may have been different if the study were conducted in today's highly computerized work environment. Another shortcoming of the BOSTI work is the lack of objective performance measures. Workers were asked to subjectively assess the impact of the physical environment on their work performance. Data from a recent study which compared subjective and objective measures of performance shows that people are not very good at assessing how well they perform.[12]

*Workplace Productivity: Looking toward the 21st Century*

More recent attempts to link the office environment to productivity have taken a broader perspective, one that links facilities decisions to business goals and missions.[13] The thinking goes like this: new workplace ideas and technologies will succeed in the marketplace only if they lead, directly or indirectly, to outcomes that the business world values. These include finances (tax breaks and reduces operating expenses), improved worker output (both quality and quantity), improved products and services, or reduced costs of doing business. The challenge for energy-effective lighting is clear: companies will invest if new lighting technologies to the extent that a definitive link can be made to business financial interests. The remainder of this report identifies what is currently known about these potential links.

## *Lighting and Work Performance: What do we Know?*

The vast majority of research on lighting has been conducted in laboratory settings and has focused on the relationship between lighting conditions and performance on visual tasks. Much less attention has been paid to the health and well-being aspects of lighting, nor has there been any significant research on the relationship between lighting and organizational level measures of productivity and performance. Nonetheless, the existing research body points to a strong, but complex, relationship between lighting conditions and work performance.

Decades of research, summarized in several key documents[14] shows that the relationship

[10] Dolden, M.E. and Ward, R. (Eds.) 1985. The Architectural Research Centers Consortium, Workshop on The Impact of the Work Environment on Productivity, Washington, DC: American Institute of Architects.

[11] Brill, et al, 1984, Op cit.

[12] Veitch, J. and Newsham,G. 1997. Experimental Investigation of Lighting Quality, Preferences, and Control Effects on Task Performance and Energy Efficiency: Experiment 1 Primary Analysis. Ottawa, Canada: National Research Council of Canada..

[13] These observations are drawn from two workshops in Washington, DC held in April 1998, one sponsored by the U.S. General Services Administration, the other by the National Research Council. The workshops were attended by representatives government agencies, private industry, the design professions, and academic researchers.

[14] See P. Boyce, 1981, *The Human Factors of Lighting*. London: Applied Science Publishers, and *Lighting and Human Performance: A Review*, a report sponsored by the National Electrical Manufacturers Association and the Lighting Research Institute, January 1989.

between lighting and performance is not a simple one. About the only generalization possible from decades for research is this: luminous conditions that are more appropriate for the task at hand will promote higher performance than conditions which are inappropriate. Factors which determine the degree of "appropriateness" include: the visual demands of the task, the time spent on the task and the degree of urgency, the other physical features of the setting, and the characteristics of the workers. For example:

- *The visual emphasis of the task*. The impact of lighting on work performance depends to a large extent on the visual nature of the task – not only the degree of visual emphasis but its relative importance to the job. For instance, inspection of a wiring system in an airplane is not only a highly detailed visual task, it is also extremely important due to the high cost of an error. On the other hand, assembling packets of materials for a conference does not require the same detail of inspection, nor are errors as costly. Thus, the lighting levels, the distribution of light in the task area, and the color rending of the light source will be more critical to the airplane job than to the clerical task.

- *Visual details of the task*. In addition to the visual emphasis of the task, a number of other task features influence task performance. These include the importance of color perception, the fineness of details that must be seen, the contrast and size of the visual elements, whether the visual target is moving or stationary, whether the task is vertical or horizontal. All are important factors in determining the right lighting design, and, thus, the relationship between light and task performance. A task that requires reading and understanding small print on low contrast background will require a higher lighting level than a task with large print on a high contrast background. A job which requires viewing moving targets on a vertically mounted computer screen (such as in an air control tower or emergency response center) will require a different lighting design than a job with intermittent computer use. At issue are concerns about attentional focus, visual discrimination, alertness, and visual fatigue.

- *The presence of distractions or discomforts*. Poor lighting not only reduces the ability to see a task, it can also create distractions that draw attention away from work. Lighting problems include reflections on computer screens from ceiling lights or windows; shadows on the work surface; contrasts between different work surfaces (such as the computer screen and the work surface); and light that is either too dim or too bright for the task.

- *The characteristics of the worker*. In general, older workers generally are more sensitive to glare and require a higher lighting level to perceive the task correctly. In addition, there seem to be strong individual differences in preferred light levels that may affect not only the ability to see, but workers motivational levels and psychological comfort in a setting.[15] Both of these factors may have effects on work outcomes.

*The complexity of the relationship between lighting and tasks clearly show that one lighting system will not be appropriate for all office environments*. The characteristics of the task, the context, and the workforce must all enter into the design equation. The complexity underscores the need for a task-based analytical approach carried out jointly by lighting professionals, the workers, and organizational decision makers.

*Lighting and Computers*

The relationship between the task and office lighting has become more difficult and

[15] Heerwagen, J. 1990. Affective Functioning, Light Hunger, and Room Brightness Preferences." *Environment and Behavior*. 22(5):608-635.

complicated with the large-scale introduction of computers. This is due to changes in the viewing environment. With computers, the visual work surface is vertical rather than horizontal. Computer screens are also self-luminous; thus, we do not need to light the screen in order to see visual materials. In fact, light on the VDT screen creates reflections and glare that make it more difficult to see clearly.

The computer also changes the relationship to other task areas. For instance, if we are working with both written and computer materials, we need to be able to see both. If we light the written materials, this often interferes with the ability to see the computer screen. If we dim the light so that we can see the computer screen, then we can't read the written materials. Finding the right balance and the right lighting system is not an easy task.

What matters most is the luminous conditions that are created, not the lighting system per se. The luminous conditions are affected not only by the lighting system but also by other environmental factors, such as the reflectance of surfaces, the presence or absence of windows, the color of the walls and furnishings, and the placement of the lighting fixtures. The same lighting system can create very different luminous conditions in different settings. Thus it is difficult to conclude on the basis of current research that a particular lighting system is better for computer based work than other systems. In some studies, recessed parabolic luminaires have been associated with higher performance and environmental satisfaction, while in other studies indirect systems have been better.

### *The Psychological Aspects of Light: What Do We Know?*

As noted earlier, lighting can also affect work performance and productivity through its impacts on motivation and well-being. However, much less is known about these factors. In large part this stems from a belief that "soft" outcomes are less relevant to performance and less convincing to the market place. The psychological impacts of light are considered by many to be highly subjective and tenuously connected to productivity. Emerging work in two areas, however, suggests that psychological factors may be more important than realized.

The first line of evidence comes from medicine. The discovery of wide ranging physiological effects of light opened up a whole new area of research in the medical professions. Researchers have found that bright room lighting affects biological rhythms, sleep quality, and seasonal affective functioning.[16] Although the research in this area tends to be highly specialized and focused on winter depression and night work, it shows that lighting has profound effects on everyday functioning.

Researchers suspect that lighting also affects our moods, motivation, and social interactions as well as our feelings of satisfaction and well-being at work. Although there is less data to support these hypotheses, it is an active area of research. The attributes and features of light which appear to influence psychological functioning include: the presence of daylight, overall room brightness, brightness on vertical surfaces in the field of view, and some degree of variability in the lighting (visual interest) as long as it doesn't produce shadows or a feeling of gloominess.

Research has focused on three primary topics: (1) lighting preferences and aesthetic impressions, (2) behavioral and emotional outcomes associated with different lighting conditions; and (3) health and well-being outcomes associated with light.

[16] See, for instance, Czeiler, C. A. et al, 1990. "Exposure to Bright Light and Darkness to Treat Physiologic Maladaptation to Night Work," *New England Journal of Medicine*, 322(18):1253-1259. Also, N.R. Rosenthal and M.C. Blehar (Eds.) 1989, *Seasonal Affective Disorders and Phototherapy*. New York: Guilford Press.

*Lighting Preferences and Aesthetic Judgements*

Personal preferences and aesthetic judgements are important to workers' overall satisfaction with the lighting environment. Although satisfaction levels may not directly affect worker performance, a dissatisfied workforce can lead to more complaints, lowered morale, and increased use of personal lighting or other adaptive behaviors.

Key findings from research on this topic show that:

- Although most effort is given to lighting for specific tasks, people's judgements of lighting are determined primarily by the perceived brightness of the overall space – including the vertical enclosing surfaces as well as the horizontal work surface. High overall room brightness, particularly the perceived brightness of vertical surfaces, is associated with high levels of worker satisfaction and high ratings of environmental quality.[17]
- Nonuniform lighting with lighting highlights on the walls (such as through wall sconces) is highly preferred.[18]
- People's preferences for lighting are also highly personalized and may be related to seasonal depression. People who show seasonal variation in moods and well-being adjust the lights to create a very bright visual environment, while others choose more dimly lighted conditions.[19]
- Even when illumination levels are within recommended ranges, workers frequently rate their workspaces as "too dim". This appears to be due to the many other factors that influenced perceived brightness, such as the brightness of the vertical surfaces, including cubicle panels.[20]
- Large differences in light levels for primary and secondary task area are associated with high levels of work dissatisfaction.[21]

*Effects on Mood, Motivation, and Behavior*

Although there is relatively little research on the psychological and behavioral impacts of light, several studies are relevant to work settings.

- Variations in the color and amount of light in a space influence people's moods; the more positively toned the mood, the more likely people are to show positive judgements of others and to engage in helping behaviors.[22]
- Lighting also affects social judgements. A study found that lighting influences whether or not a person is judged innocent or guilty by a jury; the authors conclude that lighting influences the facial features and visual appearance of the person being judged.[23]
- The distribution of light in a setting also influences movement and seating preferences. For instance, a study found that people prefer to sit where they can look at a brightly lighted space rather than to sit in the bright light themselves.[24] Studies in public settings have also found that people tend to move toward more brightly lighted spaces, perhaps because it is associated with perceived safety and visual access.[25]

[17] Collins, B. 1993. Evaluation of Subjective Response to Lighting Distributions: A Literature Review. Washington, DC: National Institute of Standards and Technology, Report No. NISTR 5119.

[18] NEMA and LRI Review, op cit.

[19] Heerwagen, J. and Heerwagen, D. 1986. Op cit.

[20] Heerwagen, J., Loveland, J., and Diamond, R. 1992. Post Occupancy Evaluation of Energy Edge Buildings. Center for Planning and Design, University of Washington, College of Architecture and Urban Planning. Also see Collins, B. 1993. Evaluation of Subjective Response to Lighting Distributions: A Literature Review, NISTIR 5119.

[21] Collins, B., Fisher, W.S., Gillette, G. and Marans, R. 1989. Evaluating Office Lighting Environments: Second Level Analysis, Washington, DC: National Institute of Building Standards, NISTIR 89-4069.

[22] Baron, B., Rea, M, and Daniels,S. 1992. "Effects of Indoor Lighting (Illuminance and Spectral Distribution) on the Performance of Cognitive Tasks and Interpersonal Behaviors: The Potential Mediating Role of Positive Affect." *Motivation and Emotion*, 16(1): 1-33.

[23] Aspenall, P.A. and Dewy, J. 1980. "Lighting and Perceived Guilt." *Lighting Research and Technology*, 12:140.

[24] Flynn, J. et al, 1973. Interim Study of Procedures for Integrating the Effects of Light on Impressions and Behavior. *Journal of the Illuminating Engineering Society*, 3:83.

[25] Taylor, L.H. and Sucovm E.W., 1974. "The Movement of People Towards Lighting," Journal of the Illuminating Engineering Society, 3:237.

*Effects on Health and Well-Being*
The study of the health impacts of lighting has grown rapidly in the past decade with the discovery of Seasonal Affective Disorder and light-mediated changes in biorhythm functioning. Much of the research has focused on the application of supplemental, bright light in shift work. In a recent study of night workers, improvements in cognitive functioning, alertness, and sleep quality were associated with the introduction of a biologically relevant supplemental lighting system that varied the light over time to make it more consistent with natural daylight patterns.[26]

## *How Important is Daylight in the Work Environment?*

Numerous studies have found that people prefer daylight to electric light and that they believe it is better for health and well-being.[27] Of special value to indoor workers is the presence of sunlight "patches" and the change in light quality over the day.[28] Psychologists suggest that daylight may be especially powerful for two reasons. First, daylight influences our biorhythms and emotional functioning. Second, daylight is a source of information about the environment, especially time and weather, two conditions we care deeply about. Although we don't need a window to tell the time of day or to provide us with local weather conditions, we still seem to prefer this "natural" form of information.

Daylighting design is an important component of energy efficiency. In one recent study of a new "green" building in Michigan, the workers gave very high marks to the extensive daylight and views in their new building.[29] The daylight was associated with higher levels of work satisfaction and with a positive attitude toward the work environment. Similar results were found in another study of energy-efficient buildings. Occupants with access to windows and daylight rated the lighting quality more positively than those whose workstations lacked windows.[30]

Daylight does not automatically lead to high satisfaction levels, however. An extensive study of new energy-efficient buildings in the Pacific Northwest found that workers' satisfaction depended on how well the design dealt with glare and heat gain from windows. In buildings with poorly designed daylighting, occupants take matters into their own hands. They disable the lighting control systems, add their own task light, or remove lamps from ceiling fixtures to increase their comfort levels.[31]

## *Personal Control: How Important Is It?*

To answer this question, we need to first ask what it is that people want to accomplish when they adjust their lighting. That is, what do they want to control? Two factors appear to be important. The first is the changing nature of visual tasks. Workers may want to adjust their lighting as their tasks change. A second important factor is the strong individual variation in preferred lighting levels. As noted in the section on psychological aspects of light, people tend to show strong lighting "styles." Some like it bright, and others like it dim. When people are able to adjust lighting to meet personal preferences, they clearly do so. In fact, there is a strong tendency for people to set the lighting (including window shade adjustments) the way they like it and then to leave it that way for the rest of the day.

Research and anecdotal accounts also show that if the designed environment does not

[26] Baker, T.L., 1995. "Use of a Circadian Lighting System to Improve Night Shift Alertness and Performance at the USNRC's Headquarters Operations Center," Proceedings of a conference on Safety of Operating Reactors, Seattle, WA: Sept. 17-20.
[27] Heerwagen, J. and Heerwagen, D. 1986. "Lighting and Psychological Comfort." *Lighting Design + Application*, 16(4): 47-51.
[28] Boubekri, M., Mulliv, R.B., and Boyer, L.L. 1991. "Impact of window size and sunlight penetration on office workers' mood and satisfaction." *Environment and Behavior,* 23(4): 474-493.
[29] Heerwagen et al, 1996. Op cit.
[30] Heerwagen et al, 1992. Op cit.
[31] Heerwagen et al, 1992. Op cit.

enable workers to adjust their lighting, they frequently take matters into their own hands. A walk through most office environments will clearly show this. Many workers have added task lamps and ambient lamps (especially common are free standing torchieres). They also delamp their overhead fixtures, deactivate lighting sensors, and add screens and filters around their computers – all of which improve conditions from the workers' perspective.[32] However, there are likely to be energy and systems efficiency costs in these occupant adjustments that could be avoided with more careful attention to individual preferences and task needs.

### *Putting it All Together: Why Should Organizations Invest in Energy-effective Lighting?*

The table below provides a summary of the potential effects of lighting on performance and well-being. It is meant as a heuristic aid rather than a definitive summary of the research presented in this report. As can be seen, it is useful to think of both the negative and positive ways lighting can influence performance and well-being.

In the past, emphasis has been placed on eliminating problems associated with light. However, if lighting quality is the goal, then equal emphasis should be placed on creating positive effects. We cannot assume that this will happen merely by ridding the environment of problems. In fact there is evidence that the problem-focused approach tends to lead to a neutralization of the environment, rather than an enhancement.[33]

Organizations care a great deal about the quality of goods and services they deliver to their clients. They also care about keeping their workers healthy and motivated. The research findings presented in this brief summary show that lighting can affect not only the accuracy and efficiency with which work is done, but also the health and satisfaction of the workforce. Eye problems and headaches associated with inappropriate lighting can clearly interfere with task performance, and may also lead to lowered motivation and desire to work. If quality lighting can improve performance, even modestly, by reducing problems or enhancing workers' satisfaction and motivation, the investment in quality light will pay off.

Since worker salaries far outweigh the combined costs of office rent, electricity, total energy and maintenance, an investment in high quality lighting that increases performance by even a small percent will pay for itself in the long term. Light affects every aspect of work in modern office environments. Investments in quality lighting can improve productivity by helping people work more efficiently and safely, and by reducing errors or accidents that may occur as a result of poor lighting. High quality lighting investments can also create a more pleasant and motivating environment that signals to workers that they are valued and worth investing in.

[32] Heerwagen et al, 1992. Op.cit.
[33] Crouch, A. and Nimran, U. 1989. "Perceived facilitators and inhibitors of work performance in an office environment." *Environment and Behavior*, 21(2): 206-226.

**Table 1: Potential Effects of Lighting on Work Performance and Well-Being**

| | High Quality Lighting | Low Quality Lighting |
|---|---|---|
| **Performance-related Impacts** | •Light is well-distributed across multiple work surfaces, making it easy to perform tasks in different areas.<br>•Light can be adjusted for different tasks as needed.<br>•Light levels and color rendering are appropriate for the task.<br>•Lighting design is based on a thorough task and context. analysis. | •Poor color of light leads to misreading of color-coded materials.<br>•Glare on computer screen reduces visibility.<br>•Light that is too dim makes it difficult to read small print.<br>•Poor lighting in hazardous areas increases chances of accidents.<br>•Lighting design does not take into consideration the nature of the task, the physical setting, or the workers in the specific setting. |
| **Psychological Impacts** | •Light can be adjusted to meet personal preferences.<br>•Lighting is aesthetically pleasing and makes the environment look and feel pleasant.<br>•Lighting creates visual interest.<br>•Light creates a sense of place.<br>•Light aids in movement and way-finding.<br>•Daylight and window views are available. | •Light cannot be adjusted or controlled by individuals to meet their personal preferences.<br>•Lighting is visually dull and uninteresting.<br>•Lack of light on signs or other important visuals leads to inability to locate people/ places, which in turn creates a stressful experience.<br>•Light distorts facial features and appearance of others, reducing interpersonal communication and increasing the potential for misunderstanding and negative social judgments. |

# Appendix E

## Energy Effective Lighting for Open Plan Offices

Energy Effective Lighting provides efficient lighting while meeting the needs of the space occupants. Effective lighting varies with each type of application. Research has shown that lighting has a significant impact on worker productivity (see Appendix D). Because the cost of labor dramatically exceeds that of energy, quality relighting can benefit both the environment and the economy.

### Office Tasks

Common tasks in the office environment include computer work, writing and reading paper tasks, and meetings. In open offices, Visual Display Terminals (VDT) are more likely to show the glare of reflections from light fixtures and daylight.

### Recommendations

***Luminaires and Layout.*** The layout of the luminaires should provide wall brightness at the top of the walls and uniformity at the work plane. The design should avoid glare (directed and reflected) and reduce contrast.

- If the core wall is a permanent corridor, consider a linear fluorescent or compact fluorescent wall-washing system to brighten your wall, and begin your troffer layout further into the room where the workspace begins.
- Generally, parabolic louvers are preferred over lenses in open plan offices with computers. If lensed troffers are used, orient VDT screens away from glare sources, and/or use low-glare screens.
- Light the walls in-between windows with sconces or wall washing.
- Glare is a source of discomfort and eye fatigue. Shield sources or reduce contrast between light sources and surrounding surfaces. Avoid glare by using semi-specular or matte surfaces for lighting fixtures and room surfaces. Avoid shiny or specular surfaces at any viewing angle.
- Most manufacturers publish Spacing Criteria, but they are meant to be used without partitions. If partitions are used (as is typical), the mounting height assumed for the calculation should be modified to account for the partitions. The working plane should be assumed to be halfway between desktop and partition height, thereby reducing the assumed mounting height. The effect of this will be to use more fixtures with fewer lamps. Often, 1- or 2- lamp 1x4s, or 2x2s, will be a more energy-effective solution than 3 or 4-lamp 2x4s.
- Meet the recommended Horizontal Illuminance requirements listed in the Illuminating Engineering Society of North America (IESNA) Handbook.

***Lamps.*** The widespread dislike of fluorescent lamps is very often a reaction to poor lamp color. Currently available lamps can overcome resistance to fluorescent sources. Certain lamps are uncomfortably bright for office workers and should not be used in luminaires where the lamp is visible at any viewing angle.

- Use T-8 lamps in luminaires with open-celled parabolic louvers. Low- wattage (32 and less) compact fluorescent T-5 (twin tube/biaxial) lamps are appropriate for downlights, wallwashing and sconces. Long T-5s are acceptable in lensed troffers, wallwashing or uplight applications.
- Use lamps with a color-rendering index (CRI) of 70 or more. If a warmer feeling in the room is preferred, use lamps with a color temperature of 3000°K or 3500°K.

***Ballasts.*** Another very common complaint about fluorescent systems is due to ballast flicker and hum. Research shows a decrease

in headaches and improved visual performance with the use of electronic ballasts. Electronic ballasts should always be used, except when a technical incompatibility exists (e.g., where there is sensitive electronic equipment).

***Environmental Considerations***.

- Keep reflectances of surfaces visible at eye-level and above and as light colored as possible, preferably 65%-75% reflectance walls and 80%-95% ceilings. Because dark surfaces absorb light, they significant reduce the energy efficiency of the space and create unpleasantly high contrasts.
- Orient computers away from windows to avoid reflections in VDT screens.
- Consider the use of luminous sconces to create visual interest in the space. Avoid harsh patterns, scallops, and shadows, especially at the top of walls.

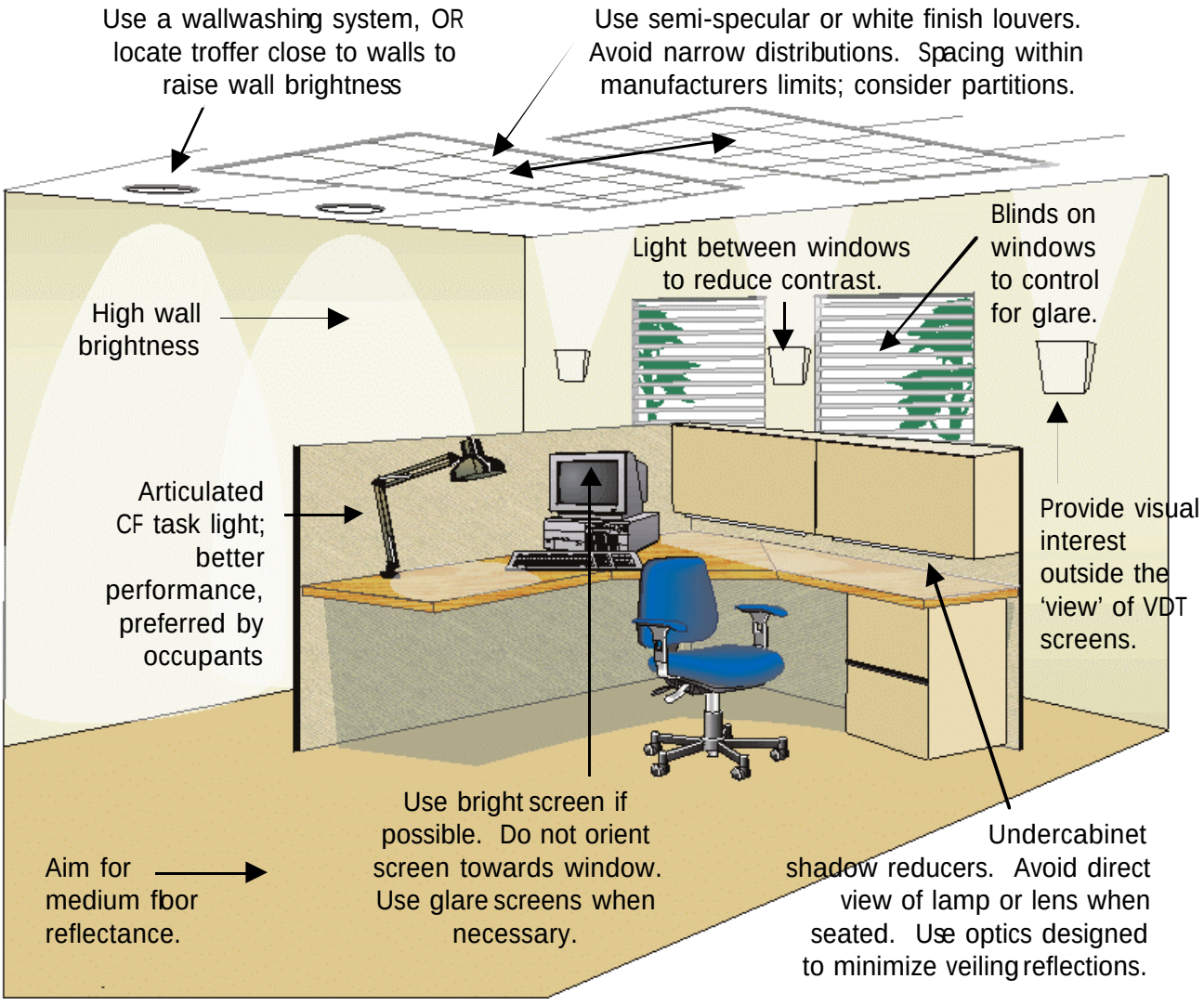



*Figure 1. Graphic showing Lighting Quality Recommendations for Open Plan Spaces. The contribution of the IESNA Quality of the Visual Environment Committee is gratefully acknowledged.*