Lighting that benefits people and the environment

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GUEST ARTICLE

RÉSUMÉ

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Lighting recommendations are notorious for their poor link to visual research, and the research literature itself is notorious for its poor quality, write guest authors Jennifer Veitch and Guy Newsham. In two articles they report on a large lighting quality research project in Canada and provide good news for those interested in both energy efficiency and high-quality lighting.

Recommendations for office lighting, such as IESNA RP-1 (American National Standard Practice for Office Lighting), or CIBSE LG7 (Lighting for Offices) are intended to help lighting designers provide adequate light on the desk surface to read documents, while screen glare on computers is reduced. Luminance ratio limits are intended to prevent excessive contrast between light and dark. The recommendations are, however, notorious for their weak link to published research, and the research literature itself is notorious for its poor quality. In most cases, recommendations are based on the opinions of experienced lighting designers and illuminating engineers, but there is no assurance that lighting designs meeting these recommendations will meet the needs of occupants, contributing to their satisfaction, task performance, comfort, and health.

The development and adoption of energy codes poses an additional challenge for office lighting planners by placing limits on the electric power that can be devoted to lighting. ASHRAE/IESNA Standard 90.1, Energy efficient design of new buildings except new low-rise residential buildings, and the Canadian Energy Code for New Buildings both limit acceptable lighting power densities for offices to approximately 19 W/m^2. The development of energy codes and standards in the late 1980s led to renewed fears in the lighting community that restricting the amount of energy that can be used for lighting would reduce its quality. This was demonstrably the case during the energy crisis in the 1970s, when delamping was the predominant energy-saving strategy. Advances in lighting technology gave rise to alternative strategies for saving energy, but in the absence of any consensus as to how lighting quality should be assessed there was little reason for confidence that these new technologies would prevent earlier problems from developing again.

Fig 1. A workstation lit with the low-LPD/high DLQ condition

These issues led to the development of a multi-year project on lighting quality, recently completed, at the National Research Council of Canada's Institute for Research in Construction (NRC/IRC). The project goals were:

- to characterize the office lighting quality provided by lighting designs of various types at lighting power densities (LPD) typical of existing conditions and in line with current and proposed energy codes and standards;
- to relate the task performance of office workers to lighting quality.
- to determine how worker satisfaction and performance are affected by giving individuals control over their office lighting.

This article describes the first of two experiments undertaken in connection with the project. Both experiments were carried out in the NRC/IRC Indoor Environment Research Facility, a space dedicated to the study of lighting, acoustics, indoor air quality, ventilation, and human factors. This space was configured as a windowless, open-plan office space containing six workstations furnished in a manner typical of mid-level, North American, open-plan offices.

RESEARCH DESIGN

Experiment 1 addressed the first two objectives of the project, i.e. assessing how the various lighting designs affect worker performance and satisfaction. Three local lighting designers, working together, 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 x 3 matrix of

experimental conditions (Table 1). Recessed troffers with prismatic lenses were used in all the low DLQ conditions; recessed troffers with parabolic louvers were used to create medium DLQ conditions; and, in the high DLQ conditions indirect or direct/indirect luminaires were used. The power density levels were approximately 9, 14, and 25 W/m^2. In the low LPD options, the ambient lighting systems were supplemented with task lighting. Electronic ballasts were used in the setups providing medium and low LPD conditions, whereas magnetic ballasts were used in the high LPD conditions. One of the experimental setups is shown in Figure 1.

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; thus, they were unaware that the experiment concerned lighting until we told them at the end of the day. Lighting conditions were

Table 1: Matrix showing specifications for experimental conditions

Designer's lighting quality, DLQ	**Lighting power density, LPD**		
1 (low) *Recessed troffer with K12 prismatic lens*	**1 (low)** **electronic ballasts** 1'x 4' fixture with 1 T8 lamp (x 20) • angle-arm task lamps (x 6) • undershelf task lamps (x 6)	**2 (medium)** **electronic ballasts** 1' x 4' fixture with 2 T8 lamps (x 20)	**3 (high)** **magnetic ballasts** 1' x 4' fixture with 2 T12 lamps (x 20)
2 (medium) *Recessed troffer with parabolic louver*	**electronic ballasts** 8" x 4' fixture with 1 T8 lamp (x 20) • angle-arm task lamps (x 6) • undershelf task lamps (x 6)	**electronic ballasts** 1' x 4' fixture with 2 T8 lamps (x 20)	**magnetic ballasts** 1' x 4' fixture with 2 T12 lamps (x 25)
3 (high) *Indirect or direct/indirect*	**electronic ballasts** 4'-long fixture with 2 T8 lamps (x 8) (furniture-mounted indirect) • angle-arm task lamps (x 6) • undershelf task lamps (x 6)	**electronic ballasts** 36'-long fixture with 16 4' T8 lamps (x 2) (18"-suspended direct/indirect)	**magnetic ballasts** 36'-long fixture with 16 4' T8 lamps (x 3) (12"-suspended indirect)

Note. Lamp types: All T-8 lamps: 32 W, 3500K, CRI > 80. All T-12 lamps: 40 W, 3500K, CRI> 80.
Articulated task lamps with 3500 K 13 W compact fluorescents. Undershelf task lights with T8 2', 3500 K lamps. All ballasts were non-dimming.

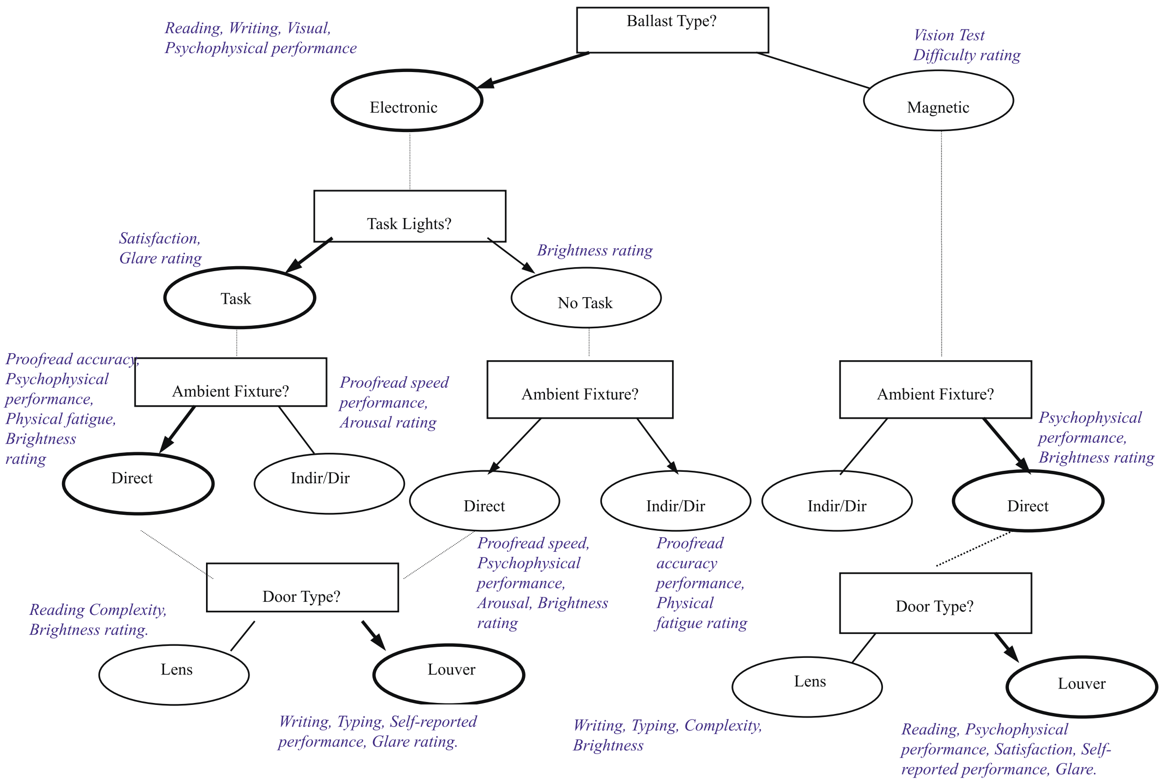

Figure 2. Schematic guide to choices between lighting systems used in Experiment 1, summarizing experimental results. The bold lines mark decision paths supported by this experiment. The italic text next to decision paths identifies dependent variables with statistically significant outcomes favoring that lighting system choice.

changed from day to day in a random order to control for extraneous variables. During working hours participants performed a variety of computer-based and paper-based tasks designed to be representative of modern office work, and at the end of each day they completed questionnaires concerning satisfaction and impressions of lighting quality, mood, physical comfort, and social behaviors. They also took visual performance tests at the beginning and end of the day.

RESULTS

The large data set generated a complex set of results, which we have summarized in Figure 2. These results can provide guidance for future research, as well as for lighting designers. (Detailed results of both experiments and other reports generated by our Lighting Quality project are available on our WWW site see address below.)

Our findings provide good news for the lighting community, i.e. that the goals of improving energy efficiency and lighting quality are compatible. People who worked under electronic ballasts, which are more energy-efficient than magnetic ballasts, showed better visual performance, did better on reading and writing tasks, and rated the tasks as being less difficult. The most likely explanation for these findings, which are consistent with previous research at NRC and elsewhere, is that the high-frequency (20 kHz) operation of electronic ballasts, being undetectable, causes no "sensory noise". By contrast, magnetic ballasts, which operate at 120 Hz (in North America, 100 Hz in European countries), cycle at a rate that the nervous system can detect although observers don't report flicker.

The results also provide supporting evidence that existing standards for lighting spaces containing computers are appropriate: Computer-based task performance was better under parabolic louvered luminaires than under lensed luminaires, and satisfaction ratings were equivalent. We believe that improved glare control can explain these results.

In addition, lighting systems incorporating both task and ambient lighting (9 W/m^2, measured LPD including task lighting) were rated as providing better quality lighting than systems without task lighting (14 W/m^2).

Although the effects found here are small, they are large enough to justify spending more for well-designed, higher-quality lighting in offices. There is reason to believe that the investment in quality lighting will pay off for the people fortunate enough to work under it. Moreover, the switch to energy-efficient electronic ballasts would be good for the environment as well.

More information can be found at www.nrc.ca/irc/ie/light