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Office Lighting Investments: Payoffs for People and the Environment

by J.A. Veitch and G.R. Newsham

The lighting industry has been hampered by the lack of a widely accepted means of assessing lighting quality. This Update reports the first results from a lighting quality research project conducted by NRC's Institute for Research in Construction.

Office conditions have changed a great deal in the past thirty years. Fluorescent lighting, the mainstay of office lighting since the 1930s, mostly consisted of regular arrays of recessed luminaires with the lamps covered by prismatic acrylic lenses. These direct lighting systems provided bright walls and very bright horizontal surfaces. Bright working surfaces were believed to be important to ensure task visibility, a concern that was highly justified: it was not uncommon for people to spend hours each day reading third-generation carbon copies, or faint pencil marks on paper.

Figure 1. Luminaires behind the seated worker cause unwanted reflections on the computer screen.

Today, almost every office worker spends at least part of the day working on a computer, a fact that has profound implications for office lighting. Instead of reading from a piece of paper on a horizontal surface, these employees now read from a self-luminous, vertical glass screen. The lensed luminaires that provided good horizontal illumination on desks suddenly became sources of unwanted screen reflections (see Figure 1). Glare can reduce a person's ability to read information on a screen, with consequences ranging from inconvenient to disastrous, depending on the criticality of the task and the extent of the problem. For example, because stock traders need to be able to read, precisely and quickly, the stock prices on their monitors, severe glare can lead to costly inaccuracies in the information they supply to their clients.

Consensus-Based Lighting Recommendations

North American lighting recommendations for lighting specifiers and designers emerge from the Illuminating Engineering Society of North America (IESNA). The current standard relevant to office lighting is IESNA RP-1 (1993), American National Standard

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Basics of Fluorescent Lighting

A fluorescent lighting system consists of three parts: the luminaire, the lamps and the ballast. Luminaire is the technical term for any lighting fixture; it contains the lamps and the ballast, and might also include optical devices to direct the light. Fluorescent lamps emit light when their phosphor coating receives energy from gaseous mercury atoms excited by an electric arc. The ballast controls the electric arc across the lamps, preventing the voltage from increasing with destructive effect.

Many people dislike and distrust fluorescent lighting. Among the most common complaints are "it flickers" and "it hums." Both are traceable to ballasts. The original ballasts for fluorescent lamps were coiled-core magnetic ballasts, which can produce an audible hum [Rea, 1993], depending on their construction and on the luminaire. Magnetic ballasts, when operating correctly, operate fluorescent lamps at 120 Hz (2x the 60 Hz AC current). Few people can perceive this modulation in light output as flicker; however, as lamps and ballasts age, the modulation rate can slow to the point where flicker is perceived. This can be a source of annoyance. Moreover, there is evidence that the nervous system can detect luminous modulation up to 147 Hz, even when the observer does not report seeing flicker.

Advances in integrated circuitry have led to the development of electronic ballasts, which operate in the frequency range 20 000–60 000 Hz. This frequency is high enough that any ballast noise is inaudible to humans and the luminous modulation cannot be detected by the nervous system. Functionally, electronic ballasts are noise- and flicker-free. The high frequency is designed not to be so high as to cause electromagnetic interference. Electronic ballasts have the added benefit of being more energy-efficient than magnetic ballasts.

Practice for Office Lighting. Table 1 provides a summary of these recommendations, which are intended to provide adequate light on the desk surface to read documents, while reducing the degree of glare on computer screens. Luminance ratio limits are intended to prevent excessive contrasts between light and dark.

Lighting recommendations are notorious for their weak link to published research, and the research literature itself is notorious for its poor quality. The recommendations are the considered opinion of experienced lighting designers and illuminating engineers, but they cannot assure us that lighting designs that meet these recommendations will meet the needs of occupants, contributing to their task performance, comfort, health, and satisfaction.

The development and adoption of energy codes for buildings poses an additional challenge for office lighting by placing limits on the electric power devoted to lighting. ASHRAE/IESNA Standard 90.1, *Energy efficient design of new buildings except new low-rise residential buildings*, and the Canadian *Model National Energy Code for Buildings* both limit acceptable lighting power densities for offices to approximately 14 W/m^2. The newly developed energy codes and standards have created renewed fears that reduced energy for lighting would lead to poorer quality lighting. This was demonstrably the case during the 1970s energy crisis, when delamping was the predominant energy-saving strategy. Advances in lighting technology have given rise to new alternatives for energy savings, but in the absence of any agreement on how to assess lighting quality, there was little confidence that these new technologies would prevent a repeat of earlier problems.

IRC Lighting Quality Research

The National Research Council of Canada's Institute for Research in Construction (IRC) responded to this concern with the project "Experimental Investigations of Lighting Quality, Preferences and Control Effects on Task Performance and Energy-Efficiency," which began in October 1994. Its objectives are:

Table 1. *Summary of recommendations from IESNA RP-1*

Illuminance on desk (lux)	Max. ceiling luminance (cd/m^2)	Task: surround luminance ratio	Task: wall luminance ratio	Ceiling max/min luminance ratio	Other considerations
300–500 (200–300 general; 300–450 task)	preferred: 850 @ 55-deg angle acceptable: 850 @ 65-deg angle	3:1	10:1 or 1:10 40:1 max. outside field of view	preferred: 4:1 acceptable: 10:1	VCP* > 70 Reflectances and finishes Maintenance * visual comfort probability

Figure 2. *A workstation lit with the low-LPD/high-DLQ condition.*

	LPD 1	LPD 2	LPD 3
DLQ 1	•	•	•
DLQ 2	•	•	•
DLQ 3	•	•	•

Increasing DLQ ↓

Increasing LPD →

Figure 3. *Lighting design matrix*

- to characterize office lighting quality under different lighting designs, at lighting power densities (LPD) typical of existing conditions and of current and proposed energy codes and standards;
- to relate the task performance of office workers to lighting quality;
- to determine the effect of an individual's control over office lighting on his/her satisfaction and performance.

Results from one experiment, addressing the first two objectives, are presently available. An experiment addressing the third objective is under way.

The Research Set-up

The first experiment took place in IRC's Indoor Environment Research Facility (see Figure 2). The 83-m^2 (880-ft^2) space is configured as a windowless open-plan office area containing six workstations. Three lighting designers created nine lighting designs for the space. The designs combined three levels of lighting power density (LPD) and three levels of Designers' Lighting Quality (DLQ), which they defined by consensus, forming a 3-by-3 matrix of experimental conditions (see Figure 3). All the low DLQ conditions used recessed troffers with prismatic lenses; medium DLQ conditions used recessed troffers with parabolic louvers; and high DLQ conditions used indirect or direct/indirect fixtures. The LPD levels were approximately 9, 14 and 25 W/m^2. In the low LPD options, the ambient lighting systems were supplemented with task lighting. The medium and low LPD conditions all used electronic ballasts, whereas the high LPD conditions used magnetic ballasts.

Tasks Performed

Temporary office workers (292 in total), recruited from a local firm, participated in the experiment. Each person worked for one day under one of the nine lighting conditions; they were unaware that the experiment concerned lighting until the end of the day. Lighting conditions were changed from day to day in a random order to control for extraneous variables. During the day, the workers performed a variety of computer-based and paper-based tasks designed to represent modern office work, and completed questionnaires to assess their satisfaction with and impressions of lighting quality, mood, physical comfort, and social behaviours. They also did visual performance tests at the beginning and end of the day.

Results

People who worked under lighting systems with electronic ballasts showed less visual fatigue at the end of the day and performed better on reading and writing tasks. They also rated the tasks as being less difficult than did people who worked under lighting systems lit with magnetic ballasts. Figure 4a shows that people typed more during a writing task when the lighting system used electronic ballasts. This set of findings mirrors the results of other research at NRC and elsewhere, which has shown that high-frequency electronic ballasts improve visual performance, improve eye movements in reading, and reduce the incidence of headache and eyestrain.

The experiment also showed that lighting systems designed for computer offices allow better performance of computer-based tasks. Figure 4b shows that lighting systems with parabolic louvers were rated as being less glaring than those with prismatic lenses, exactly as they are designed to do.

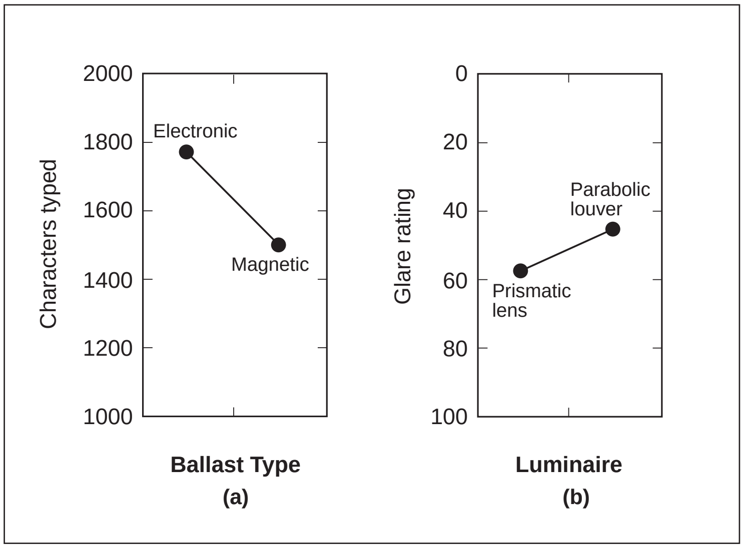

Figure 4. Examples of the effects of ballast type and luminaire

Generally speaking, performance of computer-based tasks was better when the lighting system incorporated parabolic louvers than when prismatic lenses were used. In addition, when participants were asked to compare their performance to that under the conditions they were used to, those under parabolic-louvered systems reported that their personal productivity increased by 8%, whereas those working under prismatic-lensed systems reported that their productivity was about the same as usual.

Lighting systems that incorporated a combination of task and ambient illumination were given higher satisfaction and lighting quality ratings than other systems. Because the task/ambient combination is frequently chosen as a strategy to achieve energy savings in addition to those achieved by lamp and ballast changes, this is good news. When carefully designed, energy-efficient lighting can be of high quality, too.

Research and Lighting Recommendations

Existing consensus-based lighting recommendations receive empirical support from this experiment. The lighting systems that we use today for computer offices do help people to do computer-based work. Research like this gives more power to the recommendations. Although the behavioural effects reported here are moderate, they cover important behaviours for office workers and their employers. Salaries and benefits are on the order of 10 times greater than building costs, so the small costs for lighting improvements are easily outweighed by the improvements in performance and satisfaction caused by better lighting.

Summary

A lighting quality research project conducted at IRC demonstrated that good-quality lighting — lighting that reduces glare and uses electronic ballasts — is a smart investment because it saves energy and contributes to better task performance and greater satisfaction.

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For more information, consult:
Internet: **http://irc.nrc-cnrc.gc.ca/light/lq_project/lqp.html**

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