

better lighting and  
daylighting solutions

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Improving Visual Quality in  
Office Environments

A Professional Paper from  
American Society of Interior Designers  
Orfield Laboratories, Inc.  
Haworth, Inc.  
Lutron Electronics  
Vista Window Film

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Washington, D.C. 20002-6006  
[www.asid.org](http://www.asid.org)

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Printed in the United State of America.

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Designed by Full Circle Marketing and Design.

## Foreword



We, as designers, are always looking for ways to improve the quality of interior environments for occupants. We also need to meet the demands of our clients and often other stakeholders as well. Office designers and facilities management professionals know that these objectives may sometimes clash. As the authors of this paper point out, lighting is one of those areas where competing interests often win out over what is best for the occupant.

In his seminal book on the industrial designer, published in 1955, Henry Dreyfuss states,

*In our civilization... the light we mostly see is broken, bent, interrupted diffused. Unless an adjustment is made, it can cause nervousness, eye fatigue, or illness. Corrected light can stimulate, give confidence, or induce concentration.*

Regrettably, 50 years later we are still making the argument that lighting's primary purpose is to benefit the occupant and make him or her healthier, happier and more productive. Granted, today's office environment is much more complex in regards to light and lighting than it was in Dreyfuss' day. We have to accommodate computer monitors, LCD projectors, flat panel digital screens, PDAs and other technological innovations, as well as a more demanding, multitasking workforce. On the other hand, we have better research, better technology and better tools to help us design environments that properly address these various conditions.

This paper is a companion to *Better Sound Solutions*, which ASID published in 2004 in an effort to provide designers with an orientation to current processes and methods for planning, designing and evaluating occupant-centered environments in regards to office acoustics. This new paper takes a similar approach, and uses a similar format, to address issues related to office lighting and daylighting. Together, these two reports make a strong case for the argument that we design best when we design with the occupant foremost in mind.

On behalf of ASID, I especially want to thank the authors, Steven J. Orfield of Orfield Laboratories, Inc.; Jay L. Brand, Ph.D., of Haworth, Inc., Industry Partner of ASID; and Pekka Hakkarainen, Ph.D., of Lutron Electronics, Industry Partner of ASID. They have once again produced an informative and thought-provoking document. I also want to thank the management at Haworth for their support of this project. Finally, special thanks to our sponsor, Vista Window Film, Industry Partner of ASID, for their generous support of this project and of ASID.

A handwritten signature in black ink that reads "Robert Wright, FASID".

Robert Wright, FASID

President

American Society of Interior Designers

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## Preface



Having been involved with the landscaped and open office for 34 years, I am quite familiar with the relevant physical lighting and daylighting issues. Eight years ago, Orfield Laboratories founded the Open Plan Working Group (a building performance and occupancy research collaboration) to develop an international research and design focus on building performance and occupancy research. The work within this group and with these colleagues has helped to expand our thinking about the perceptual dimensions of the open plan office.

For the past 20 years, the energy movement has been a dominant issue in lighting practice. Federal funding of energy research in lighting has, in a way, co-opted lighting quality by holding it hostage to “efficiency,” thereby changing the focus of lighting design and, inadvertently perhaps, reducing the quality of both luminaires (fixtures) and lighting system design. In the built environment, we have been laboring under the impression that if we employ the most highly-rated, energy-efficient lighting and daylighting products, we have achieved a sufficient lighting solution. From an occupancy standpoint, however, energy is only a secondary issue. The primary issues are visual task performance and the visual quality of the environment. These are compatible with energy efficiency but must be the first priority.

Lighting is determined by a wide range of practitioners, not all of them lighting professionals, especially in the context of office buildings. Some understand vision and visual performance, some understand user preference, some view lighting as a “design factor,” and some focus on standards and energy efficiency. As a result, there are at least four levels of practice with regard to lighting, and there is clearly no single intent. And if we have no common question, we can have no common answer. This paper is intended to begin a dialogue on these issues, to supplement and bridge the understanding between the designer and the lighting professional, who often share similar concepts and approaches to lighting.

**We now face a series of important questions regarding lighting and daylighting that research can resolve in the next few years:**

- What determines user preference for lighting and daylighting?
- What are the reasonable benchmarks for visual performance in these fields?
- What are some reasonable approaches to lighting with regard to visual quality?
- What are the reasonable expectations for energy approaches in these fields?
- If design has clear value (i.e., it helps occupants to function better in ways that benefit them and their employers), which of these issues, in the final analysis, has the most “currency” in the design equation?

Good occupancy research can answer the first and last questions. Good lighting and visual research have begun to answer the second question. The third question is a function of all the other questions and of the global design approach. The fourth question can be addressed with energy-based lighting research, which must have quality as its baseline. The fifth question is the summary question in lighting design. People comprise at least 85 percent of the operational cost of an office. Lighting and daylighting have clear and strong effects upon occupants. Once we demonstrate lighting and daylighting benefits, will we have the courage to rearrange our priorities in these fields and make the decision that occupants, rather than buildings (and energy efficiency), should be our profit and benefit centers?

A word here on the sustainability movement as it involves issues related to the energy questions in lighting. While sustainability is an important movement, we at Orfield Labs have argued for some time that its importance in building design is only established when we are talking about solutions that encourage human as well as environmental sustainability. Occupancy quality has a far greater impact on a building's occupants than does sustainability. Sustainability issues, including lighting and daylighting, can be applied in ways that are negative, neutral or positive for the occupant, and this needs to be understood. It is also clear that a building can be designed to meet all the sustainability guidelines of one of the many sustainability programs and still be a bad building for the occupant. Sustainability, energy efficiency and all other secondary movements should serve the primary movement in office design, and that is and has always been the movement toward occupant quality.

The authors would like to thank Tom Smith, Ph.D., Mike Role and Sherry Role of Orfield Labs for their assistance and reviews of this publication. We would like to thank Mike Role for his many helpful illustrations. We would like to thank two lighting professionals, Professor Michael Kroelinger, Ph.D., AIA, FIIDA, LC, of the University of Nevada, and Katherine Abernathy, IALD, of Abernathy Lighting Design, for their focused comments and suggestions. Finally, we also would like to thank Michael Berens, director of communications and knowledge resources for ASID, for his willingness to support new directions and for his much directed critique and suggestions.

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## Overview

This paper addresses visual environmental issues in building environments, with a primary focus on office environments. In this regard, the lighting community has developed a relatively clear understanding of physical lighting issues (for example, how light travels in open offices) many years ago. However, subsequent to the initial applications of this knowledge, perspectives on interior design have changed dramatically. It now seems obvious that lighting can and should be addressed in a broader design context that considers not only the physical attributes of light, but also how lighting and daylighting quality in work environments influence occupant perceptions of their work in relation to other interior design factors.

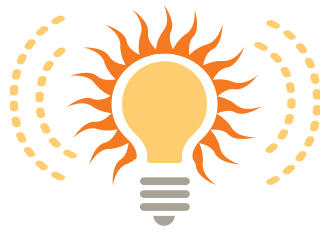
The introduction to the *American National Standard Practice for Office Lighting* (RP-1-04) issued by the American National Standards Institute and the Illuminating Engineering Society of North America includes a broad philosophical statement with regard to office lighting:

*Offices are designed to house working people engaged in thought and in multiple forms of communications — written, visual, aural, electronics and face-to-face. Office lighting should enable these workers to perform such tasks comfortably and effectively in an environment where they will spend one-third of their lives. It is essential that office lighting be included as a vital consideration towards the successful operation of any business. (Page 1)*

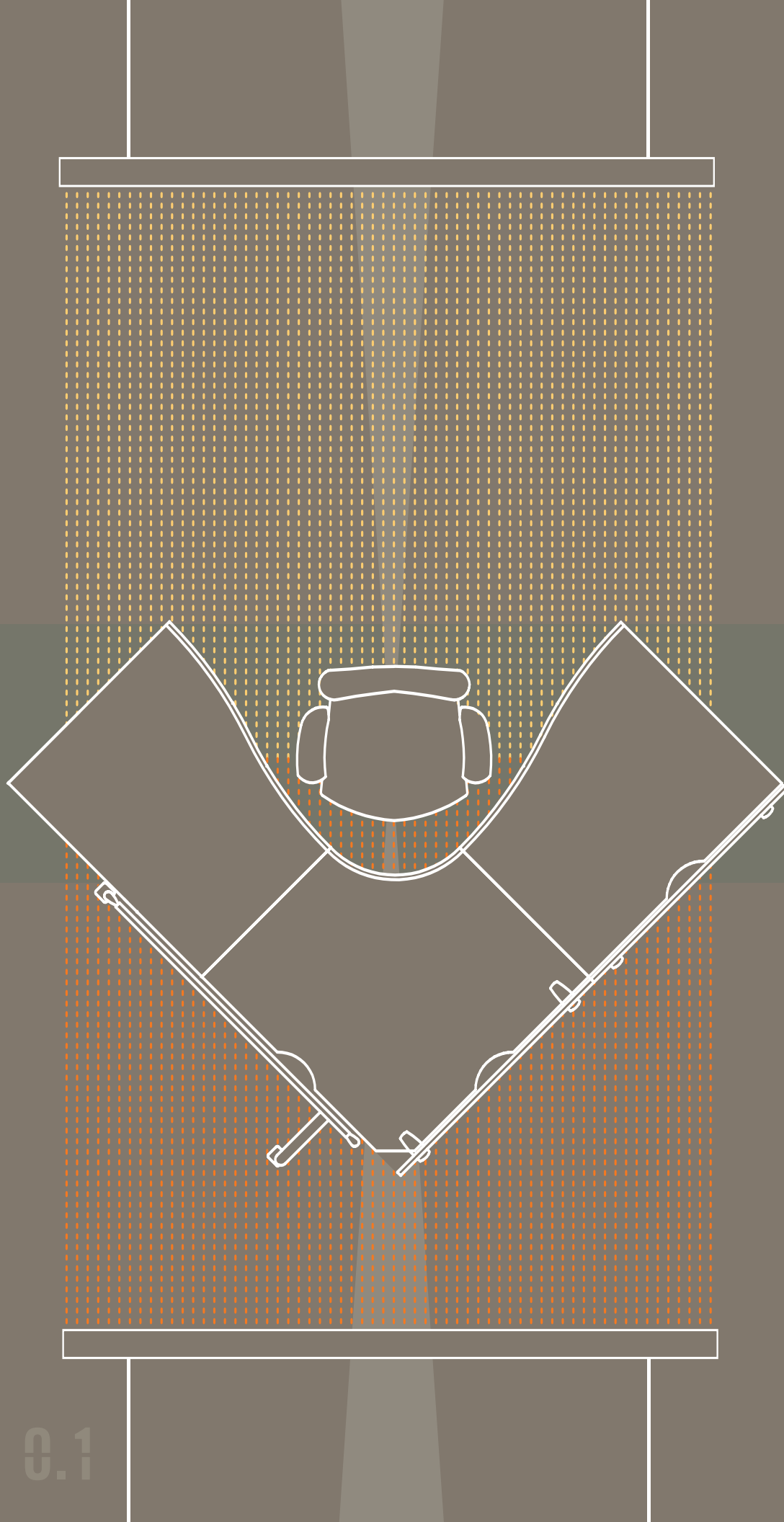
This paper, therefore, takes an occupancy-systems approach to the analysis of office lighting issues. This conceptual model assumes an interaction among *exposure* to light (quantified by physical lighting measures), *perception* of lighting quality (which influences employees' attitudes, motivation, morale, satisfaction and emotional state regarding their work — and thereby their functional capacity for work performance), and *work performance outcomes* (such as productivity or standard human resource metrics).

The rationale for the multi-dimensional approach to office lighting analysis adopted in this paper rests on the premise that lighting design embraces all of the systems components specified in the previous paragraph and that lighting design analysis therefore must consider system interactions among all of these components in order to arrive at an understanding of the nature and determinants of lighting design quality. This perspective assumes a multidisciplinary framework for understanding office lighting that encompasses not only lighting physics and engineering but also interior design, building performance analysis and standards, perceptual psychology, occupancy research, facilities management, organizational behavior, and human factors and ergonomics.

This paper consists of six sections. The first three present a general introduction to office lighting and daylighting issues, namely, the general design context of the office (Part 1), the visual experience of light (Part 2) and conceptual issues in office lighting and daylighting (Part 3). Part 4 examines more specifically the technical practice of lighting and daylighting. Part 5 lists some common problems in office lighting and daylighting. Part 6 proposes future research directions for office lighting and daylighting.



## PART I



## PART I The General Design Context of the Office

### Introduction

Since its inception in the 1970s, the open plan office has engendered much discussion, many publications and many studies with regard to lighting and performance. Much of this discussion has focused on visibility and the need for visual comfort in the open office and on “visual performance,” generally in terms of the ability to see a task clearly without visual strain. The problem in both cases is a physical one, although visibility and visual preference relate more to occupants’ perceptions and may be influenced by many other variables. For this reason, this paper, although focusing on lighting, will also discuss other modalities.

In the 1970s, some lighting designers understood how the open plan office functioned visually, and early open plan or “landscaped office” projects generally included a daylighting and a lighting consultant on the design team. Since that time, through the 80s, 90s and early 2000s, an interesting trend has emerged in office planning. As space density has steadily increased, reducing the amount of lighting and daylighting available, the claims for the need for a high-quality visual environment have become more and more pronounced. We used to have open offices in which the occupants faced toward the opening of their workstations. Now, with the current 6' x 6' workstations, the occupant faces into a corner, and the lighting level has been reduced from the 50 percent of the ambient illumination that the old workstation allowed to about 25 percent that the newer, corner-oriented cubicles allow (see, for example, Figures 23 and 24 on pp. 46). As a result, the daylighting has often mostly disappeared from the typical workstation. Where surface reflectance was an issue before in terms of net luminance and visual comfort, it has now become a dominant issue unto itself. Especially in call centers, an interesting subset of the open office, the work areas are generally significantly even smaller than those of a typical open plan office, thus presenting the attendant lighting and visual problems of highly dense spaces.

We are faced, then, with a set of fundamental questions that are essentially unanswered as yet:

- How do we make the case to have visual comfort and visual performance get more attention in today’s lighting and daylighting solutions?
- How do we address the fact that in most office spaces poorly designed or inadequate daylighting, high density and finish reflectance diminish the quality of the visual environment?
- If occupants seem to prefer nonuniform (task-oriented) ambient lighting and task lighting systems, how do we design to give them that?
- What other visual stimuli influence the perception of lighting and daylighting?
- What other preferences are driven by visual comfort and visual performance?
- How do we ensure sufficient energy recovery without sacrificing lighting or visual environment quality for occupants?

For some time lighting quality has taken a back seat to energy consumption as the primary concern of lighting designers. Since no one has yet established the economic argument for visual quality, the simpler economic argument based on conservation and fixed costs has prevailed.

It is interesting to note that while energy plays the central role in many lighting projects, IESNA has placed it far down on its list of office lighting issues. Good lighting can clearly be designed to perform at well controlled energy consumption levels, but lighting design based principally on illumination levels and energy consumption typically does not produce high quality lighting. *The American National Standard Practice for Office Lighting* also makes the economic case for high-quality lighting, stating that

*Even when quality lighting is initially designed, it may fall victim to the “budget crunch” where lower quality luminaires are substituted and/or lighting layout is changed without fully considering the implications for the application at hand. The cumulative effect of an attempt to save money may well be to raise operating costs through diminished productivity in the office environment. (Page 1)*



We thus find ourselves in a quandary: We believe we need good lighting, we don't get it, yet we seem to manage just the same. How do we resolve this impasse: Accept a significantly lower value of visual performance in the name of sustainability and cost control, or prove that such performance is, in fact, important and cost effective?

The remainder of this section considers various strategies that may be deployed for resolving this question. The next section places the lighting design environment in the broader context of environmental perception. The two subsequent sections deal, respectively, with the role of building performance analysis in delineating physical design conditions in the office environment and the role of occupancy research in documenting perceptual effects of exposure to these conditions among occupants of such environments. Methodological tools for occupancy research are outlined in the next section, followed by a consideration of the implications of lighting design for occupant productivity as an outcome measure.

As the reader moves through this paper, it is important to note that much of this information is well known to the lighting professional, but it is far less well known by many lighting practitioners, especially those who are not familiar with the science of lighting and the science of vision.

## Environmental Perception

Lighting does not stand alone as a variable in the open plan office; it forms part of a broader stimulus context. An office occupant lives and works in a multimodal environment. That environment may be rich in stimuli or very limited in stimuli. The stimulus content may be in flux, and thus highly noticeable, or static, and thus perceptually neutral.

The typical office environment goes from highly stimulating to less stimulating as one moves from the public, "corporate" spaces to the departmental level and on to the individual workstation level. In large corporate buildings, for example, one walks through high levels of visual, acoustical, thermal, olfactory and tactile stimuli. These environments generally feature highly complex stimuli that can be difficult to process, potentially prompting disorientation on many levels. At the departmental level, one encounters a moderately complex environment, where typically visual and acoustical complexity are significantly reduced by comparison, and thermal and olfactory stimuli are moderately reduced. Within the individual workstation or "cubicle," the environment becomes even less complex.

As one sits in a typical workstation configuration, facing an office panel and looking at a corner-mounted computer screen, the most radical perceptual change occurs. Visual stimulation — including views, daylighting and exposure to activity and complexity — reduces dramatically, and distant views generally are not available. Thermal perception is much reduced, as the workstation significantly affects airflow and other thermal comfort criteria. Olfactory and tactile stimuli are also usually much reduced. The occupant may habituate to this perceptually limited environment and move toward perceptual stasis.

## Building Performance Background

Because most visual, air movement, tactile and olfactory stimuli have been eliminated, the occupant of a typical workstation may respond in a very sensitive way to the only still-intrusive stimuli, speech and noise. To a lesser degree, the occupant begins to feel the extreme visual compression of the new environment and may notice the absence of visual stimulation. Thus, “visual privacy” can result in visual deprivation.

Perceptual research shows that reducing the input to one sense often increases the sensitivity of the remaining senses. Yet, we often fail to recognize that this may be precisely the reason occupants have so many complaints about the open plan office. Moreover, since sound is such a prominent stimulus in the typical cubicle arrangement, this increased sensitivity to isolated stimuli may explain why lighting quality and the visual environment, which are far more difficult for the occupant to assess and verbalize, rank much lower on employees’ complaints about their work environment than do noise and speech privacy.

We have long been on the march to improve the performance of the office environment, and the science of improving this performance has come to be known as *building performance*. The study of building performance generally includes evaluation of the quality of daylighting, lighting, acoustics (including vibration) and thermal comfort. More recently, we have begun to evaluate the office environment in terms of levels of scale. From this view, the larger scale of open plan offices corresponds to a macro-ergonomic environment, while the smaller scaled workstation environment is often referred to as a micro-ergonomic environment. Since the inception of building performance in architectural planning, human factors and ergonomics evaluations have increasingly informed the micro-level issues to insure that building performance relates to the personal environment.

Building performance science will add benefit to the open office project via the evaluation of pre-occupancy performance, determination of deficits in this performance, comparison to “state-of-the-art” performance, and specification of a set of building performance standards that can be used in the design process, verified by engineering and simulation, and confirmed in the commissioning of the project. Employing this process adds performance responsibility to the other responsibilities of the design team and assures the client that there are clear expectations and minimum performance levels. This helps the design team to understand which of their decisions influence building performance and which do not.



Currently, building performance competes for attention with space utilization and energy use, as well as with the construction and operating costs of the office facility. Because clients are focused on building costs, the design and facilities communities have put forth much effort with regard to the cost side of constructing and operating offices. However, in the overall lifecycle of a building, facilities costs represent from only five to eight percent of the total cost of operating an office; the other 92 to 95 percent is comprised of the costs of people, along with IT/IS. While we know much about how to control the facility cost structure through design, we know very little about influencing the cost of people — whether those costs are human resource costs (hiring, retention, absenteeism, illness) or direct or indirect productivity costs.

Thus, instead of the conventional programming narrative, exact standards can be applied consistently to any project of this type. This has clear benefit for the design firm, which can pass these standards along to the engineering and consulting team, who also will have to comply with them. There will be less need for discussion about building system quality because a quantitative set of standards has been developed to describe exactly what is wanted.

It is now possible to easily put in place a building performance standards program that can help to ensure building performance and satisfaction. One example of a standards program that is available nationally is the OPWG Certified Building Performance Standards program. This provides a building performance paper, updated annually, that includes performance information, standards and acceptance testing (see Figure 1).

The client can include this type of building performance standards manual with the RFP or as part of the contracting process when retaining a design or development team. This will ensure that the project team knows what the client requires, understands what the specific performance standards are, and knows how their success will be measured after the project is completed.

**Introduction****Building Performance Background****Occupancy Research****Acoustics — Recommended Practices**

Room Acoustics  
 Speech Privacy  
 Workstation Design and Occupant Placement  
 Office Equipment  
 Electronic Sound Masking System  
 HVAC Acoustics  
 Environmental Acoustics  
 Acoustic Standards  
 Acoustical Test Methods

**Lighting — Recommended Practices**

Ambient and Accent Lighting  
 Lighting Type Selection  
 Lighting Performance  
 Glare and Aging  
 Luminaire Selection  
 Lamp Selection  
 Dimming Capability  
 Controls  
 Surfaces  
 Reflectance and Specularity  
 Task Lighting  
 Lighting Standards  
 Lighting Test Methods

**Daylighting — Recommended Practices**

Daylighting Type Selection  
 Daylight Benefits and Savings  
 Daylighting Control  
 Work Area Integration  
 Daylighting Standards  
 Daylighting Test Methods

**Thermal Comfort — Recommended Practices**

Variables  
 General Thermal Comfort  
 Local Thermal Comfort  
 Thermal Comfort Standards  
 Thermal Comfort Test Methods

At the end of the project, these measures can be employed as part of a commissioning post-occupancy study to determine

- What performance is in compliance
- What performance needs to be resolved
- What the correlation is between occupant complaints and specific performance

The building performance can then be resolved with no disagreement between the owner and the design team.<sup>1</sup>

<sup>1</sup> *Orfield Labs has written and administered building performance standards for about two decades. One notable example was the first program in use by the State of Minnesota for the renovation of the Minnesota Department of Transportation Central Office Building in St. Paul. This program, which was submitted to and approved by the state legislature, included pre- and post-occupancy studies, both with building performance measurements and standards. The post-occupancy studies of this building found the initial performance of both the HVAC and the masking systems not in compliance. They were then extensively readjusted until these systems fully complied with the standards — at no cost to the State of Minnesota. Without this program, both of these systems would have had significantly sub-par long-term performance.*

Figure 1 — OPWG Certified Building Performance Standards/Contents

## Occupancy Research



The most recent addition to the equation of office design is the application of occupancy research to the design process. Occupancy research is, in general, the testing of office occupants and of offices to determine

- How the occupant ranks his or her quality of work
- How the occupant is affected by the principle variables<sup>2</sup> that influence and are influenced by the office design, such as
  - Perceived organizational quality
  - Perceived work task quality
  - Perceived compensation quality
  - Perceived environmental quality
  - Perceived workstation quality
- How the occupant responds due to his or her perceptions of facilities quality
- How the occupant's perceptions of office quality relate to measures of prevailing environmental conditions

From a small but growing body of research, it seems clear that the occupant responds to the environment in measurable ways, and these responses influence the occupant's perception of the quality of other work-related benchmarks.

Based on pre- and post-occupancy comparison of specific facilities, it has been demonstrated that increasing the occupant's ratings of the environment and the workstation can increase his or her ratings of the organization, the work task and compensation. Decreasing the quality of the environment can cause concomitant reductions in ratings of these variables. Early research also suggests that responses to negative changes in the environment can be partially measured by negative changes in relevant human resource measures, including ease of hiring, worker retention, absenteeism, tardiness, etc.

In repetitive task environments and in those "knowledge worker" environments where group performance metrics have been established, it also seems clear that productivity can be affected by environmental quality. From an occupancy standpoint, environmental quality must be defined as the personal,

subjective experience of the people occupying that environment. For example, a recent study of lighting found that reducing the discrepancy between objective lighting conditions and subjective lighting preferences improved occupants' mood and satisfaction (Newsham and Veitch, 2001).

Thus, we have an approach for resolving questions of lighting performance via the use of occupancy research to determine

- How occupants currently rate their environment and other job quality issues
- How these ratings are affected by changes in the visual environment and lighting performance of the office
- How these ratings relate to human resource values within a given organization

### Occupancy Research / Case Study

Recently, a client of Orfield Laboratories began a project for the consolidation of staff from a number of different sites into a renovated building at the company's headquarters. The client has been very interested in the concept of occupancy research to determine if it can provide better baseline information in the design of new projects. The company's director of facilities decided the company would use this project as a test case for the utility of occupancy studies.

The building in question was an old, saw-toothed-roofed brick warehouse that was being converted into an open plan office. Prior to the commencement of design, a pre-occupancy study (an OPWG Certified Building Performance Measurement study) was undertaken to determine the current perceptions of the occupants within the following five categories of information:

- Organizational quality
- Work task quality
- Compensation quality
- General environment quality
- Workstation quality

<sup>2</sup> From *OPWG Certified Building Performance Measurement program*

The project then commenced, with design tasks occupying the next few months. After move-in, a post-occupancy study was completed to commission the project and to measure early results of the process. Graphs of some of the findings are shown on this and the following two pages.

In the pre-occupancy study, employees gave higher quality ratings to the first three variables above than to the latter two variables. This confirmed that the employees were more satisfied with regard to their organization, job and compensation, but were less satisfied with their work environment and workstation. The ratings for the first three values were as high as very satisfactory post-occupancy values for most companies. This raised the inevitable question of whether such a highly rated company could actually increase its value to its employees by improving facilities design and performance.

The post-occupancy study confirmed the value of facilities design, even in highly rated organizations.

The major findings included

- High quality ratings increased for all of the variables above except for organizational quality. This demonstrated the value of facilities changes in organizations whose employees are otherwise highly satisfied. Figure 2 illustrates these results.
- The drop in high quality ratings for organizational quality may be attributed specifically to a lighting quality problem in the new facility.

Application of post-occupancy research to characterize the lighting problem in the new facility revealed the following:

- The daylighting control on a major south window plane was not executed as designed. As a result, occupants of workstations near the south wall of the new facility were exposed to high levels of illumination from daylighting, with concomitant glare.
- Much of the overhead lighting that was originally designed was left out temporarily to see if the daylighting would be “enough.” Consequently, illumination levels for workstations near the north, east and west walls of the new facility were lower, relative to those for workstations near the south wall.

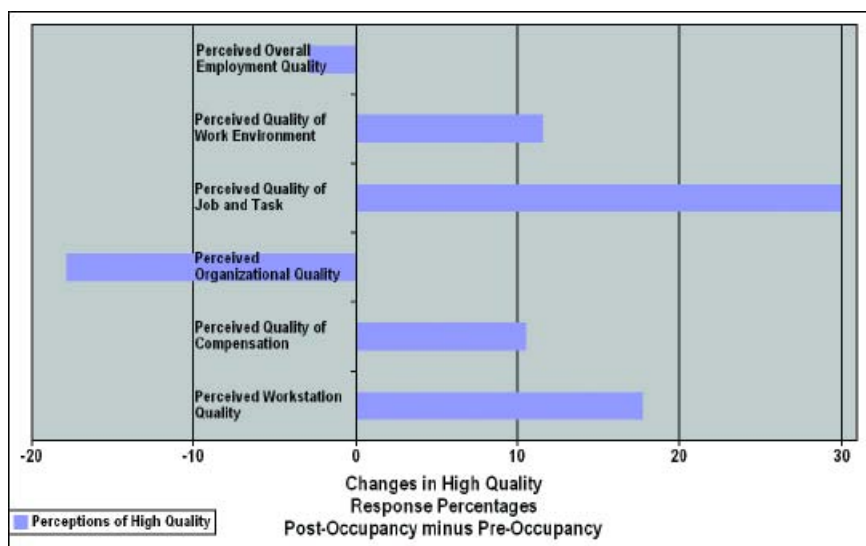


Figure 2 — Employee Perceptions of Major Indicators of Occupancy Quality Changes in High Quality Response Percentages, Post-occupancy Minus Pre-occupancy



The net effect of the post-occupancy lighting design problems was that average employee ratings of overall lighting quality in the new facility were somewhat lower, compared with overall lighting quality ratings for the old facility (Figure 3), and measured workstation illumination levels in the new facility also were lower, compared with the old facility (Figure 4).

However, because of the prevailing disparity in illumination due to daylighting in relation to workstation position in the new facility, a dramatic difference emerged between occupants assigned to south-wall workstations relative to those assigned to workstations positioned elsewhere in terms of the relationship between measured workstation illumination levels and occupant perceptions of daylighting quality. Specifically, for occupants of workstations not near the south wall, there was a direct correlation between perceived daylighting quality and measured illumination levels (Figure 5), but for occupants of workstations near the south wall, there was an inverse correlation between perceived daylighting quality and measured illumination levels (Figure 6).

In other words, because of dramatically higher illumination levels along the south wall (compare light level scales in Figures 5 and 6), with its associated glare, south wall occupants, unlike their counterparts elsewhere in the facility, equated more daylight with lower lighting quality. This effect, in turn, spilled over into a net reduction in high quality ratings for overall organizational quality in the new facility (Figure 2), presumably because of perceptions by south wall occupants that lighting design in the new facility had not been addressed properly. When these south wall occupants' rankings were removed from the data, overall rankings changed to positive for both lighting and organizational quality.

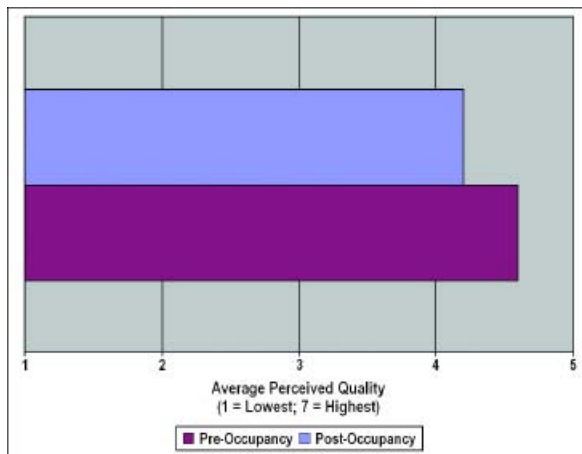


Figure 3 — Perceived Quality of Overall Lighting Post-occupancy vs. Pre-occupancy

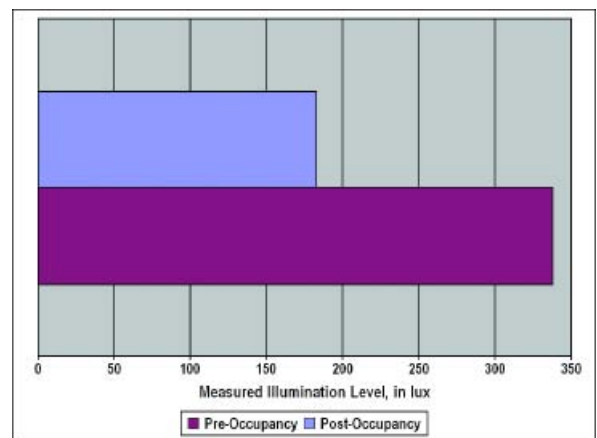


Figure 4 — Measured Workstation Illumination Levels Post-occupancy vs. Pre-occupancy

The findings from this case study support the general hypothesis that lighting can serve as a strong driver of occupant response, and that the influence of lighting conditions on the scope of such response can extend well beyond the narrow realm of visual perceptions. In this particular case study, most occupants apparently made no explicit complaints about lighting quality. (For reasons discussed above, lighting often does not find its way into the list of complaints about the office environment.) Yet in the area of the post-occupancy facility where lighting design was notably flawed, both specific and general negative perceptual responses emerged. Thus, it is particularly important to subject lighting to occupancy research analysis; unlike acoustics, it often does not come to the surface on its own.

The value of occupancy research demonstrated in this case study includes the result that even in a very highly rated organization, facilities benefits can be achieved and measured. Additionally, early post-occupancy studies can quickly identify problem areas indicated by both specific environmental ratings and broader organizational ratings from the occupants. Were these problems left undetected and unaddressed, longer-term employee dissatisfaction might result.

Through assigning human resource values to the consequences of addressing occupant perceptions, one can begin to calculate the long-term financial value of undertaking such projects. By employing these calculations iteratively over numerous projects, the economic benefits of determining exact design and performance strategies becomes clear.

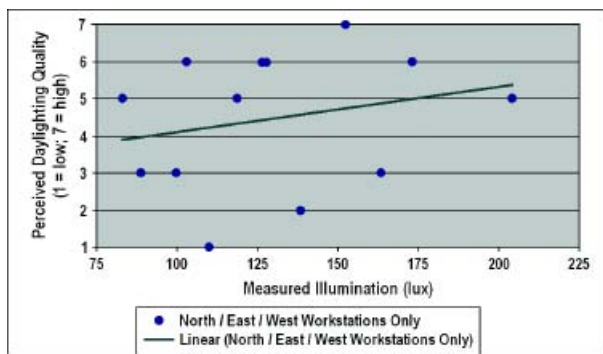


Figure 5 — Post-occupancy – Correlation of Measured Illumination Levels and Perceived Daylighting Quality for North, East and West Wall Workstations

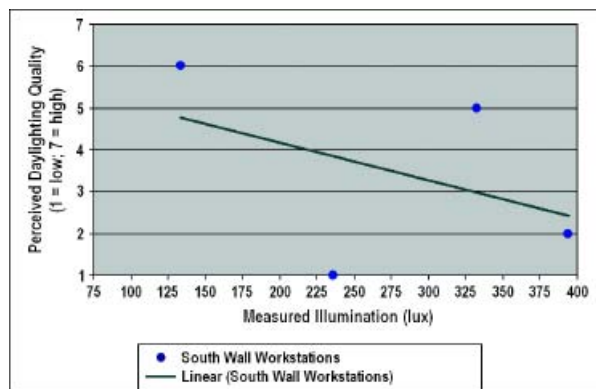


Figure 6 — Post-Occupancy – Correlation of Measured Illumination Levels and Perceived Daylighting Quality for South Wall Workstations

## Design Tools / Prototyping, Simulation and Testing



Since the inception of the open plan office, design prototyping has been considered an extremely useful tool for understanding both the performance of a space and people's response to it. Visually, it can allow members of the design team, as well as occupants, to experience the future space, thus providing useful experiential design guidance. When office projects begin, designers often have clear views on what impact they would like the lighting to have on the space. However, these ideas may get compromised during implementation unless the project team includes a professional lighting designer, as the lighting engineering staff usually concentrates on energy use and illumination.

As most designers realize, within reasonable illumination and energy standards, either a very good or a very poor lighting system can be designed. Clients have a very hard time understanding the difference in concept; they have to experience it. The prototyping process helps align the understanding among the lighting engineer, the design professionals (including the lighting designer) and the client. In our experience, experiential design (prototyping and modeling) often results in the client selecting a high quality lighting solution.

Even with a seemingly well-thought-out design, the actual performance of the space often will not achieve the results that were defined in the program for the following reasons:

- Less light than predicted
- Uncontrolled brightness
- Poor occupant orientation
- Standing occupant problems
- System not commissioned correctly
- Low reflectance values of finishes

These problems occur on many projects for a number of reasons.

- Many budgets are tightened by accepting commodity grade lighting systems that severely limit the quality of lighting.
- Many lighting designers are most familiar with only two issues in design, illuminance and energy consumption.
- Many firms and individuals designing lighting systems have little training and/or experience in advanced lighting design.
- Many lighting systems are designed without regard to layout, reflectance and other design considerations because the "base building" systems design is done separately from the office design.
- Many office lighting systems are designed in advance for build-to-spec and lease spaces, where the tenant and the program are unknown at the time of construction.
- Since it is more profitable in the short run to be repetitive, many architects and designers reuse previous design work rather than doing a new design.

A lighting consultant can calculate the lighting impact of a complex open plan office design with reasonable accuracy, but the complexity of modeling the workstations together with all the relevant details makes the use of prototypes more inviting. Experimental results from such simulations will often save time and allow consideration of both pertinent standards and other issues that may have been ignored previously.

The reasons for testing and prototyping are multiple and complex.

- Occupants must experience the environment in order to begin to understand their complex responses to both lighting and other variables that might affect perceptions of visual quality.
- Interactions between variables cannot be intuitively understood without experiencing the designs.
- The actual technical performance may not achieve what the ratings suggest, due to either design failures or to product performance failures. (Many products do not perform as calculated due to the design and resolution of the IESNA tests. For example, maximum luminance of a luminaire may be based on a very small area of the luminaire; its overall performance can only be measured by different methods.)
- Design questions that might never have arisen will begin to become clear experientially once prototypes are in place. Often questions that were never discussed become issues at the point of prototyping.



Figure 7 — Prototyping — Orfield Laboratories 1981 Open Plan Lab



Figure 8 — Prototyping — OPWG Open Plan Laboratory of 2001



Figure 9 — Visibility Testing of Workstation — Video Photometry

In 1981, Orfield Labs developed its first open plan office lab (Figure 7). The ceiling was installed on a wire lift system that can adjust the ceiling height within a fairly broad range. The ceiling grid was adjustable between a 2 x 4 and a 2 x 2 grid for experimenting with different types of direct and indirect lighting. This lab was used for much of our asymmetric lighting research in the mid-80's that culminated in an article on asymmetric lighting published in *Lighting Design+Application*, the journal of the Illuminating Engineering Society of North America, in 1987 (see bibliography).

In 2001, Orfield Labs developed its second Open Plan Laboratory (Figure 8) in conjunction with the Open Plan Working Group, which was founded in 1998. This space has the capacity to install most types of lighting and to remotely control these systems to demonstrate illumination and quality issues. It has recently been used to prototype lighting for a renovated headquarters office building for Allina Health Systems with Perkins+Will.

The most important photometric measurement for occupants is luminance, the amount of visible light leaving a surface. In 1990, Orfield Labs became the first user of video photometry outside of the Institute for Building Research of NRC/Canada, which developed the system. This system allows the luminance mapping of entire views of environments (Figure 9) and provides the best single measurement tool for understanding the performance and effects of lighting in actual environments. This system can be used to measure quality metrics important to professional lighting designers, such as visibility, glare and luminance ratios. These are often the most critical issues the designer faces in achieving better lighting design.

The Orfield Labs visual performance laboratory (Figure 10) was developed in 1991 to test the specific visibility of visual tasks under different levels of illumination, ambient lighting, angularly controlled task lighting and adjustable glare sources. This lab was used for lighting research in all commercial building types and was recently used to design the lighting systems (and to develop a new industrial luminaire) for Harley-Davidson's new Softtail assembly plant in York, Pa.

In addition, it is now possible to simulate the visual and acoustical performance of spaces — and to measure aspects of the occupants' response to these "virtual" environments — with a high probability that these tests will indicate future success or failure for specific design approaches. These simulations include computer (CAD) visualizations and lighting simulations (Figure 11). Occupants can view the possible visual outcomes of various space designs prior to rating design quality or indicating their preferences.



Figure 10 — Visual Performance Lab



Figure 11 — Visual Simulation of an Open Plan Office – Lighting and Daylighting Harley-Davidson Renovated Office, York, PA.

## Design Tools / Perceptual Response Programming



Various tools have been developed for obtaining occupant input to inform workspace design. Most often they consist of surveys, interviews, focus groups (often called “design charettes”), observation or some combination of these basic techniques. Although different design firms tend to employ distinct labels for implementing these tools, in general this process is termed *programming*. Programming presumably ensures that the environmental solution resulting from the design process will meet the expectations of its occupants — particularly their functional needs and preferences.

Programming no doubt serves a useful function. By engaging those people most affected by the space design, programming may assist in the organizational behavior aspects of change management and perhaps with other issues relevant to corporate transition. Certainly details, such as the number of chairs, phones, workstations and offices, must be determined, and thus some sort of data gathering is necessary.

However, it is unlikely that occupants can provide reliable, predictive information about how their work environment *influences* them. Most of us do not know, in a technical sense, how objective light levels, air movement and temperature gradients, or ambient noise levels affect us — at least not within the ranges typically encountered in office environments. Thus, seeking occupants’ *opinions* about design characteristics, particularly from groups requiring consensus, will rarely provide useful information, i.e., information that can predict future behaviors and attitudes relative to the design. Other more indirect, yet consistent, methods based on measuring individuals are needed for this purpose.

One such method developed by the Open Plan Working Group is Perceptual Response Programming. Similar to Perceptual Market Research, PRP quantifies immediate, individual responses to images of spaces that differ in terms of features relevant to design alternatives for a project. This method thus captures perceptual preferences that lie outside of awareness but are nonetheless important to understand in order to represent occupants’ expectations.

One particularly effective method of researching the visual side of privacy is via visual juries, which present images of offices for “semantic ranking” by occupants. Semantic ranking simply involves participants selecting a number along a scale defined by extreme descriptions of some environmental characteristic, such as “tense” to “calm.” The occupants, upon viewing the images, often infer conditional performance via the visual image and can consistently rank perceived privacy among the attributes that are included in the testing. (Each of the images shown to the occupants is often “content mapped” so that correlations can be calculated between aspects of the image and semantic rankings; for example, “degree of enclosure” might relate to perceived privacy levels.)

## Perceptual Response Programming / Examples

An interesting example of this type of design research was performed for the GSA Integrated Workplace Lab (IWL) project in Pittsburgh. This jury was conducted with the future occupants of the GSA IWL as an indirect test of spatial quality based on lighting, modeled by applying a series of lighting types to a given GSA space design that was part of this project. The jury was about lighting and acoustics preferences, but the subjects were not informed of either intent and were simply asked to rank the images with regard to specific semantics. Two illustrative images are at right.

With regard to lighting preferences, the design team predicted that this jury would rate indirect lighting very highly for quality, as it is often assumed by designers to be the best quality system (Figure 12). In fact, the very simple and inexpensive system in Figure 13 was rated higher. Most likely this outcome had little to do with the appearance of the lighting, but rather was based in the belief that the latter was a more spacious office, a perception created because the lighting is not defining a lower ceiling plane, a problem common in smaller scale offices. Thus, the preference is for a design solution rather than for a lighting solution per se. Without perceptual juries, this knowledge would not be available to the design team.



Figure 12 — GSA Jury – Indirect/Direct Lighting



Figure 13 — GSA Jury – Recessed Lighting

## Productivity



The final consideration for determining an approach to lighting and daylighting in office environments is to view them in the context of direct and indirect productivity measures. Here is where the strongest business case can be made for an occupant-centered approach to designing quality visual environments.

Direct productivity is measured principally in repetitive work environments, such as call centers or production areas. In these types of offices, it is easy to track the speed and output of work. Productivity is simply the change in output per worker, and it can often be assessed individually. This can then be converted into economic values, and the profit per worker can be calculated.

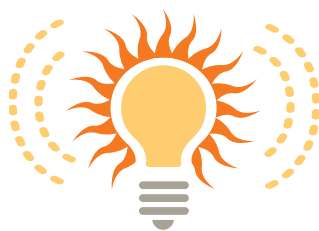
In the case of employees performing nonrepetitive tasks, the group commonly referred to as “knowledge workers,” indirect measures of productivity often must be used. These measures include such human resource issues as ease of hiring, retention, absenteeism, illness and tardiness, and sometimes include business metrics developed by an individual company or department to measure the ability of a worker population to meet specific short- and long-term goals.

When workers are asked if they believe there is an association between lighting and productivity, they will generally indicate that there is not. But, as in all opinion-based research, gathering opinions about the perception of productivity and its causes often proves unreliable as a method for predicting or understanding outcomes. Therefore, we must establish causal relationships between various aspects of lighting and productivity via high-quality occupancy research that does not simply rely on shared opinions.

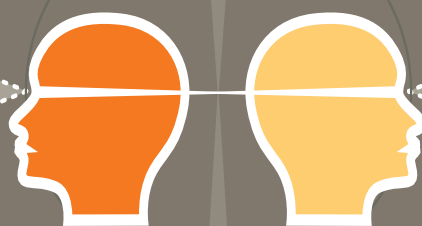
One of the few efforts to evaluate the possibility of a direct link between lighting quality and office worker productivity was carried out by the Light Right Consortium in 2003 (refer to the Albany Lab Study at [www.lightright.org](http://www.lightright.org)). This study involved a typical open plan workplace in which nine temp workers (hired for the study) were asked to perform typical office tasks under six different lighting conditions with exposure to each condition sustained for one eight-hour workday. The key finding pointing to a connection between lighting conditions and productivity was that, relative to workers lacking personal control, workers provided with a control that allowed them to dim their overhead direct lights persisted longer on difficult tasks and were more accurate on a task requiring sustained attention.

Although possible confounding effects on these findings cannot be ruled out, the results nevertheless suggest that under some design conditions, lighting and office worker productivity may be closely related.<sup>3</sup> Once that causal relationship has been established, whether based on direct or indirect productivity measures, the result can be converted into an economic value to demonstrate the benefit of high-quality lighting and the cost/benefit of providing such lighting when weighted against the effects on occupants and their productivity.

<sup>3</sup> *The classic “Hawthorne Effect” ascribes no link between physical conditions, such as lighting or daylighting, and productivity; however, that research focused exclusively on factory jobs and, therefore, may have limited relevance to office environments and so-called “knowledge-worker” productivity.*



## PART II



## PART II The Visual Experience of Light

### Introduction

Obviously, visual perception represents the primary way people interact with lighting and daylight. Indeed, light is defined as the visible portion of electromagnetic radiation (EMR). Essentially, any luminous source, such as an incandescent or fluorescent light bulb, produces radiant energy from the electromagnetic spectrum. People respond to this radiant energy through photoreceptors — specialized cells in the retina — an intricate layer of cells lining the back of each eye. From there, visual signals are conveyed to the primary visual cortex lying at the back of the outer covering of the brain.

For millennia, daylight from the sun and reflected from natural scenes provided the primary source of vision and visual perception; this remains one reason why daylight is still important for maintaining healthy built environments. It is also interesting to note that neural pathways from the retina provide input to a “neural clock” that regulates our sleep/wake cycle. This neural clock also influences mood and other elements of subjective experience. For example, the disruption of this 24-hour sleep/wake cycle due to shorter winter days contributes to Seasonal Affective Disorder — a form of depression that some people living in northern latitudes suffer from. Regular, systematic exposure to very bright, high-luminance localized lighting helps combat the effects of SAD.

## Visual Optics



Beginning with the retinas and continuing through the dozens of brain areas devoted to interpreting visual input, the eyes connect to a truly marvelous device for creating visual experience. Nonetheless, it remains important to keep in mind that the experience of vision rests on only partial input from the optic array. This subset of the light potentially available is characterized by blurring of location and color, uneven acuity and two-dimensional object ambiguity. Old age tends to exacerbate these optical deficiencies, so the negative consequences of poor lighting/daylighting design tend to increase with age. For example, although very important for lighting and daylighting quality to any office occupant, glare control becomes mandatory for visual comfort and adequate task visibility for older workers.

The brain compensates for poor optics in a number of ways, including combining an enormous dynamic range (relationship between physical intensity and subjective brightness) with high contrast sensitivity. Thus, we are able to detect very small differences in contrast (requiring a small operating range) within a broad range of background intensities (requiring a large operating range). The brain accomplishes this through shifting vision's operating range to correspond to ambient conditions (see page 29 under **Visual Adaptation and Habituation**). Again, age tends to reduce the efficiency of this system, making lighting quality design extremely important for older workers.

## Visual Psychophysics

Several basic visual phenomena may be relevant for lighting design. These have been investigated within the field known as *psychophysics*. This field of research studies the relationship between the physics and subjective experience of perception. In vision, psychophysicists measure light both as physical stimulus and as subjective experience. Many basic aspects of the perception of light have been discovered with this approach. For example, Bloch's Law states that in dim light, stimulus presentation time and stimulus intensity are interchangeable up to a critical period of time. A related phenomenon under bright conditions, the critical flicker-fusion frequency (CFF), describes the frequency of single light pulses needed to yield the perceptual experience of continuous light. Some people appear to have particularly sensitive CFFs; this may contribute to their distaste for fluorescent lights — all of which emit pulses of light.

## Visual Thresholds

A number of basic perceptual phenomena relate to visual thresholds. For example, the absolute threshold for visual experience corresponds to the light from a single candle seen from 20 miles away. In this sense of its absolute threshold, if vision were any more sensitive, we might experience stroboscopic effects caused by responses to individual photons. The so-called difference threshold, summarized by the Weber-Fechner Law, states that our perception of a change in a given stimulus dimension, such as light intensity, is a constant function of the average — or comparison — level. This means that we notice less of an increase in light level at low average light levels than we do at higher light levels. This relationship is very important for lighting and daylighting design, because occupants' experience of visual quality with respect to their visual tasks will always be related to the overall, average light levels reaching their eyes.

## Visual Adaptation and Habituation

To achieve vision's astonishing flexibility, many components of the visual system readily adjust in response to changing stimulus conditions. For example, the diameter of the pupil (the opening in the iris that admits light to the retina) ranges from one to eight millimeters as average (background) light levels decrease. Additionally, in accommodation (see below), the optical power of the eye changes a full eight diopters (refractive units inversely related to the focal length specified in meters). The sensitivity of the two types of photoreceptors in the retina — rods and cones — adjusts by six orders of magnitude from a bright, sunny day to a moonless night. This phenomenal change in sensitivity to light involves the difference between photopic and scotopic vision. Cones (photopic) need higher light levels to respond than do rods, and they provide our experience of color and fine resolution. Rods (scotopic), by contrast, register only achromatic (color neutral) vision, and respond better to movement and low light levels than cones. Both rods and cones must adjust to any given background light level in providing visual experience. Thus, dark adaptation (40 minutes from bright to dim conditions) and light adaptation (10 minutes from dim to bright conditions) refer to the sensitivity of vision adjusting to changes in background (average) light levels.

A perceptual phenomenon related to distinctions between rod and cone vision highlights the difference in peak color sensitivity of the cones and rods. As light moves from cone-vision to rod-vision levels, first long-wavelength light (such as red) appears brighter, followed by short-wavelength light (such as blue), before color vision gives way entirely to the experience of shades of gray at very low light levels. This shift in experienced peak brightness from long- to short-wavelength colors as light levels decrease constitutes the Purkinje Effect.

Dark and light adaptation, the Weber-Fechner Law, and the fact that responses to lights of different wavelengths relate to the wavelengths from sources already in the field of view, all illustrate the principle of sensory habituation. Current levels of stimulation strongly influence the brain's response to light. This holds true across the many different dimensions of light as a stimulus — intensity, specularity, color warmth, wavelength, clarity and resolution. In fact, this represents a general law — the brain appears to be specialized to register changes in sensory input rather than specific levels of stimulation. The brain always includes the current background in its creation of dynamic perceptual experience. This general principle has a number of important implications for lighting and daylighting design, which are explored in the remainder of this paper.

## Color Perception



The retina has three types of cones that respond to long-, medium- and short-wavelength light, according to type. Through processes too detailed to cover here, the brain integrates output from these three cone types to provide us with the subjective experience of color. Deficiencies in one or more of these cone types or their output have been implicated in color blindness, the inability to distinguish among two or more colors. Although very low incidence rates for color blindness exist, if the design of warning or other safety systems depends critically on color coding, this perceptual deficit must be considered. The brain's response to color also involves so-called opponent processes, neural networks that respond in opposing ways to complimentary colors (for example, red/green, blue/yellow and white/black). Together with the three types of cones, these opponent processes underlie the wonderful variety of our color experience, including color saturation and color combinations.

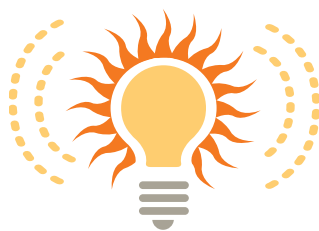
## Visual Acuity and Accommodation

This element of visual experience begins with the refraction of light by the front of the eye. If this refracting system bends light rays from some object correctly, an image of that object will be experienced in clear, sharp relief (“in focus”). However, if these light rays focus in front (nearsighted) or behind (farsighted) the retina, the object will be blurry, or out of focus. Accommodation is the process whereby this system focuses objects that are close to the eye correctly at the retina. As people get older, accommodation does not work as well (presbyopia), and thus most people need “reading glasses” sometime within their 40s. Many other physical changes to several structures in the eye that come with increasing age result in older people being bothered by glare much more than are younger people. This sensitivity to glare is one of the most important factors to consider when designing lighting for different age groups — particularly task lighting and its relationship to ambient (background) lighting.

## Perceptual Constancies

Thankfully, visual perception has been designed to be forgiving of bad lighting — at least for visual task performance. Other elements of subjective experience tend to suffer before actual visual performance as the lighting environment moves from good to bad. Various perceptual constancies demonstrate the flexibility of visual perception. For example, color constancy describes the fact that we experience the same color reflecting from a surface at vastly different luminance levels. Brightness constancy means that the contrast between the dark and light areas of an image remain subjectively similar across a wide range of luminance levels — even though the dark areas under bright illumination may be reflecting more light than the dark areas under dim illumination. (Imagine reading a book by firelight or at noon on the beach; in both situations, the letters appear dark and the surrounding page appears bright — even though the letters reflect far more light at the beach than the page does by firelight.) Simultaneous contrast simply means that in calculating our experience of the brightness of a surface, the brain takes into account the brightness of surrounding surfaces (the same contrast effect works for color perception as well as brightness perception).

These perceptual phenomena serve to guide design principles for lighting and daylighting systems within the built environment. Certainly for any visual experience, light levels must surpass threshold minimums, and for color-based tasks, light levels must exceed those required for photopic vision. If color coding is used in low light levels, blue colors might be more visible than red colors; the opposite would be true under bright conditions. In general, task lighting must surpass ambient light levels to provide adequate visual acuity for most tasks, since our response to light relates to background levels of illumination. The role of daylight and darkness in the control of sleep/wake rhythms suggests that more could be done with dynamic light levels within the built environment — particularly for background, or ambient, illumination — to improve mood and other aspects of subjective experience. Finally, the dozen or so monocular depth cues (elements within 2-D images that signal relief in 3-D) can be exploited in a number of ways (e.g., through the relative placement of luminaries) to contribute to the emotional and aesthetic aspects of visual experience.

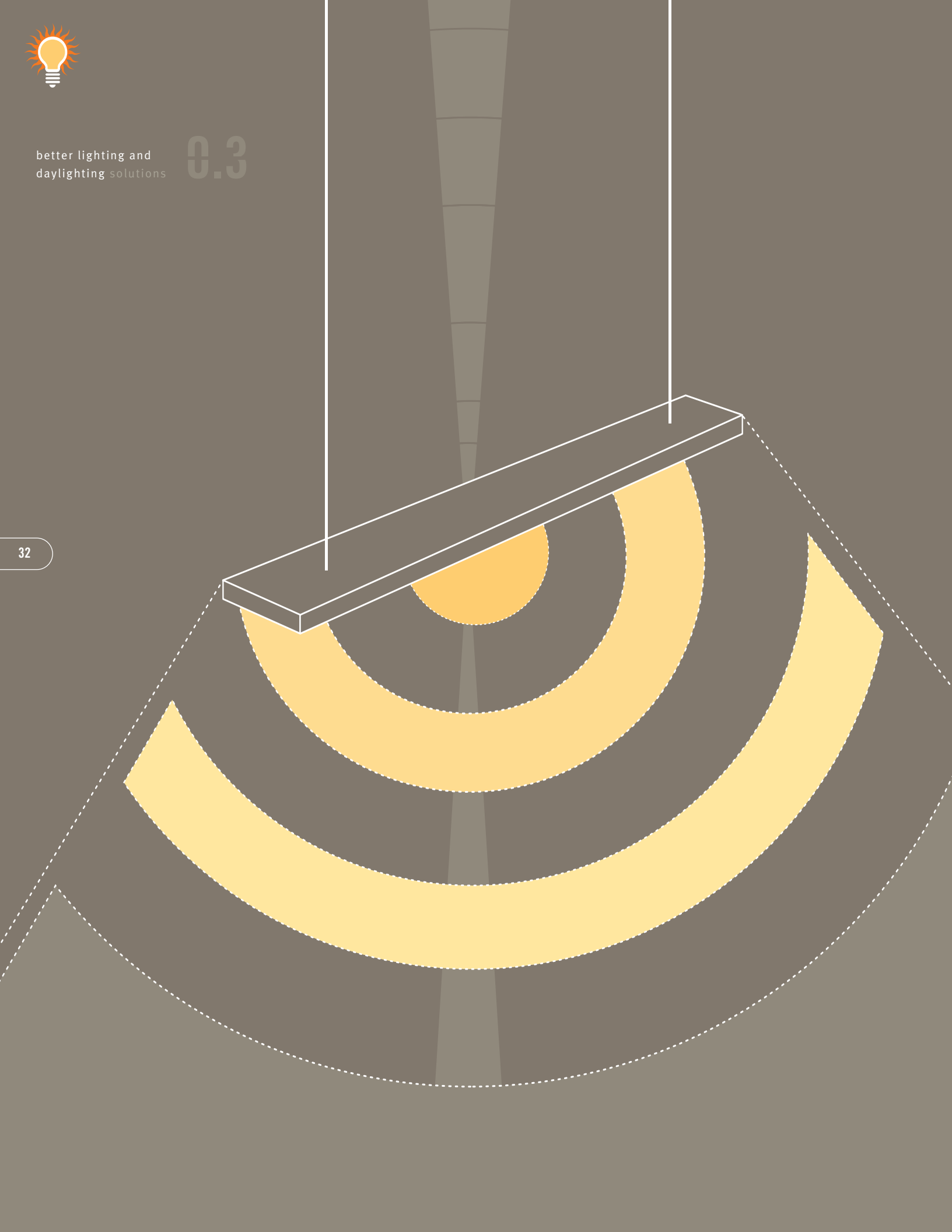


## PART III



better lighting and  
daylighting solutions

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## PART III Conceptual Issues in Office Lighting and Daylighting

### Introduction

In our investigation of the physical lighting issues of the office we also need to consider that office lighting is not only about visual performance and energy efficiency; it can also be about preferred environments. Moreover, while the occupant can converse about lighting, he or she cannot generally articulate his or her complex illumination preferences.

### Visual Environments and Building Types

Architectural building types, as well as outdoor environments, often employ particular visual environments to create a specific mood. Some encourage reverence (churches, libraries), some encourage activity (day care centers, shopping centers, athletic facilities), some encourage communication (offices, conference centers), some encourage comfort (homes), and some encourage excitement (night clubs, restaurants). Many of these environments are preferred environments. We go to such places to experience the expected complex stimulus set and the higher order behaviors for which those spaces were designed. The workplace may be either a preferred or nonpreferred environment for workers, or a mix of each. Occupancy research can help clarify where the current or intended environment falls along this continuum.

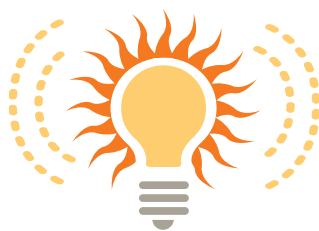
### Office Lighting and Visual Quality

One of the most profound changes in space design in the last 25 years has been the movement toward visual quality as a method of evaluating products and environments. The visual quality movement — or the movement toward the psychological assessment of the feelings and associations engendered by appearance — entered the United States via quantitative subjective research on product appearance and, in approximately the last five years, has moved into environmental appearance. This applied approach has ties to ecological psychology, environmental psychology, experimental aesthetics, aesthetics engineering, hedonomics, visual quality programming and similar lines of inquiry.

This visual quality emphasis contends that consumers do not necessarily want sophisticated visual design of products (and environments), but rather products and environments that visually reinforce their attitudes and emotions about quality, value, appropriateness and performance.

The office environment, from a visual quality perspective, must have an appearance that reinforces occupants' attitudes and feelings about the workplace, e.g., that makes the occupant feel peaceful, secure, private (or public), valuable, etc. Such environments should also allow the occupant to have some choice over the selection of these visual qualities, either by control (adjusting the lighting and daylighting level, etc.), behavior (moving toward or away from the visual stimulus), or changing environments (moving into a conference or teaming room).





**PART IV**



## PART IV The Practice of Office Lighting and Daylighting

### Introduction

Modern office lighting and daylighting are reasonably well-known practices that developed between 1960 and 1990, and are broadly based on the physical model of light source transmission and control. Their intention is to control lighting and daylighting by various techniques, so that the occupant will find the office environment visually positive and visually comfortable. Beyond their ability to enhance visual task performance, proper lighting and daylighting can affect employees' job satisfaction, preference for workspaces, and overall satisfaction with their environment — and, thus, with their employment as a whole.

Research conducted in a number of different venues — from elementary school classrooms to hospital rooms — has demonstrated the importance of adequate lighting and daylighting for mood and attitude regulation. Positive benefits include improved mood, improved sociability, improved immune function, improved energy, improved hygiene and a number of other advantages. Studies of the effect of lighting and daylighting on productivity have yielded less consistent insights.

## The Source-Path-Receiver Model



The physics of lighting are complex but can be simplified by a model that is used to explain the relationship between a sensation and the perception of that sensation. This model characterizes the light source, the paths it takes (directly and by reflection), and the values it achieves at the occupant (the receiver). The model does not deal with occupant processing of the stimulus.

The SPR model helps the designer to understand the problems of getting light to the occupant, so that these may be avoided and efficient light transmission will result. The process goes something like the following:

- Daylight, a brightness source, moves through office windows, often at many thousands of candelas.
- The daylight is dispersed in a pattern that is related to the geometric distribution of the source, including reflections and scattering.
- This daylight moves toward the viewer along a series of paths.
  - Daylight travels through openings in the large- and small-scale environment.
  - Daylight reflects from the ceiling and lighting fixtures.
  - Daylight reflects from adjacent walls and furniture components.
  - Daylight reflects from the floor.
  - Daylight scatters from certain surface types.
- The daylight arrives from all these paths, with its losses on each path, and it recombines to form the total daylight at the viewer's eye. Unlike sound, the direct paths generally dominate. (Figures 14 and 15 illustrate the light path created by different sources in different plans.)

If the amount of daylight exceeds the background ambient luminance level of the viewer's work area, it is then perceived as "visible" (i.e., consciously perceived).

In this model, light (whether daylight or electric) can be controlled via three strategies.

- Source Control (at the window or light source) by means of shades, window film, ceiling or task lighting
- Path Control (intervening between the source and the viewer) by means of barriers, reflectors and the like
- Receiver Control (by the viewer) by means of sunglasses, glare protectors and individual lighting controls

Each of these strategies entails various methods and products that can be employed to solve defined problems.

- Source Control
  - Direct and diffuse source level
  - Source orientation
  - Computer screen control
  - Distance between source and viewers
- Path Control
  - Visual transmission of workstations
  - Absorption of reflections at ceiling, floor, walls and furniture components
  - Attenuation of direct brightness via barriers
- Receiver Control
  - Viewer orientation
  - Visual filtering use
  - Masking of brightness via environmental luminance control

These strategies are treated in more detail in the following pages.

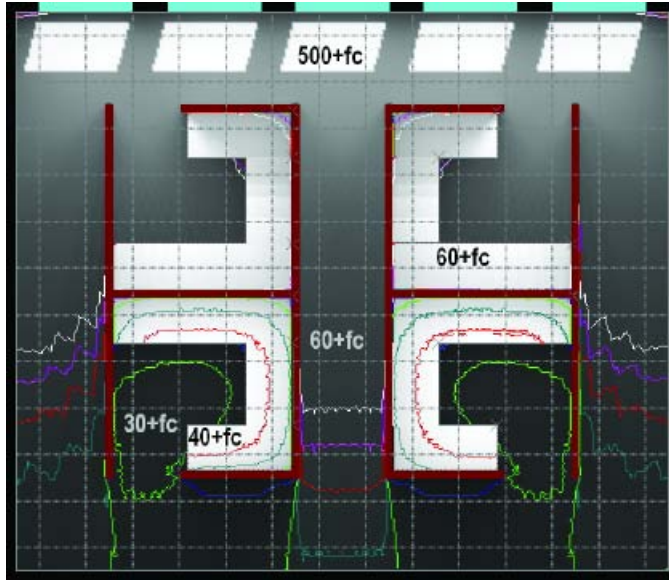


Figure 14 — Diagram of Daylighting Path in the Office – Plan View

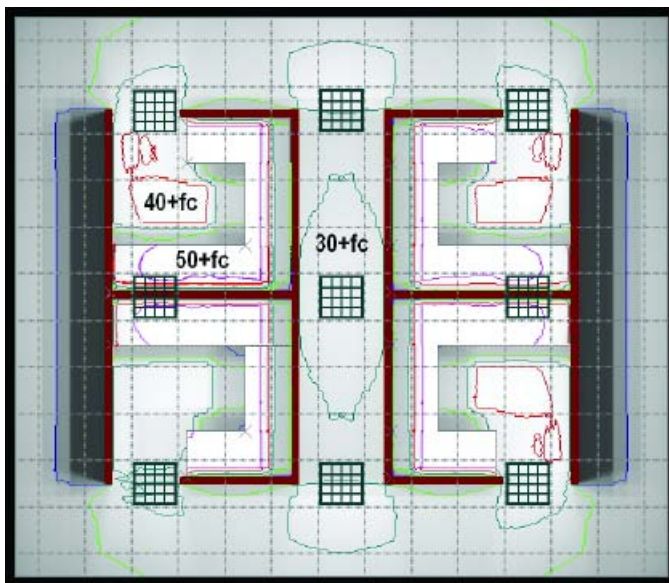


Figure 15 — Diagram of Lighting Path in the Office – Plan View

## Process and Product Ratings



Lighting and daylighting products are rated in terms of source and process descriptors. These characterize the product's performance and the product's benefit to the user, respectively. Additionally, ratings of "system performance" rate not the products but rather total performance of the products and the environment within their specific application.

Figure 16 shows a set of typical information on a lighting product specification sheet provided by a manufacturer. It includes illumination tables, candlepower statistics, CU values, light distribution data, visual comfort probability data and luminance (brightness) data. These data are useful for basic engineering, but much of what the designer would like to know (visual quality, localized glare) cannot be inferred from this information.

Ratings that are more useful to the designer include the following, which can be found for products commonly used in open plan offices:

- Partitions may have a reflectance (i.e., the amount of light reflected from the surface) and specularity (i.e., the amount of light mirrored, rather than diffused or spread out, from the surface) value.
- Ceiling tiles may have a reflectance and diffuseness value.
- Acoustic wall panels have a visual reflectance value.
- Carpet has a reflectance value.
- Many furnishings have a gloss (specularity) value.

## Light Distribution

Degrees	Lumens	% Lamp	% Fixture
0-30	2983	25.7	39.1
0-40	4923	42.4	64.5
0-60	7591	65.4	99.5
0-90	7631	65.8	100.0

## Typical V.C.P.'s

Room Size	Mounting Height Lengthwise		Mounting Height Crosswise	
	8.5	10	8.5	10
30x30	96	92	97	91
40x40	98	95	98	94
60x30	98	95	98	94
60x60	99	97	99	96
100x100	98	99	99	98

## Average Luminance CD/Sq. M With 2900 Lumen Lamps

Angle	End	45°	Cross
45	4948	4948	4366
55	3271	3480	4567
65	85	66	54
75	38	25	19
85	38	38	19

## Maintained Illumination Table- Square Feet/Fixture\*

- 80-50-20 Reflectances (Ceiling -Wall -Floor)
- LLF = 0.75 2900 Lumens/Lamp very clean
- Room width divided by room height = 5 or more, 2 or 1

Fixture Size & # of Lamps	Room Width = Room Height	Approx. Area (sq. ft.) per Fixture				
		10 ft-c	30 ft-c	50 ft-c	70 ft-c	100 ft-c
2' X 4' 4 Lamp	5	-	-	125	89	62
	2	-	-	92	66	46
	1	-	116	70	50	35

## Coefficient of Utilization

pfc pcc pw RCR	20	50	30	70	50	30	50	30
	80			70			50	
0	78	78	78	76	76	76	72	72
1	73	70	68	71	69	68	67	66
2	68	65	60	67	63	59	60	58
3	64	57	54	61	56	54	56	52
4	58	53	47	57	52	47	51	46
5	55	47	42	54	46	42	46	41
6	51	44	39	50	42	38	41	38
7	47	40	34	46	39	34	38	34
8	45	36	32	44	35	30	34	30
9	41	34	28	40	33	28	33	28
10	39	30	26	38	30	26	29	26

## Candlepower

Angle	End	45	Cross
0	3460	3460	3460
5	3463	3478	3480
10	3395	3505	3590
15	3290	3532	3695
20	3166	3521	3789
25	3025	3470	4343
30	2849	3696	3916
35	2648	3618	2951
40	2416	2914	2220
45	2133	2133	1882
50	1758	1667	1686
55	1144	1217	1597
60	166	164	66
65	22	17	14
70	10	8	6
75	6	4	3
80	3	3	2
85	2	2	1

\*Observe Fixture S/MH Requirements for Specific Applications

Figure 16 — Manufacturer's Luminaire Photometric Data

## Illumination Values and Their Application



The most common measure of lighting is illuminance, the amount of light falling on a given area, such as a desk, from all sources that contribute to that illumination. The unit of measurement is lux in the international system and foot candles in the American system.

The selection of illuminance has many standards that might apply, but the most common and accepted standards in North America are those published by the Illuminating Engineering Society of North America in its *Lighting Handbook, 9th Edition* (pg. 10-13, figure 10-9), shown in Figure 17.

The selection of illuminance is dependent upon task difficulty and the age of the viewer. For example, the same task may be quite visible under one viewing condition (e.g., no intense daylighting) but less visible under another condition (e.g., intense daylighting). While the luminance measure may not change in this example, the brightness in the field of view will change dramatically for the person performing the task. Thus, illuminance is a limited metric that does not describe lighting quality or the quality of the visual environment.

	Illuminance Category	Type of Activity	Foot candles
Orientation and simple visual tasks	A	Public spaces	3
	B	Simple orientation for short visits	5
	C	Working spaces where simple visual tasks are performed	10
Common visual tasks	D	Performance of visual tasks of high contrast and large size	30
	E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	50
	F	Performance of visual tasks of low contrast and small size	100
Special visual tasks	G	Performance of visual tasks near threshold	300 to 1000

Figure 17 — IESNA Illuminance Guidelines Chart

## Luminance Values and Their Application

The most important measure of lighting effect is luminance, the amount of light emitted from a given area, such as a desk, from all sources that contribute to that luminance. The unit of measurement is candelas (or nit) in the international system and foot lamberts in the American system.

IESNA also prescribes the selection of luminance criteria. Figure 18, taken from the *American National Standard Practice for Office Lighting* (ANSI/IESNA RP-1-04), suggests maximum candela values at relevant angles for direct and direct/indirect luminaires.

The *American National Standard Practice for Office Lighting* also states that calculating the Visual Comfort Probability for various direct lighting systems allows a more comprehensive comparison. For example, it recommends a VCP of 80 or greater to minimize discomfort glare for tasks involving video display terminals. (We recommend a VCP of 90 or greater.) VCP tables are available from most luminaire manufacturers.

Angle from Vertical	VDT Intensive	VDT Normal
55°	300 cd	-
65°	220 cd	300 cd
75°	135 cd	185 cd
85°	45 cd	60 cd

Figure 18 — IESNA Maximum Luminaire Luminous Intensity (Candelas)

Surface	Reflectance
Ceilings	80% or more
Walls	50-70%
Floors	20-40%
Partitions	40-70%
Furniture	25-45%

Figure 19 — ANSI/IESNA RP-1-04 – Recommended Surface Reflectance for Offices

## Luminance Ratio Guidelines

The luminance-ratio limits set forth in the *American National Standard Practice for Office Lighting* are

- Between a paper task and an adjacent visual display terminal screen: 3:1 or 1:3
- Between a task and immediately adjacent surroundings: 3:1 or 1:3
- Between a task and remote (nonadjacent) surfaces: 10:1 or 1:10

For visual interest and distant eye focus, it is not essential or aesthetically pleasing to maintain the ratios throughout the entire space.

Determining the amount of luminance for office surfaces involves allowing for both illuminance and surface reflectance. Reflectance is extremely important, as it contributes to visual quality in a number of ways.

- It affects the value of illuminance at a given point, in that illuminance is generally a combination of direct and reflected light.
- It affects the luminance ratios in the field of view, often in very dramatic ways.
- It affects visual comfort and visibility, as these are a function of both illuminance and the luminance.
- The financial cost of selecting the right reflectance values (Figure 19) is generally zero. Thus, a given lighting system can range in quality from excellent to poor, based solely on the selection of reflectance values.

The selection of luminance values affects both task difficulty and the performance of the viewer, especially the older viewer. Luminance is the variable seldom planned, calculated or measured. When measurement evaluations are done in problematic spaces, it is the variable that seldom meets reasonable standards.

## Gloss and Specularity



Gloss and specularity, or the ability of the material to directly mirror sources of light, is a consideration very commonly left out of design of lighting and daylighting. It is important because most surfaces in an office are diffusely reflective. This means that no matter what direction light comes from, it is reflected back in a diffuse or widely spread reflection (Figure 20). This moderates the brightness of reflections. For specular surfaces, the angle of incidence equals the angle of reflection.

In daylighting, this is particularly important, in that window framing, daylight shields and other materials in the path of sunlight need to be both low in reflectance and matte (diffuse) in finish. Otherwise, they will become secondary sources of brightness and glare. The same is true for luminaires (Figure 21).

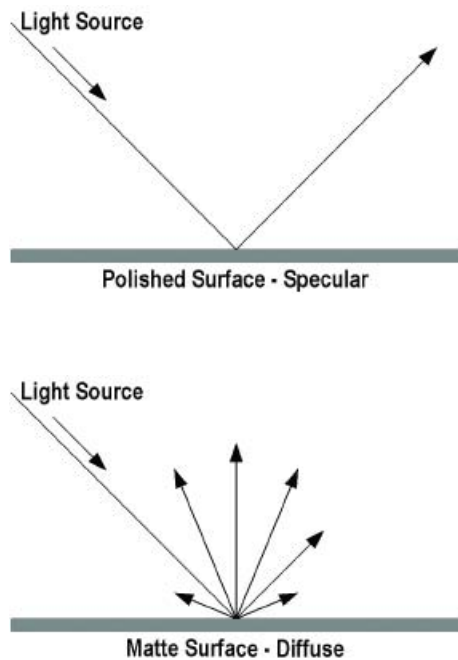


Figure 20 — Specular and Diffuse Reflection



Figure 21 — Satin Finish vs. Specular Lens

## IESNA and Open Office Lighting

IESNA has established many of the lighting and daylighting practices and recommendations that are used by American consultants and lighting laboratories. Its *Lighting Handbook, 9th Edition* (“the bible of lighting”) is helpful because it frames lighting and daylighting issues in terms of its own test standards and recommended practices, and employs a reasonable approach to defining many of the variables involved, with an emphasis on both process and product variables.

The handbook is intended for lighting professionals and may in parts be difficult for designers to use. Some of the information most relevant to a designer’s needs includes the following recommendations with regard to design applications:

- Ceilings – higher reflection values, ideally 80 percent or greater
- Ceilings – continuous color without “framing” of beams, etc.
- Lighting – must not be a flanking acoustic reflector
- Barrier heights – minimum 60”, glazing above 60”
- Hang-on components – will generally degrade the lighting performance of the ambient system

### Topics Covered in IESNA *Lighting Handbook, 9th Edition*

The Luminous Environment  
 Visual Task Considerations  
 Task Lighting  
 The Psychological Effect of Lighting in Offices  
 Ergonomics  
 Economics and Energy Considerations  
 Lighting Design Considerations  
 Design Issues for Specific Areas  
 Offices with Visual Display Terminals  
 Emergency Lighting  
 End User Responsibility - Maintenance

## The Office Lighting Design Process

In typical open office projects, the design process is often a simple selection of previous lighting approaches, the calculation of illuminance (foot candle levels) and the calculation of energy consumption in line with local codes. Thus, the resulting lighting system may be the most inexpensive solution that is energy efficient and provides minimum illumination. This type of lighting system is designed to be high in uniformity and relatively even in illumination, until the cubicles are installed.

A professionally designed lighting system is far more complex in that it must be evaluated for issues such as

- Task visibility and visual comfort
- Architectural and design impact
- User preference
- Desired level of uniformity – nonuniformity
- Interaction with daylighting
- Interaction with office cubicles
- Problems due to the barrier effect of cubicles
- Interaction with distance views
- Interaction with the reflectance values in the space
- Interaction with specularly (gloss within the space)
- Quality of luminance distribution

## Ambient Lighting



Office lighting is commonly separated into ambient lighting systems and task lighting systems. Ambient lighting generally refers to the main architectural lighting system installed in the building, often without regard to the layout being employed (especially in lease spaces). Ambient lighting can also be furniture-mounted or floor-mounted indirect lighting, but this is an approach that has grown out of favor since it was first used quite heavily in the 1970s and 1980s.

Most ambient lighting is uniform and is installed in regular patterns. The following are the three typical types of ambient lighting (Figure 22):

- Direct, lay-in “troffer” luminaires
- Indirect point or line source ceiling-mounted or furniture-mounted luminaires
- Direct/indirect point or line source ceiling-mounted luminaires

Each of these types of ambient lighting has many variations, for example,

- Direct, lay-in troffers are most commonly found as
  - Flat lens systems
  - Parabolic systems
  - Special lens systems (such as a “paracube” lens)
  - Direct/indirect systems, where the luminaire is direct, but there is an internal shield to bounce light up into the troffer and back down
- Indirect systems are most commonly found as
  - Linear indirect cable hung systems
  - Single luminaire rod or cable hung systems
  - HID rod hung systems (far less common)
- Direct/indirect systems are most commonly found as
  - Linear direct/indirect cable hung systems
  - Single luminaire rod or cable hung systems



Figure 22 — Images of Indirect, Direct/Indirect and Direct Ambient Lighting Systems

All uniform ambient lighting systems have some similar characteristics, when used in an open plan office. The most important of these are the following:

- They are relatively inefficient in providing illumination at the cubicle task surface. Orfield Labs studies in the 1980s demonstrated that a system that provides 50 fc in an empty open space typically provides about 12 fc at the partition-mounted work surface with 60" panels, for a loss of 75 percent of illumination. If partition and component surfaces are not within normal reflectance ranges (80 percent for ceilings, 50 percent for walls and 20 percent for floors), the losses can be far greater.
- They often provide too much luminance (brightness) in the peripheral visual field (in the forward peripheral field of the seated cubicle occupant). This is particularly true with many newer parabolic systems, which are designed to appear dim in distance views (ostensibly to reduce reflections in VDT surfaces) but are bright in the peripheral field. This has occurred because of two lighting system misconceptions:
  - Most seated cubicle occupants do not have a distance-direct or VDT-reflected view of these systems, and most monitors are now well controlled for veiling (contrast reducing) reflections via the use of low-reflectance coatings.
  - Most seated cubicle occupants are very sensitive to peripheral brightness, which has been steadily increasing in many parabolic systems in order to increase their energy efficiency. This increase in the coefficient of utilization, a measure of how much light “escapes” from the fixture, is highly correlated with glare, which results from the use of “high efficiency” or poorly shielded lighting systems.

Because most uniform ambient lighting systems are inefficient, lighting professionals have been lowering ambient lighting standards and employing task illumination as a less expensive and more energy efficient solution. The professional lighting societies around the world have been following this design trend and have set standards that recognize that the “tasks” performed when one is not seated at a workstation generally require far less illumination. For example, the IESNA recommends illuminance ranges for non-task office areas of

- Public spaces / 3 foot candles
- Simple orientation for short visits / 5 foot candles
- Working spaces – simple tasks / 10 foot candles

There is no need for employees to work in their cubicles with 50 fc of illumination and walk through open spaces with 100+ fc at standing height.

## Nonuniform Ambient Lighting



Since the 1970s, many ceiling-mounted, free-standing and office system-mounted ambient lighting systems have been nonuniform in design. These systems have been very popular for some time because

- Most occupants prefer non-uniform environments, which are similar to their homes and other preferred architectural spaces.
- Nonuniform lighting tracks the use and density of office spaces, in that the density of task areas can be tracked by the placement of ambient floor or office-system-mounted systems.
- Nonuniform systems, if task-oriented (placed near task locations), are more efficient.

One of the most energy efficient lighting applications, introduced in the 1970s and '80s, is the use of parabolic lighting (with 2 x 2 fixtures) mounted over each workstation. Research by Orfield Labs in the 1980s suggested that "task-oriented" ambient systems provide twice the illumination, on average, as uniform systems. And 2 x 2 systems were likely to be twice as close to the task, on average, as 2 x 4 systems. Finally, 2 x 4 systems are on the wrong axis with respect to the viewer half the time, providing more forward-facing peripheral glare.

## Vertical Luminance

While many office lighting systems are ambient only, many of the more sophisticated systems have separate "wall washing" illumination systems in order to control the luminance ratios needed to ensure visual comfort within the field of view. These systems can range from fluorescent cove systems to incandescent, fluorescent and LED systems running along full-height wall surfaces.

When glazed private offices are part of the design process, wall washing cannot be used adjacent to these offices, and office occupants are generally more comfortable with no separate corridor lighting.

## Task Lighting

Task lighting has grown from its inception as optional under-cabinet lighting to the lighting professional's preferred method of providing the occupant with local workstation task illumination. In the early open plan office, the only task fixture was the crude under-shelf systems that were adapted from under-counter kitchen lighting. (Some of the same manufacturers made both.)

From its earliest uses, it became more sophisticated via the following types of changes:

- Better lenses, such as batwing lenses, were installed to reduce veiling glare reflecting from office tasks.
- Asymmetric lights were designed to cross shoot the task from the edges of the work surface, thus reducing veiling reflections and reducing shadows.
- Articulated systems were designed on arms (an imitation of early drafting table lighting), in order to allow user adjustment and control.
- Dimming systems were added in order to provide further control.
- Occupancy sensors were connected, or multiple circuit tracks were installed, in order to turn off the task lighting when the occupant was not there.

During this age of task lighting development, the sources moved through a series of options from incandescent to fluorescent linear tubes, to circular tubes, to compact fluorescents and halogen sources. We are now headed toward newer sources, such as LED.

## Reflectance Values and Specularity

One of the most important issues in professional lighting design is the consideration of reflectance values and specularity (gloss) values. Their importance is founded on two basic problems:

- Room lighting and daylighting are supported by what is known as “interreflection,” which is the support of light by the environment in which the light is found. Thus, installing two identical lighting systems in two rooms of the same size but with different furnishings and/or finishes can produce entirely different results. In a room with darker furnishings or finishes that absorb more light, the values of illuminance will be significantly lower. The values of luminance from surfaces will be even lower still.
- Dark finishes provide far greater luminance ratios in the field of view. For example, when dark boardrooms are installed along the curtain wall (window wall), the daylight entering the room is much more easily perceived as glare, since the luminance ratio in the room due to daylighting can change by a factor of 10 times due to the dark finishes.

A current trend in office design is to create darker, even charcoal, interiors. These interiors have a high-tech look, but they don’t support the lighting systems or the daylighting at all well. It is best to use much lighter hues, which meet the 80-50-20 percent rule on reflectance values for ceilings, walls (and partitions) and floors.

It is useful to know that the eye estimates reflectance at approximately double its value. It is also useful to know that white finishes (like printer paper) are about 80 percent reflectance rather than the 100 percent that many people believe. Thus, if the designer thinks he or she has designed an 80-50-20 percent interior, it is likely that the second and third values are really 25 percent and 10 percent. The only guess that is easy is the ceiling, as most manufacturers do not make standard ceiling tiles below 75 percent reflectance due to the lighting system problems that darker ceiling tiles cause.

With regard to specularity, the changes can also be dramatic. If the finishes along a curtain wall include high-specularity (high gloss) values, these finishes will mirror bright lighting sources, including the sun or the overcast sky. High-specularity window frames or window blinds will do the same. During certain seasons or times of the day, these surfaces will greatly increase glare or other visual distraction or discomfort.

## Lighting and Workstations



Many design issues in the approach to office planning will aid in lighting and daylighting performance, as well as in other building performance modalities.

- Occupant orientation in workstations
- Distance between occupant and barriers
- Height and reflectance rating of partitions
- Workstation entry orientations
- Selection and placement of glazing in workstations
- Selection and placement of components in workstations
- Type and placement of VDT screens

One general guideline with regard to layout is that if the occupant is not facing into a panel, improvements in performance will often occur in lighting, daylighting, acoustics and thermal comfort (see Figures 23 and 24).

Measurements made over the past three decades suggest that when one faces into a partition in a typical cubicle

- Ambient light levels at the front of the work surface are approximately one quarter of their empty room value. When occupants work on surfaces at right angles to the partition (normal desk style), this value doubles.
- Daylighting, if available, decreases dramatically, because the occupant's body shadow and the partitions reduce daylighting from all four directions.
- The occupant has no distant view and thus cannot relax his or her eyes.
- The occupant often confronts stagnant air conditions when facing into a partition, reducing thermal comfort and increasing local pollution due to decreased air movement that could otherwise rid the area of off-gassing.

Additionally, occupants generally prefer to face toward the entry to the workstation, as this allows them to see whoever may be standing at or near the workstation entry and listening to their conversations. This orientation also tends to prevent persons in the corridor from overhearing workstation conversations, since the occupant can now see such potential eavesdroppers.



Figure 23 — Typical Workstation Layout — Corner Orientation



Figure 24 — Advantageous Workstation Layout — Office Orientation

Many different types of lighting approaches for workstations are possible, and their performance and patterns are very different in the complex workstation environment. The following images illustrate some of these approaches and their resultant illuminance performance. Illuminance performance, however, does not directly equate to visual performance, which depends on the task involved and the luminous environment of the complex cubicle environment. To properly assess visual quality, or the design impact of the lighting selection independent of its technical performance, prototyping or visualization of the lighting environment is highly recommended.

The following illumination models are illustrated in Figures 25-32 on the following two pages:

- 2 x 2 symmetric lighting plan
- 2 x 2 asymmetric lighting plan
- 2 x 4 symmetric lighting vertical plan
- 2 x 4 symmetric horizontal lighting plan
- Linear symmetric indirect vertical lighting plan
- Linear symmetric direct/indirect vertical lighting plan
- Linear symmetric direct/indirect horizontal lighting plan
- Linear symmetric direct/indirect vertical lighting plan at 60 percent with task light

These models demonstrate that many different solutions can quite easily be designed to illuminate the same space, and that each of these solutions has advantages that can be characterized for visual quality, visual performance and for energy efficiency. They all are bound by the limits of the task and the task environment, and they can only optimize the task up to the limit of the task quality itself.

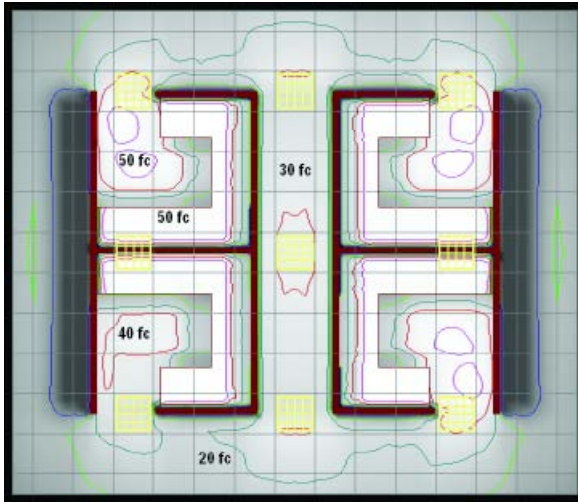


Figure 25 — 2 x 2 Symmetric Lighting Plan

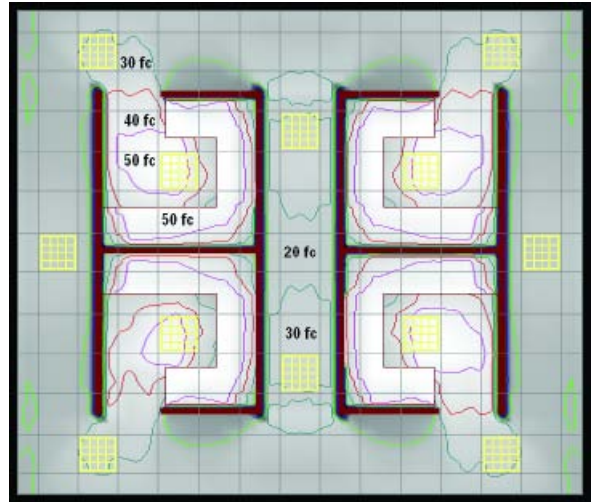


Figure 26 — 2 x 2 Asymmetric Lighting Plan

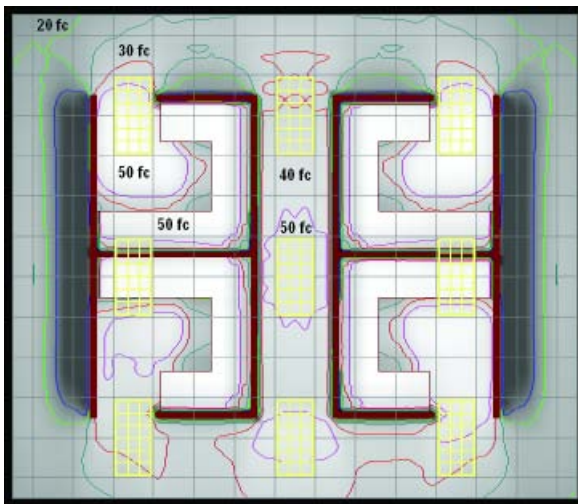


Figure 27 — 2 x 4 Symmetric Lighting Vertical Plan

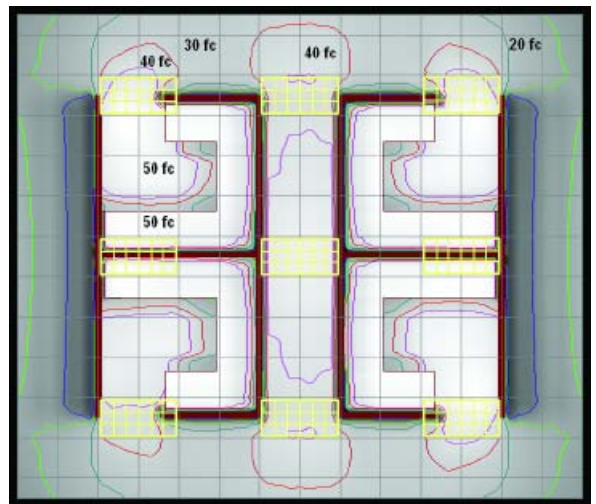


Figure 28 — 2 x 4 Symmetric Horizontal Lighting Plan

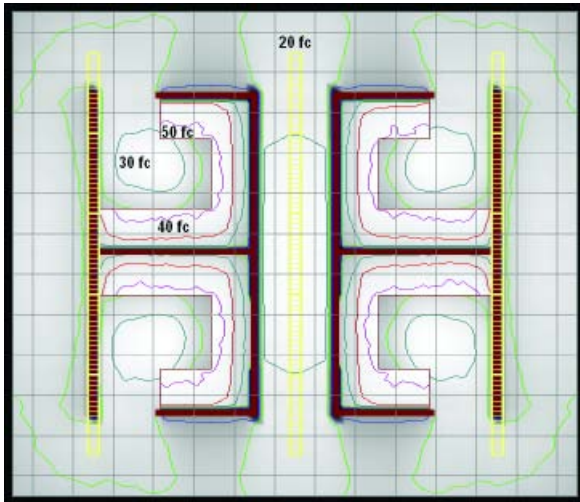


Figure 29 — Linear Symmetric Indirect Vertical Lighting Plan

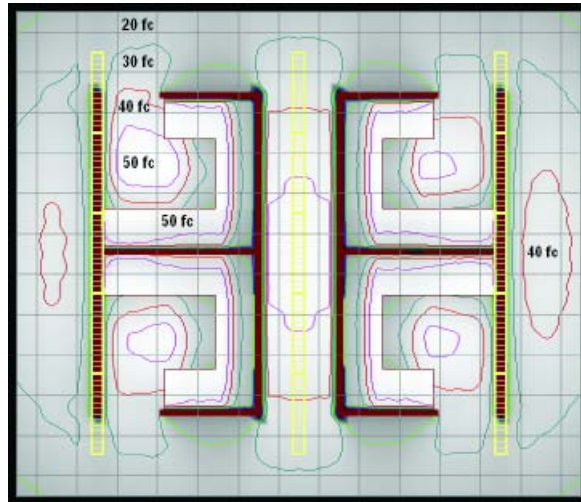


Figure 30 — Linear Symmetric Direct/Indirect Vertical Lighting Plan

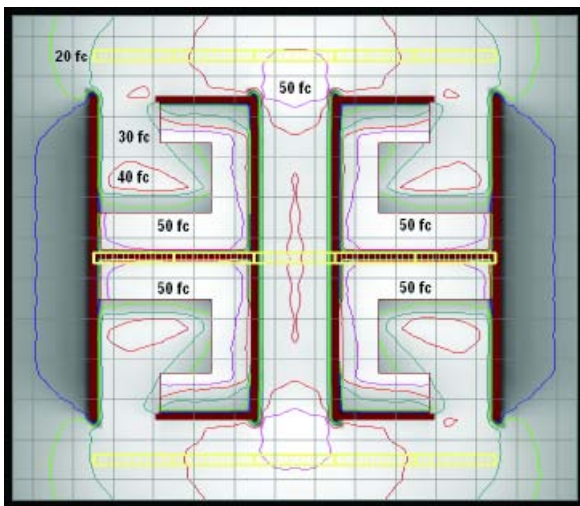


Figure 31 — Linear Symmetric Direct/Indirect Horizontal Lighting Plan

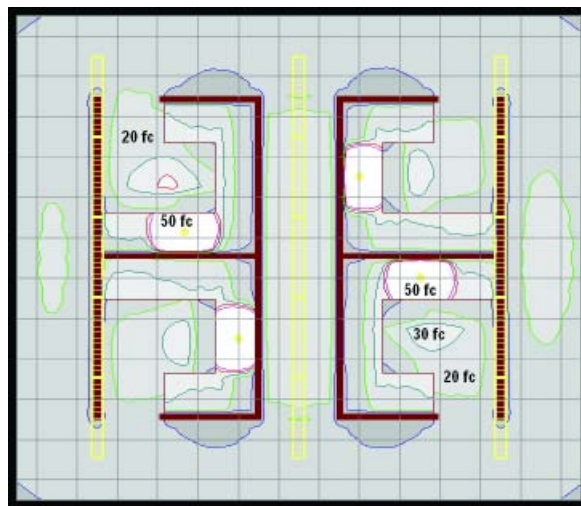


Figure 32 — Linear Symmetric Direct/Indirect Vertical Lighting Plan @ 60 percent w/Task Lighting

## Lighting in Offices and Conference Rooms



Private offices are often assumed to provide better lighting performance because of the more common presence of daylighting, the single occupant control of switches and dimming, and the presence, in many cases, of high-quality task and incidental lighting. While these conditions often do exist, other considerations arise with respect to the lighting and daylighting of closed office and conference spaces. These include

- Adjacencies to windows and issues of brightness and glare
- More concern with reflectivity and specularity of surfaces, as they must support more intense lighting and daylighting solutions, as well as maintain consistent luminance ratios
- Need for controls for brightness adjustment and energy capture

It is recommended that private offices have glazed fronts. Glazing the corridor wall will allow for much better open plan daylighting for the many occupants in cubicles with views of the office.

## Introduction to Lighting and Daylighting Control

*Daylighting* is the term used to describe that aspect of the architectural design of buildings that allows daylight to penetrate into interior spaces and which makes use of the available daylight in some fashion. Typically, a daylighting design consists of two components: (1) Diffuse skylight or dispersed sunlight effectively enters the building through adequate-sized windows or skylights, and (2) the building also uses a lighting control strategy that in one way or another makes use of information about available daylight to control the level of electric light and/or the penetration of daylight into a building. The latter is achieved by controlling the position of movable covers (shades, blinds, etc.) on windows and skylights. While daylighting control also can be used to control exterior lighting, this paper is only concerned with lighting control inside a building — the control of electric lighting, window and skylight covers, and the combination of the two.

The goals of lighting and window shade control in commercial buildings can be expressed as follows:

- Provide visual and thermal comfort for the occupants.
- Provide good visibility for tasks.
- Enhance personal safety and security. (Lighting is a part of the building's life safety system.)
- Protect interior surfaces. (This is more crucial in applications such as museums than in standard office buildings.)
- Save energy and reduce the demand for electricity.
- Improve maintenance of the lighting system. (For example, the control system can alert the owner when lamps have operated a given number of hours and should be replaced, or when it is likely that the fixture should be cleaned to improve light output and the efficiency of the system.<sup>4</sup>)

A daylighting control system consists of several components: lighting fixtures that are controllable (usually by being dimmed), motorized window and/or skylight covers of some kind, photo sensors that measure the available daylight, and a lighting controller that executes the control algorithm with the photo sensor reading as an input parameter. The outputs from the lighting controller are the lighting levels of the various lighting zones and the positions of the window covers.

<sup>4</sup> *The U.S. Green Buildings Council's LEED™ Rating System for commercial buildings has become quite popular with leading architects. This rating system addresses many of the considerations listed here but not all. Most notably, many of the occupant-based requirements are absent, such as visual comfort, visibility of the task, and human health and safety related matters. A lot of the applied work in this area is relatively new, but some results are starting to be available.*

## Recent Architectural Approaches to Enhance Daylight Penetration

To better understand the lighting and daylighting issues that arise in interior environments, it is helpful to begin with a few examples of how modern architecture tries to bring more daylight into commercial buildings.

The most effective way to enhance daylight penetration is by the use of skylights. It has been reported that fully 60 percent of commercial space in the United States is directly “under roof.” This often surprises people who think about skyscrapers in downtown settings when they think about commercial real estate in American cities. However, high-rise buildings account for just seven percent of the total commercial real estate. The majority are large numbers of one- and two-story buildings. With improved technology, previously reported problems with skylights (mostly water leaks) have been solved, and the current trend is to use more and more skylights in these low-rise commercial buildings. Indeed, California (in the 2005 edition of Title 24, the state’s energy code) has gone as far as mandating the use of skylights and daylighting control systems in single-story commercial buildings with ceiling heights greater than 15 feet.

On floors that are not directly under roof, architects have developed other ways to bring daylight deeper into the space. A very straightforward way is to increase the window-to-wall ratio of the exterior wall. However, it should be noted that windows located high on the wall are much more effective than windows lower down, for a given surface area. Therefore, we sometimes talk about daylighting windows (high up) and view windows (at eye level) as if they were different glazing systems entirely. Sometimes the ceiling is raised all the way to the concrete floor above to enable the use of even higher windows that increase daylight use. Furthermore, daylighting designers sometimes add light shelves above the view windows to bounce the incoming daylight onto the ceiling, which then reflects it down to the room so that the daylight distribution in the space becomes more uniform. Some manufacturers

have recently started developing louver systems, which in effect do the same job as light shelves but do not protrude so far into the space. Other manufacturers can provide complex skylighting systems that allow daylight to be directed through skylight openings and channeled down to lower floors.

The reasons for these trends are many, and almost all of them are tied to some aspect of human performance. Several studies have reported statistically significant improvements in student performance in schools, cash register sales in retail stores, and the like when the amount of daylight is increased in the space; however, at least in the case of daylight and elementary student performance, replications of some of these studies have failed to reproduce their results. Nonetheless, in the office environment, many people have begun to recognize that employees who have a view to the outside have a chance to rest their eyes during the day and have fewer problems with eye strain and headaches.



Another trend is to use highly transparent glass. In the 1980s, office buildings were built as more or less rectangular glass towers, fast and cheap. To reduce the solar heat gain in the buildings, the glazing material that was chosen had poor light transmission properties, i.e., it was highly tinted. The result was an unnatural view to the outside, and in today's terms, a poor "connection" with the outside. Whether to appease occupants or perhaps as a reaction to the recent problems of trust in corporate America, "transparency" has become a desired quality in recent corporate architecture. Corporations believe they gain public trust by being "transparent," and clear windows can serve as a metaphor for transparency, since one can see into the buildings from the outside. Renzo Piano's design for the Times building in New York is a good example of this new architecture. (That highly compensated employees also benefit from a better view and improved morale may factor into some boardroom thinking as well.)

The immediate effect of these new trends is that shading of the windows in some form is required; otherwise, the interior of the building becomes too hot, and the radiant heat and glare from the sun become uncomfortable. Once this need has been determined (whether in the construction phase or as a retrofit), daylighting as a control strategy becomes almost a given.

## Daylighting Control

Daylighting control can be based on a predetermined time schedule or on a system that employs sensors that actively measure available daylight. The former is suitable for noncritical applications, such as exterior lighting and perhaps lobbies and atria. The latter is used in critical applications where maintaining light levels to within a predetermined range is important. In these cases, we decide on the critical task surface or surfaces on which the target light level is maintained.

Very rarely is it permissible to place a sensor directly on the task surface, although from the control system's view point this would be ideal. For example, in the office environment the task surface is usually the desk surface, on which the goal is to maintain a certain illumination level (such as 50 fc or 540 lux). However, the desk is also a work surface and therefore will be covered by office equipment, papers and other materials, whose amounts and locations vary throughout the day. It is therefore impractical to place a sensor on the work surface, so some other sensor location needs to be found. Typically, it is the ceiling above the desk. If the reflected light from the sky is perfectly *diffuse* (that is, not directional), then the correlation between the ceiling illumination and the work surface illumination should be reasonably good.

Generally speaking, photo sensors respond to light that is incident on the sensor surface, and, as will be discussed below, sensors are not typically oriented directly toward a light source (whether the sun or electric light sources). Other than direct sunlight, which in most cases we want to eliminate from the task surface anyway, the other source of daylight is the *reflected* (and relatively diffuse) sunlight from the sky and from clouds.

In daylighting applications, the challenge is to orient the sensor in such a way that it measures this reflected daylight in proportion to how it varies on the task surface. Sensor placement, so that it does not face the exterior, is important because the sensor may be influenced by reflected light (that is, bright glare) from the exterior of the building (vehicles, parking areas, walkways, snow, etc.) that does not contribute to the illumination of the task surface. The ideal placement is such that the sensor has a high level of illumination from daylight but is shielded from any exterior glare sources.

When designing the interior of the space, it should be kept in mind that *specular* reflector surfaces (e.g., mirrors) need to be avoided. They appear relatively dark to the sensor most of the time, but when the sun is in precisely the right spot, they become very “bright.” Such readings do not correspond to the daylight environment in the room in general, and thus the signal of a sensor pointed toward a specular surface is not representative of the control needs in the room. *Diffuse* surfaces work best, since they randomize the direction of reflected light, and thus maintain a signal to the sensor consistent with the general daylight conditions.

Most hard surfaces in a commercial environment have diffuse and specular characteristics that may cause some difficulty. Such surfaces reflect most of the light in a diffuse manner, but they have a specular reflection component that is often about 10 percent of the amplitude of the incident sunlight. The diffuse component means that the (horizontal) surfaces directly illuminated by the sun have luminance that is consistent with the available daylight most of the day: The signal strength is high, and these target surfaces are very appropriate for a proportional control system. However, when the sensor is affected by the specular component of the reflection, it produces too high an output signal, so the control system needs to employ some time delay or long-term averaging to deal with this problem.

From an engineering viewpoint, it is tempting to define the illumination target for daylighting control systems as a constant illumination level throughout the day. For example, commonly the lighting designer or the building owner wants to ensure that the task surface (e.g., desk) has a certain level, e.g., 50 fc (540 lux), of illumination, which will be provided during the day by a combination of electric lighting and daylight. However, it is well known that different people prefer different illumination levels for similar tasks. Physiologically, these differences arise from, among other things, differences in the amount of scattering in the individuals’ eyes, so designing for a single light level is not acceptable. Furthermore, the *adaptation* that individuals experience during the day varies, but generally people are more dark-adapted during the early morning and late afternoon than in the middle of the day.



In an attempt to address these simultaneous needs, some people are advocating a lower illumination target profile at dawn and dusk that steadily increases from dawn to noon, for instance, and then decreases thereafter. This may complicate the control system commissioning process. A simple “compromise” method that satisfies almost all occupants is often preferred: The electric lighting systems are designed to deliver, for example, 35 fc in the absence of daylight (nighttime illumination level), while during the day the target set point for the lighting system is set to perhaps 50 fc. In addition, the occupants are given personal control of the lighting in their workspace, which allows them to dim the lights from the set points but not operate them at levels higher than the target. In the rare cases when an occupant demands more light, that particular lighting fixture setting can be changed to a higher set point.

## Four Strategies for Daylighting Control

With daylighting control, as with any control system, one needs to define the goals for the system performance. One of the following four strategies is typically employed in daylighting installations:

### Maximizing Energy Savings

Daylighting controls are most commonly used to reduce the energy consumption of an electric lighting system by taking advantage of available sunlight. Many commercial building codes are starting to strongly encourage or even require the use of daylighting controls in retail and office buildings. The goal is to reduce overall energy consumption and to reduce the use of nonrenewable energy resources. When this strategy is employed, the most common desire is to keep the illumination of the target surface more or less constant as the ambient daylight varies, so that the system adjusts the electric light level inversely with available daylight. Of course, when the daylight contribution alone exceeds the target illumination level, window treatments are going to be required if it is important to keep the target illumination constant. Equally often, the goal is only to ensure that a minimum illumination level is maintained. To be acceptable for the occupants, an energy saving strategy should be combined with a strategy to control sun glare, as described in the next section.

### Control for Visual Comfort and Visibility

Sometimes, daylighting control is used just to eliminate or reduce direct glare. This strategy requires the use of movable window treatments, such as horizontal blinds or roller shades. The goal is to keep horizontal or vertical *contrast ratios* below some critical value, typically 3. This strategy is primarily concerned with occupant visual comfort and visibility, and thus with occupants’ ability to perform their work. The idea is to program window covers so that direct sun glare is blocked during clear or partly cloudy days.

### Reverse Daylighting

Sometimes it is important to consider dynamic aspects of visual performance when designing a lighting control system, as described by the process of *adaptation*, or how the human eye adapts to a new lighting environment. All of us have experienced walking out of a dark movie theater and being momentarily blinded, or going from a bright outside environment to a relatively dark entry to a building and having to stop for a while before we see anything. During this time physiological changes take place in the eye (e.g., pupil size changes, and photo pigments are restored), and our brain makes adjustments in order to use the new visual signals that are of a very different magnitude from those it just previously received. In some applications, it is desirable that we assist this adaptation process by creating transitions from one light level to another. For example, this is commonly done at the entrances and exits of roadway tunnels, where being momentarily blinded is unacceptable. The same principle is also used in the case of street front retail stores, where the retailer wants to create a comfortable overall experience for the clients. The strategy used in this case is “reverse daylighting,” where the electric light levels are proportional to the available daylight. This strategy may also be combined with glare control.

### Minimize Daylight Exposure

Finally, some daylighting strategies are concerned with the exposure of the target to light, especially ultraviolet light. Museums provide a case in point, where some objects of art are sensitive to and can be damaged by excessive UV exposure. These objects are often rated as being able to withstand, for example, 1,000 lux-hours each year. Automatic control systems can be employed that keep track of the total lux-hours during the course of the year and operate window treatments, as well as electric lights, according to such a schedule. Both electric lights and window or skylight covers need to be part of this type of system.

It is important to remember that the definitions of lighting quality will drive the process of lighting analysis and the specification of solutions. If the project is defined as a collaborative environment where groups of people work together and have many standing meetings/discussions, then lighting should respond to this issue with broader task definitions. Work styles do make a difference in how lighting quality will be perceived.

## The Role of Window Films in Improved Visual Quality



Properly selected window films are a time-proven solution for improving the visual environment in offices. Below are some guidelines for properly selecting a window film to alleviate two common window problems, excessive glare and excessive heat.

Window films are often used in situations where excessive sunlight is passing through the building's windows, causing harsh glare on work surfaces, especially computer screens. Based on results obtained from many real-world applications, in cases where the amount of glare is a minor to moderate nuisance, typically a window film with a visible light transmission of 20 to 40 percent is sufficient (see Figures 33 and 34). However, when glare is extreme (such as with west- or east-facing windows where sunlight is directly shining through windows at low sun angles), use of window films with visible light transmissions of less than 20 percent are recommended. In these severe glare situations that involve single-pane clear windows, it usually is necessary to use films with visible light transmissions of less than 15 percent.

Window films are also commonly used in environments that are uncomfortable — where excessive sunlight heats the space too much or where cooling systems are undersized. A typical response is to use blinds or shades for long periods during the day in an attempt to reduce solar heat gain and make the space more comfortable. Unfortunately, blinds and shades normally completely obstruct the occupants' view to the outdoor world and are not always sufficiently effective at reducing solar heat gain. Using solar-control window films allows occupants to significantly curtail their use of blinds and shades, provides an unobstructed view and reconnects the occupants to the outdoors. Window films are able to do this by significantly reducing solar heat gain through windows (as much as 79 percent). In situations where occupants regularly complain of being uncomfortable, a window film with a Shading Coefficient of 0.40 or less (as measured on single-pane clear glass) will give the best results.

In environments that are uncomfortable from excessive solar heat gain, but where it is desired to maintain as much of the visible light from the sun as possible when adding window film products, newer generation spectrally-selective window films are the solution. These products use sophisticated ceramic coatings within the window film to mainly reject solar infra-red (IR) heat, while transmitting most of the visible light. This combination provides what is called a high “luminous efficacy,” which is the ratio of a window's solar heat gain coefficient divided by its visible light transmission. Products that are able to maintain a luminous efficacy above 1.0 are labeled as “spectrally-selective” and provide good heat rejection performance while maintaining ample visible light transmission.



Figure 33 — Office Lobby without Window Film



Figure 34 — Office Lobby with Window Film

## Lighting and Daylighting of New Office Building / Case Study

An example of the problems that can arise in lighting and daylighting design is an office project in the midwestern United States. This project is an 110,000-square-foot office building designed as the headquarters of a national firm. At groundbreaking, the client contacted Orfield Labs and indicated that he wanted a second opinion and review of some of the building performance issues, as he was uncomfortable with his current understanding of performance. The issues identified for review concerned daylighting, lighting, acoustics, sound masking and audiovisual systems. A daylight review was performed on the outside and inside of the building. On the outside, the architects had faced the long axis of the building to the west and designed a horizontal sunshade for this face. Although they believed it would have some benefit, they had not modeled the system on computer or calculated its benefit. Orfield Labs' analysis of the sunshade suggested that there were three problems:

- The sunshade was a south-facing design on a west-facing wall.
- The sunshade was dark in reflectance.
- The sunshade was specular in finish.

The existing sunshade was determined to have no significant sunlight shielding benefit, and Orfield Labs proceeded to design a south, east and west sunshade that was computer modeled to perform well with regard to shielding, reflectance and specularly (Figure 35). Thus, the east and west faces included vertical fins, and the south face included a horizontal overhang. The finish was changed from a very dark color to a very light color and from a glossy (specular) finish to a matte finish, and the architects changed the window mullions to match.

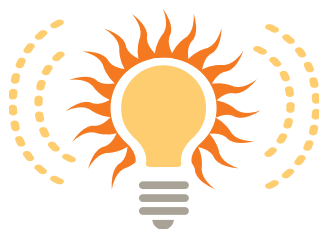
On the interior of the building, the indirect lighting system created significant glare on the ceiling. The color scheme was dark in reflectance. The cubicles all oriented the occupant into a corner. Orfield Labs explained to the design team that the reflectance values of the interior colors were too low and would not support daylight penetration into the building, and recommended they select lighter finishes. This process moved through a series of iterations, until all reflectance values were in the specified ranges. With regard to cubicles, all were redesigned to give all occupants a forward view out of their cubicles and no components were allowed to block the ambient lighting system or occupant views. The indirect lighting system was redesigned as a direct/indirect system of similar appearance but greater efficiency.



Figure 35 — Day-light Shielding

*This headquarters building, which would have had very little daylight, high glare, a dark and contrasting interior, and fatiguing lighting systems, now has a strongly daylighted interior with a high quality visual comfort range and perception of daylighting throughout the building. Most importantly, at seated occupant positions the building now has significantly higher visual quality, visual comfort and comfortable lighting and daylighting.*



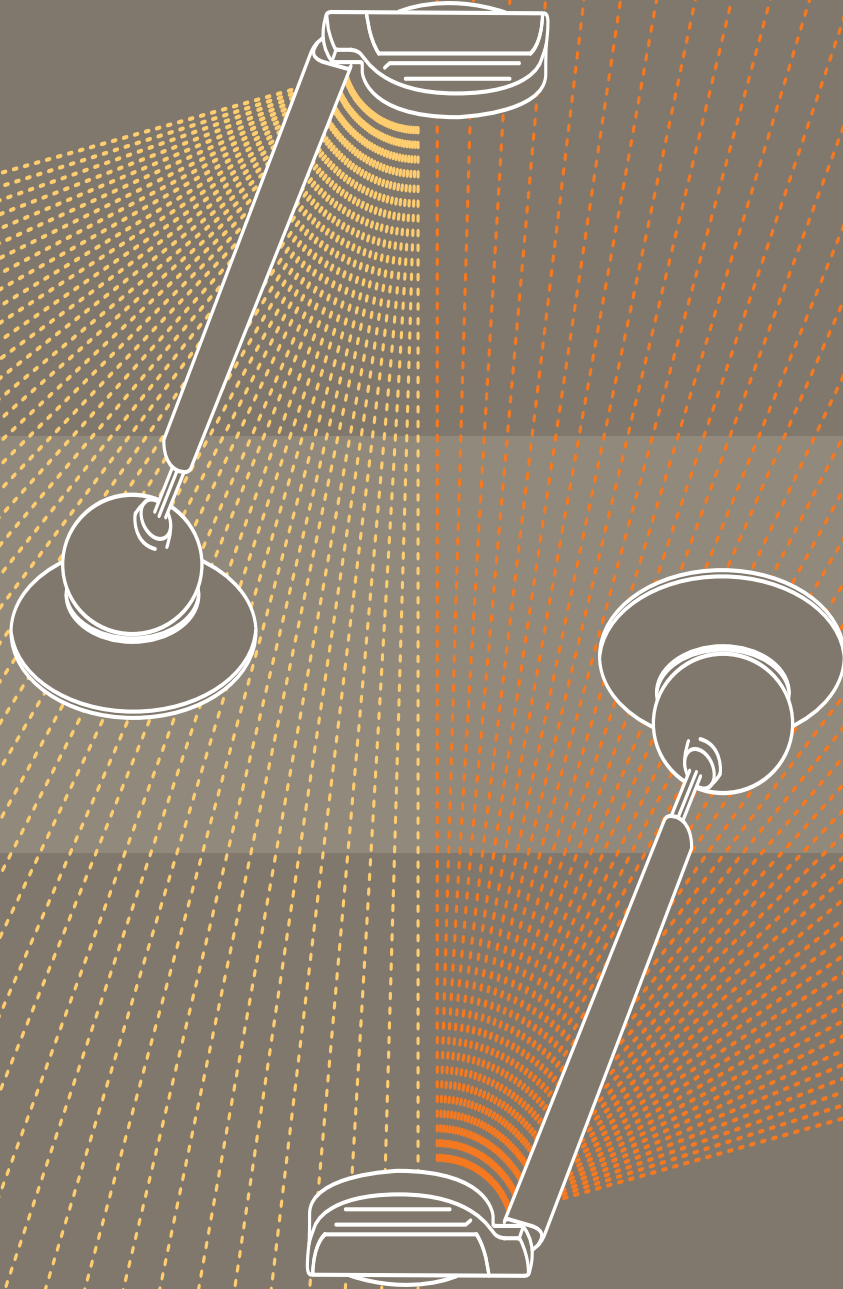


**PART V**



better lighting and  
daylighting solutions

0.5



## PART V Common Problems in Current Office Lighting and Daylighting

The lighting field has informed the lighting design community very well for many years. Yet most office projects still fail to follow important aspects of good lighting practice. In our experience, the following are the most commonly missed issues in lighting and daylighting design.

### Workstation Visual Quality

- **Less Enclosure** – Most workstations are being designed lower to create a more open visual environment. Higher workstations should be used where privacy is needed, but with upper glazed levels.
- **Occupant Views and Orientation** – Most occupants of open plan offices are faced into an office system panel, thus taking away their view and their supervision over their workstation entry, reducing their acoustical privacy, and reducing their thermal comfort. Orientation should always be toward the entry, not into a panel.
- **Task Illuminance** – Most occupants are given too much ambient lighting and too little task lighting. They are also given task lights they cannot control, other than to turn on or off.
- **Task Position Glare** – Most occupants are sitting in a glare field, as a result of poor ambient lighting. Reducing glare should always be a prime criterion in office lighting.
- **Glazing in Workstations** – Most workstation layouts do not use glazing effectively. As a result, the occupant receives poorer lighting and little perception of daylight.
- **Reflectance and Luminance Ratios** – Most occupants sit in spaces where reasonable reflectance values have not been maintained. As a result, they have less lighting, poorer luminance ratios and more glare.
- **Specularity of Reading Tasks** – Most occupants have reading tasks that are difficult to accomplish with the nonadjustable task lighting and high-level ambient lighting they are provided. These tasks often have some level of specularity, due to the materials used in printing. Adjustable task lighting should always be specified for these workers.

### Ambient Lighting Visual Quality

- **Ambient Lighting Selection** – Ambient lighting selection must be made based on visual quality and visual performance quality. Visual performance is the dominant issue that is generally unresolved. Thus, most ambient lighting systems are high in peripheral glare and therefore low in visual efficiency. Limiting levels of luminance is recommended.
- **Vertical Luminance** – While most ambient lighting is designed for horizontal luminance, most cues to satisfactory lighting levels are vertical luminance cues from walls, partitions, etc. Via the right selection of reflectances and adequate lighting on vertical surfaces, the typical “dark space” perception can be resolved.
- **Energy and Luminaire Selection** – Most ambient lighting systems are designed based solely on illumination level, calculated in an empty room. They miss their illuminance targets by a large margin and do not take lighting quality into account. Most lighting is selected partially by considering the CU (Coefficient of Utilization), which is a measure of efficiency but a poor guide to lighting quality.
- **Asymmetric Lighting Option** – Asymmetric lighting is very seldom considered, even though it is one of the most efficient and economic types of systems. It should be assessed on any project where budget is an issue.
- **Controls** – Research has shown that lighting controls must fall into two categories: general lighting, which must be automatically and continuously dimmed, and local task controls, which should be dimmable and controllable by the occupant.

## Ambient Daylighting Visual Quality

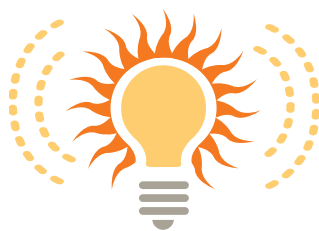


### Interior Issues

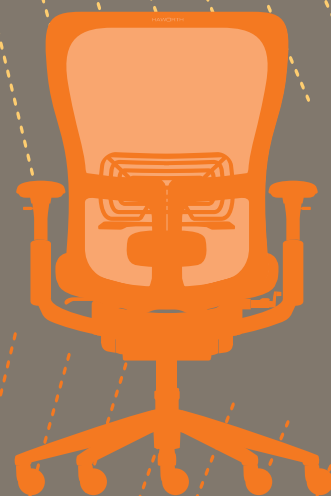
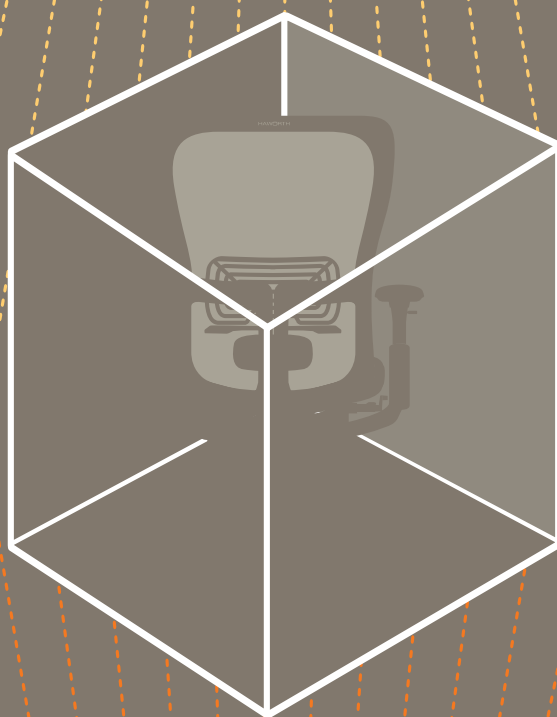
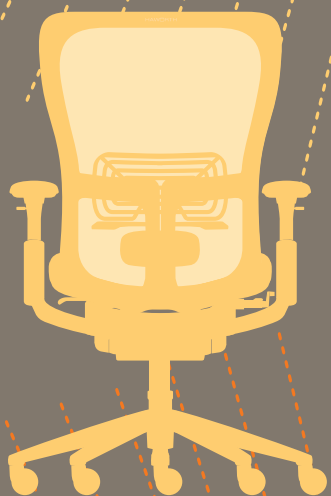
- **Daylighting Glare** – Most occupants sit in spaces where direct sun and overcast daylight have not been considered and designed into the lighting and daylighting control; they are often visually uncomfortable and sometimes visually disabled.
- **Daylighting Dimming** – Most offices do not use daylight dimming, even though it saves energy costs by reducing unnecessary light. This is part of the sustainable movement and should always be considered.
- **Window Controls** – Many new offices do not use window controls, as the designer wants the “look” of exposed glass. This always causes daylighting problems. Daylighting controls on windows and skylights must always be designed and specified, based on lighting and daylighting criteria.

### Exterior Issues

- **Glazing Selection** – Many architects are still selecting dark tinted and reflective glass, although good daylighting practice demands high-visibility glazing. In the absence of extreme conditions, high-visibility or clear glass should always be the first choice.
- **Exterior Shading** – The most efficient energy window control, it is hardly ever considered. It should always be assessed on any major project.
- **Selection of Leased Buildings** – Buildings should be selected primarily by their occupant quality, including daylighting as a primary criterion. The closer one is to daylight openings, the more the building will be preferred.
- **Building Shape and Orientation** – Building shapes and orientation are generally not carefully selected. In considering buildings in regards to new design or leasing, shallow shapes with long east/west axis (facing south) are most preferred.



**PART VI**



## PART VI The Potential for Future Office Lighting and Daylighting Research

At least some modest developments have changed the nature of office lighting and daylighting product quality over the past 20 years. In the 1980s we had

- Parabolic lighting
- Indirect lighting
- Direct/Indirect lighting
- Highly rated luminaires
- Understanding of color reflectance and gloss
- Understanding of visual performance and visual comfort
- Less restrictive lighting budgets

Many things have happened to reduce product performance.

- Higher open plan densities and much smaller workstations have led to reduced lighting and daylighting levels due to barrier effects and less open spaces.
- Our current energy-based lighting approach has provided us with many luminaires (parabolic, cans, HIDS, etc.) that are far worse in terms of peripheral brightness at the seated position within cubicles.
- Attention to high-angle brightness for parabolic luminaires to achieve dim distant views has reduced lighting quality by increasing local glare above workstations.
- Specular reflectors have become popular, increasing glare and visual discomfort.
- Newer sources, such as T-8 and especially the T-5 tubes, have greater surface brightness than the T-12 tubes used in most luminaires in the 1980s.
- Color schedules have become darker in many cases.
- Budgets for lighting are generally based on less expensive products.
- Indirect lighting is far more often used for total ambient lighting.

Part of the reason for these reductions is the misperception that product energy specification alone will resolve lighting and daylighting issues, without either understanding the co-efficient of utilization specification or knowing whether the

relevant performance ratings are correct. This confusion may be due partly to the infrequent use of lighting consulting and testing of open plan offices.

Some clear advances in lighting products and processes also have made better lighting more possible, if not probable.

- Much better software tools are available for both lighting and daylighting. The better programs provide three-dimensional modeling of daylight and light levels, which aid in understanding the visual impact of lighting.
- Better testing and analysis systems, including video photometry, allow for superior luminance mapping of environments and quick measurements of point-source glare.
- Some new approaches to ceiling lighting systems are available, including the so-called “direct/indirect” luminaire that mounts within the T-bar ceiling grid.
- We now have better knowledge of the visual performance of older occupants.

As we look toward the future of the open plan office, we must look for more complex and meaningful implementations. This means that

- We need to better understand the needs for and benefits of lighting and daylighting quality for each project, and we must measure (pre and post) the occupants and the office to determine the outcomes and value of the design process.
- We need to bring lighting and daylighting expertise back into the design process, where it has been set aside. The probability that a design team, working with a lighting vendor team alone, will produce an optimized visual environment has been very low in practice. This relates to both definition and results.
- We need to be able to put a dollar value on lighting and daylighting benefits for each client, which means that projects must use occupancy studies both before and after project implementation, using commissioning on the project and employing remediation at the early post-occupancy phase.



With regard to products, many interesting applications from lighting and daylighting, psychological perception, ophthalmology and behavioral science could be employed in the development of a whole new range of products and practices for the open plan office. These products have the potential to

- Increase the visual connection to daylighting
- Reduce the visual barrier effect of office panels
- Reduce speech-related noise at the receiver
- Reduce the perception that privacy is necessary in some cases
- Increase the perceptual value of each level of privacy
- Increase personal control of the visual environment

We have done much to argue for high-quality lighting and daylighting, but we need to prove its need and value. Compared to research comparing lighting or daylight to its absence, there has been less research directed toward the specific, unique benefits of daylight, for example, or regarding the specific, unique benefits of full-spectrum lighting compared to alternatives. What portion of the benefits from a well-lit space does daylight contribute? What portion does task lighting contribute? What portion does ambient lighting contribute? Does having an external view (a view outside of a building) incrementally improve on mere exposure to natural light (such as through a translucent skylight)? Does a liquid-crystal display of an external view projected onto an interior wall provide the same benefits as an actual external view? Comparisons between typical ambient lighting and full-spectrum lighting have been inconsistent regarding the impact on human performance and productivity — although full-spectrum lighting does appear to impart consistent mood benefits. Thus, the quantitative, independent benefits of the various possible kinds of lighting within the built environment that would be necessary to conduct a thorough costs/benefits analysis remain to be delineated.

In addition, we now need to begin to understand how lighting affects older workers, what differences in lighting they need, how we can provide it and what is the cost-benefit equation. We have to understand implicitly that this is not about lighting but about occupants and their perception of the quality of their environment. In other words, with the help of the design and facilities communities, we must put the evaluation and measurement of people back into the design equation.

## Appendix. Outline for an Occupant-Centered Open Office Project

The process and methods discussed in this paper can be easily and directly employed on any project to ensure that lighting and daylighting (or other perceptual stimuli) will be positively perceived by the occupant and will provide a measurable economic benefit to the client, principally due to the increased preference and comfort of the occupant.

These methods can be incorporated into the standard design phases in most projects, and they do not change the normal activities included in the design process but simply add substantial definition and performance to the project.

### Schematic Design and Pre-occupancy Studies

1. Assemble full design team, including the lighting and daylighting consultants.
2. Perform pre-occupancy studies of each relevant department or work group to draw baselines on current building performance and job quality rankings. (These studies should include human resource statistics and productivity statistics, if available.)
3. Based on the pre-occupancy studies and other programming results, develop a building performance hypothesis and an occupancy performance hypothesis.
4. Employ visual juries, simulation, prototyping and lighting and daylighting engineering to test schematic designs for building performance and occupancy satisfaction.
5. Take iterative steps based on the results of step 3.
6. Finalize schematic design approach.

### Design Development

- Employ ongoing lighting and daylighting consulting to insure that the standards adapted in Schematic Design are followed and to suggest and test engineering solutions for the project.
- Develop final lighting and daylighting applications that meet the performance standards of Schematic Design. Develop plans, specifications and performance standards for solutions.

### Contract Documents

- Review inclusion of plans, specifications and performance standards in the final contract documents.

### Contract Administration

- Assist design team and vendors to understand the specifications and to respond to the bids for the project. Review and accept/reject alternatives.

### Commissioning and Post-occupancy Studies

- Perform early post-occupancy studies and building performance measurements to determine issues that are problematic and in need of resolution.
- Develop a list of compliance issues for contractors.
- Retest to confirm compliance and perform final adjustments.
- Perform late post-occupancy studies to determine outcomes of the project in terms of building performance, occupancy satisfaction and financial outcomes from changes in human resource values or productivity.

### Considerations When Selecting Lighting and Daylighting Consultants

Whenever possible, an experienced lighting professional, such as members of IESNA and IALD, should be included as part of the design team. Design firms must investigate the knowledge, abilities, experience, and testing and modeling capabilities of the lighting consultant, as well as their general orientation to the holistic design process. Although lighting can often be the missing link in office projects, sometimes the opposite occurs, and lighting becomes the most important part of the project, an equally bad mistake. Projects that over-emphasize one building performance area over others frequently suffer from failures in daylighting, lighting and thermal comfort.

In design-build projects, the lighting and daylighting engineering are the responsibility of the electrical and mechanical contractors, who seldom have a depth of expertise in these areas. On other projects, the electrical and mechanical engineering staffs may be tasked to determine lighting and daylighting solutions. While these engineers generally have a higher degree of training and expertise than do some other contractors, they are rarely trained in the nuances of lighting and daylighting consulting, and thus often rely on contractors and vendors for the development of lighting and daylighting solutions. In either case, the results are usually less than satisfactory.

## About the Authors



### Steven J. Orfield

Steven Orfield founded Orfield Laboratories 35 years ago after majoring in philosophy at the University of Minnesota. In 1970, he began researching and consulting on acoustics and lighting in the open plan office for two of the first manufacturers of office systems in North America.

Orfield Labs worked principally in the architectural building performance field (daylighting, lighting, acoustics, audiovisual) until 1980, when Orfield entered the corporate research field. From an early interest in perception and measurement, he has developed the firm into the only multi-disciplinary subjective-objective research lab in the United States, serving clients here and abroad. He holds patents in both the acoustics and lighting fields.

Orfield has also been instrumental in introducing new approaches to these fields with the founding in 1991 of the Sound Quality Working Group, in 1998 of the Open Plan Working Group, and in 2003 with the founding of the Medical Facilities Working Group. These three organizations are intent upon changing their fields in fundamental ways and moving them toward perceptual and occupant-based approaches. He has published more than 100 articles in the firm's disciplines in the national press and has presented many seminars locally and nationally. In 2001, he was invited to serve as an Adjunct Professor of Acoustics at the Architecture School at the University of Minnesota while teaching a graduate course in Acoustics with the staff of Orfield Labs. Orfield Laboratories is a federally certified acoustical laboratory.

### Jay L. Brand, Ph.D.

Prior to joining Haworth, Inc., Industry Partner of ASID, seven and a half years ago, Dr. Brand was chair of the department of psychology at La Sierra University in Riverside, Calif., and later associate professor of psychology at Loma Linda University, where he helped develop Ph.D. and Psy.D. programs in psychology — both accredited by the American Psychological Association. He has held various positions at Haworth,

including human factors/cognitive engineer, organizational behavior specialist and corporate ergonomist. His current title is cognitive psychologist.

As a member of five professional societies, Dr. Brand conducts and applies research in a number of areas, from sensation and perception, cognition and industrial/organizational psychology, to the design and evaluation of work environments. The results of this work have contributed to over 50 professional publications and provided implications for specific product designs, space configurations and layouts, and individual and organizational outcomes. Currently a public director on the American Institute of Architect's board of directors, associate editor of *Ergonomics in Design*, and newsletter editor for the Environmental Design Technical Group of the Human Factors and Ergonomics Society, Dr. Brand believes that the strategic blending of both artistic and scientific understanding of emotion, intuition and cognition within their cultural and spiritual contexts will guide the design of effective work environments that delight their occupants.

### S. Pekka Hakkarainen, Ph.D.

Dr. Hakkarainen has worked at Lutron, Industry Partner of ASID, for the past 15 years, and has been involved in a variety of lighting system designs and applications in the commercial market. His current title is director, technology and business development, and in this role he is involved, among other things, in the development and applications for daylighting control systems, which include both electric lighting and motorized window shades.

Pekka received his education at Cambridge University, England, and at the Massachusetts Institute of Technology, where he received a Ph.D. in the area of plasma physics, with application to nuclear fusion. Pekka is active in IESNA, and currently serves as the chair of the Papers' Committee. He is also Lutron's representative at the National Electrical Manufacturers' Association (NEMA), where he has previously chaired the Lighting Controls section.

## Glossary of Lighting Terms

### A-Line Lamp

A type of incandescent lamp generally used in indoor residential lighting applications.

### Accent Lighting

Lighting used to accent or highlight a particular object, such as a work of art. To be effective, accent lighting should be approximately four or five times the level of ambient light in the area. House plants can be accented by aiming an uplight at the wall behind the plant, creating a dramatic silhouette of the plant against the wall.

### Ambient Lighting

General background lighting used to soften contrasts between task lighting and the surrounding areas.

### Ballast

An electrical device used with fluorescent or HID lamps to supply sufficient voltage to start and operate the lamp but then limit the current during operation.

### Brightness

The perceptual (subjective) response to light level of a given intensity either emanating from a luminous (incandescent) source or reflecting from a surface (see **Incandescence**).

### Brightness Contrast

The perceptual response to adjacent surfaces reflecting different light intensities.

### Clarity Diffuseness

The amount of visual clarity attained when light is viewed or transmitted through a nonopaque surface.

### Coefficient of Application

The amount of light that actually strikes task surfaces as a percentage of total light source power (nonstandardized).

### Coefficient of Utilization (CU)

The amount of light that escapes a luminaire, as a percentage of total light source power; it is used to evaluate luminaire efficiency.

### Color Constancy

When the subjective colors of surfaces remain consistent over a wide range of luminance values.

### Color Rendering Index (CRI)

A measure of a lamp's ability to render colors accurately. The scale ranges from 1 (low pressure sodium) to 100 (the sun). A CRI of 85 is considered to be very good.

### Color Temperature

A measure of the color appearance of a light source that helps describe the apparent "warmth" (reddish) or "coolness" (bluish) of that light source. Generally, light sources below 3200K are considered "warm" while those above 4000K are considered "cool" light sources.

### Compact Fluorescent Lamp (CFL)

A generic name used for a whole family of small, single-ended fluorescent lamps with a folded, bridged or spiral glass tube design, with high color rendering (CRI>80) and a long life (>8,000 hours).

### Cove Lighting

A lighting system comprised of light sources shielded by a ledge or recess, used to distribute light over the ceiling and sometimes the upper part of the wall.

### Dimmer

A device in an electrical circuit used to vary the brightness of lamps in a lighting installation. Dimming controls are ideal for almost any type of room because they easily allow the amount of lighting to be modified to suit the mood or activity at any given time.

### Down Light

A small light fixture recessed into the ceiling that usually concentrates the light in a downward direction; also referred to as recessed down light, "can" or recessed can.

### Emergency Lighting

Lighting used when the normal lighting fails, such as during a power failure. National, state and local codes require emergency lighting in commercial, industrial and institutional buildings.

### Flexible Track Lighting System

A low voltage or a line voltage lighting system where the suspended track (sometimes called a monorail) that holds the light fixtures in place and conducts electricity to those fixtures can be bent into creative shapes.

## Glossary of Lighting Terms



### Fluorescent Lamp

A low-pressure mercury electric-discharge lamp in which a phosphor coating on the inside of the glass tubing transforms some of the ultraviolet energy created inside the lamp into visible light.

### Foot Candle

A measure of the amount of light reaching a subject. The common United States unit of measurement of lighting level (illumination) is the foot candle (fc). The international unit of measurement of lighting level (Illumination) is the lux (lx). The relationship between the lux and the foot candle is  $1 \text{ fc} = 10.76 \text{ lux}$ .

### General Lighting (Ambient)

Substantially uniform lighting of a space without providing for special local lighting requirements, like task lighting or accent lighting.

### Glare

Direct glare is caused by light coming directly to the eye from a light source. Indirect glare is light reflected from a surface in the direction of the eye. Both can harm vision and cause visual discomfort or disability.

### Halogen Lamp

A type of incandescent lamp (sometimes called a tungsten halogen lamp or a quartz lamp) that contains halogen gases (such as iodine, chlorine, bromine and fluorine), which slow the evaporation of the tungsten filament.

### HID Lamp

High intensity discharge (HID) lamps have a longer life and provide more light (lumens) per watt than most other light sources. Available in mercury vapor, metal halide, high pressure sodium and low pressure sodium types.

### Incandescence

Light emission by a heated filament.

### Incandescent Lamp

Lamp in which light is produced by means of an element heated to the point of incandescence by the passage of an electric current.

### Infrared Radiation

A type of invisible radiation for which the wavelengths are longer and frequency lower than those for visible radiation.

### Instant Start

Fluorescent lamps that start instantly without pre-heating the cathodes and without the need for starters.

### LED

A light-emitting diode. A small electronic device that lights up when electricity is passed through it. LEDs are quite energy-efficient and have very long lives. They can be red, green, blue or white in color.

### Light Fixture

A complete lighting unit consisting of a lamp or lamps, a housing and a connection to the source of electrical power.

### Louver

A type of "screen" made of translucent or opaque material and geometrically designed to prevent lamps from being viewed directly within a given angle. Louvers are intended to minimize direct or indirect glare.

### Lumens

The amount of light that a lamp produces or emits.

### Luminaire

A light fixture.

### PAR Lamp

A parabolic aluminized reflector (PAR) lamp may use an incandescent filament, a halogen filament tube or an HID arc tube. It is a precision pressed-glass reflector lamp that reflects light coming from the filament much like a parabola. PAR lamps (such as PAR20, PAR30 and PAR38) rely on both the internal reflector and prisms in the lens for the control of the light beam.

### Pendant

A type of lighting equipped with shades or globes to avoid glare that are suspended from the ceiling over dinette tables, game tables, kitchen counters or other work areas. When used over end tables or night tables, they free up the space occupied by table lamps. In general, pendants should be hung about 30 inches above the tabletop and be about 12 inches narrower than the table on all sides. Pendants can provide both task and general lighting.

**Rapid Start**

A fluorescent system that does not require starters and takes one to two seconds to emit light. The ballast preheats the electrodes within the fluorescent lamp and initiates the arc without a starter or the application of high voltage.

**Rated Life**

The rated life of a lamp signifies the time at which 50 percent of a large quantity of these lamps will have burned out. That means that 50 percent of these lamps will burn out BEFORE the rated life and 50 percent will burn out AFTER the rated life. The rated life does NOT mean that every one of the lamps will last at least that long. Also, please note that the Actual Life of a Lamp = the Rated Life of that Lamp x Rated Voltage/Operating Voltage raised to the 12th power. For example, the Actual Life of a certain lamp that is designed to be used with 130 volts is equal to the Rated Life of that lamp (let's say, 1000 hours) multiplied by 130 volts/120 volts raised to the 12th power. The Actual Life of this Lamp is, therefore, equal to (1000 hours) x (1.083) raised to the 12th power = (1000 hours) x (2.61) = 2610 hours. That means that an incandescent lamp that has a rated life of 1000 hours and is designed to be used with 130 volts BUT is used with 120 volts instead will have an "Actual Life" of 2610 hours.

**Simultaneous Color Contrast**

The situation where two surfaces reflecting identical wavelengths of light appear to have different colors if surrounded by areas reflecting different wavelengths.

**Simultaneous Contrast**

The situation where two surfaces of identical luminance appear to have different brightness if surrounded by areas with different luminance.

**Starter**

An electrical device used in conjunction with a ballast for the purpose of starting an electric discharge lamp, such as a fluorescent lamp or an HID lamp.

**Task Lighting**

Lighting that is specifically installed to light an area where a task is performed.

**Troffer**

A large recessed luminaire (light fixture) that often uses several fluorescent lamps, measures 24" x 48", and is usually installed with the opening flush with the ceiling.

**Uplight**

The percentage of lamp lumens directed from a luminaire at or above 90 degrees.

**Wall Sconce**

A luminaire affixed to the wall and usually decorative in nature.

**Wall Washing**

A lighting technique that produces a relatively smooth, even level of illumination on the wall and reduces the texture of the surface.

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- (See also NRC's [http://irc.nrc-cnrc.gc.ca/pubs/ci/v8n01/v8n01\\_4\\_e.html](http://irc.nrc-cnrc.gc.ca/pubs/ci/v8n01/v8n01_4_e.html). This provides an annual daylight analysis of buildings featuring translucent solar panels. A daylight simulation model and tutorial are also available at <http://irc.nrc-cnrc.gc.ca/ie/light/daysim.html>.)



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