Building Simulation
Seventh International IBPSA Conference
Rio de Janeiro, Brazil
August 13-15, 2001

USING LIGHTING SIMULATION TO ASSESS THE PERFORMANCE OF AND INDIRECT OFFICE LIGHTING SYSTEMS IN DYNAMIC WORKPLACES

R. Ries, University of Pittsburgh, Pittsburgh, PA, 15261, USA
A. Mahdavi and V. Loftness, Carnegie Mellon University, Pittsburgh, PA, 15213, USA
G. Steffy, GarySteffyLightingDesign, Inc, Ann Arbor, MI, 48104, USA
A. Nahikian, Steelcase NA, Grand Rapids, MI, 49501,USA

ABSTRACT

Despite discussions of the universal workstation, there is increasing workplace dynamics in organizations. These dynamics include space configuration changes, changes in occupant density, and increasing equipment density. Building infrastructures have not evolved to meet these demands, with little flexibility in air conditioning and ventilation, lighting, electrical, and telecommunication systems in new or existing office buildings. Simulation tools can be used to evaluate dynamic workplace scenarios and provide guidance for designers by modeling indoor environmental conditions. This paper presents the results of a study that used a commercially available lighting simulation tool to examine the effects of workplace dynamics and lighting design decisions on the visual quality provided for the individual worker by alternative office lighting systems.

INTRODUCTION

At the same time that organizational dynamics is rapidly changing workplace planning, the competitive market in luminaires and lighting system types is expanding the number of alternatives that must be evaluated to assess lighting performance in the workplace. The goal of this study is to evaluate the relative effectiveness of a representative selection of lighting system types under dynamic workplace conditions (Steelcase 2000). The study evaluated seven luminaire types, which when combined with task lighting, create fourteen lighting systems. The lighting systems were evaluated at two ceiling heights and in four workplace layouts. The study used ten visual criteria to assess lighting system performance (IESNA 1996).

The seven luminaire types, labeled LM-1 to LM-7, were selected for the study as being representative of current commercial office lighting practice. Each luminaire was evaluated both with (referred to as split task and ambient) and without (referred to as combined task-ambient) workstation-mounted task lighting, resulting in the fourteen lighting systems. For the purposes of this study, a combined task-ambient lighting system, labeled LS-1, is one comprised of lights suspended from or recessed into the ceiling intended to meet all task and ambient lighting needs. A split task and ambient lighting system, labeled LS-2, is one comprised of a task lighting component and an ambient lighting component. The task lighting component consists of individual task lights mounted at the workstations and which alone provide about half the lighting needed for tasks. The ambient lighting component is comprised of lights suspended from or recessed into the ceiling intended to provide about half the task lighting needs and the general ambient lighting needs.

The ability of the lighting systems to adapt to changing furniture layouts was evaluated by designing a lighting layout to meet the Illuminating Engineering Society of North America (IESNA) lighting guidelines for a base case furniture plan. The furniture layout was then modified to each of three alternative layouts. The alternative furniture layouts modified occupant density, work surface location, systems furniture panel heights, and storage bins, while maintaining the ceiling lighting grid.

The Baseline Layout (LO-1) represents a standard configuration for systems furniture office spaces. The plan consists of an 8' x 8' square work space with 5'-6" high wall panels. Each workstation has work surfaces and overhead storage bins hung from the panel wall system. The Reduced Footprint Layout (LO-2) represents the trend towards smaller workstations. The footprint of each workstation is 6' x 6' square. The system wall panels are 4'-6" high and they support two work surfaces and binder bins along the shared spine wall. The Caves and Commons Layout (LO-3) represents the neighborhood/team space approach to work space design. The layout has a mix of open, closed, and teaming spaces, as well as smaller touchdown work areas. The panel heights range from full height to 5'-6" tall. The Non-orthogonal Layout (LO-4)

represents designs that have a non-orthogonal relationship of the furniture and lighting layouts. The furniture components are the same as the baseline layout (LO-1). Table 1 summarizes the study parameters.

LIGHTING PERFORMANCE EVALUATION CRITERIA

The following ten lighting performance criteria were used to evaluate the performance of the lighting configurations in this study.

- Average Work Space Horizontal Illuminance

This is the average of the illuminance levels for regularly spaced grid points on a horizontal plane. The horizontal plane covers the whole area of the work space with grid points on 3-inch centers with all calculation points at least 9-inches from any partition at 30-inches AFF. For the task light and ambient light from ceiling condition, the average illuminance required from the ambient lighting system was 50 fc (anything from 44.5-54.5 fc acceptable). The ambient light from ceiling (task lights at desk) condition illuminance required from the ambient lighting system was 35 fc (anything from 29.5-40.5 fc acceptable).

- Horizontal Illuminance Average / Min and Average / Max Ratios

This is the ratio between the average work space horizontal illuminance and the minimum (or maximum) illuminance value on the horizontal work plane. The horizontal plane covers the whole area of the work space with grid points on 3-inch centers with all calculation points at least 9-inches from any partition at 30-inches AFF. The average to minimum requirements were less than 2.45:1 and the average to maximum requirements are less than 1:1.34.

- Average Vertical Illuminance

This is the average of the illuminance levels in the north, south, east, and west directions at each point on a regularly spaced horizontal grid. The horizontal plane covers the whole area of the work space with grid points on 3-inch centers with all calculation points at least 9- inches from any partition at 39-inches AFF. The average vertical requirements were between 0 and 20 fc.

- Maximum Ceiling Luminance

This is the maximum luminance of the ceiling. For a diffuse ceiling surface the luminance is independent of the viewpoint location. The maximum ceiling luminance allowed is 250 fL.

- Ceiling Luminance Maximum / Minimum Ratio

This is the ratio between the maximum ceiling luminance and minimum ceiling luminance as seen from a viewpoint below the ceiling. For a diffuse ceiling surface the luminance is independent of the viewpoint location. The requirements for the maximum to minimum ratio is 5.45:1 or less.

Table 1 Summary of the study parameters, including furniture layout and luminaire specifications

Key	Description
LS-1	Task-ambient lighting system: no workstation mounted task light
LS-2	Split task and ambient lighting system: workstation mounted task light
LO-1	Baseline furniture layout: 8 by 8 foot open office plan
LO-2	Reduced footprint layout: 6 by 4 foot open office plan
LO-3	Caves and Commons layout: mixed open and closed spaces
LO-4	Non-orthogonal layout: 8 by 8 foot open office plan at a 45^{o} angle to the lighting grid
LM-1	Basic 2 x 4 recessed parabolic luminaire; 3" deep 18-cell parabolic semi-specular louver
LM-1	Basic 2 x 4 recessed parabolic luminaire; 3" deep 18-cell parabolic semi-specular louver
LM-2	2 x 4 VDT recessed parabolic luminaire; 4" deep 12-cell parabolic specular louver
LM-3	Basic 2 x 2 recessed parabolic luminaire; 4" deep 9-cell parabolic semi-specular louver
LM-4	1 x 4 VDT recessed parabolic luminaire; 4" deep 8-cell parabolic specular louver
LM-5	Indirect/direct T8 suspended luminaire; 30% down light and 70% up-light distribution
LM-6	Indirect T8 suspended luminaire; 100% up-light distribution
LM-7	Indirect T5 suspended luminaire; 100% up-light distribution
CH-1	9'-0" floor to ceiling height
CH-2	10'-6" floor to ceiling height

- Luminaire Luminance

This is the maximum luminance of the luminaire. The maximum luminaire luminance allowed is 250 fL.

- Work surface Horizontal Illuminance

The average of the illuminance levels for regularly spaced grid points on the desk surfaces.

LIGHTING DESIGN PROCEDURE

Lighting simulation software, Lumen Micro™ 7.5, was used to design the lighting systems as well as generate the data for the lighting performance criteria used to evaluate the systems. Simulation output for horizontal and vertical illuminance and luminaire and ceiling luminance in the work space were used in the analysis. A centrally located 30' by 30' area in a hypothetical office layout was the area modeled for each alternative. The variables in the model were the furniture (according to each of the four furniture layouts LO-1 to LO-4), the lighting layout (for each of the luminaire types LM-1 to LM-7), and the ceiling heights (CH1 and CH-2). The simulation model included desks, partitions, overhead storage bins, storage cabinets and chairs. Surface reflectances for typical commercial office construction materials and furniture were used: 90% for the ceiling; 30% for the walls and partitions; 50% for the work surface; and 10% for the floor. All reflectances were matte finishes.

Horizontal grids, surface grids, and ceiling grids were specified for the lighting calculations. The work space horizontal illuminance horizontal grid has a spacing of 3" and starting a distance of 9" away from the partitions. For the work surface, a surface grid with a spacing of 6" and a width of 1'-6" running along the length of only the work surfaces was used. To ensure that the evaluation would not be vendor specific, multiple products were selected and combined to generate the profile the performance specifications for the luminaire types and the task light. Daylight was excluded from the calculations.

For each of four pairs of lighting system types, either without (LS-1) or with (LS-2) individual task lights at the workstation, and ceiling height, either 9'-0" (CH-1) or 10'-6" (CH-2), the base furniture layout LO-1 determined the lighting system design used in the evaluation. A lighting system was designed for each of the luminaire types, LM-1 to LM-7, and modeled in the simulation tool. The output from the simulation model was used in the design process to insure that the lighting system as configured met the performance criteria. The lighting system designs for LO-1 for each luminaire type were then used sequentially in a simulation model of with the remaining furniture layouts - LO-2, LO-3, and LO-4. The simulation output for LO-2, LO-3, and LO-4 was used in the lighting performance criteria, and as the basis for the lighting system evaluation. The visual performance indices established the relative ability of the lighting systems to continue to provide visual quality while workstation changes were made.

LUMINAIRE SCORECARDS

The scorecard summarizes the performance of each luminaire in terms of achieving the lighting system criteria. Eight luminaire scorecards were created: two for each pair of a lighting scheme and a ceiling height. The results for the base case layout, LO-1, is shown in an individual table. The results for layouts LO-2 through LO-4 are shown combined. The scorecards show the performance for all of the layout alternatives combined so as to illustrate the ability or inability of the luminaire to adapt to changing furniture and spatial conditions.

A "√" in the table cell of the luminaire scorecard indicates that the luminaire was able to meet that criteria in all of the layouts in that lighting scheme and ceiling height. An "X" in the table cell of the luminaire scorecard indicates that the luminaire was unable to meet that criteria in one or more of the layouts in that lighting scheme and ceiling height.

CONCLUSIONS

Simulation was used in this study to explore lighting system alternatives in a dynamic office context. Although the study results presented here cannot provide definitive guidance for lighting system design in all cases, the following conclusions from the results of the luminaire scorecards could be used to make early design choices when it is known that the furniture configurations of an office space will frequently change.

- In general, average work space horizontal illuminance criteria was maintained more consistently across changing workstation layouts in the split task and ambient lighting scheme, LS-2, compared to the combined task-ambient lighting scheme, LS-1.

This illustrates the importance of individual task lights in maintaining lighting performance. Ceiling-based luminaires cannot reliably provide both task as well as ambient lighting needs across changing layouts.

- No luminaire met the design criteria for horizontal illuminance average/minimum,

average/maximum, and ceiling luminance maximum/minimum ratios for all of the alternatives.

This is because the criteria were developed for use with a design procedure that was not followed in the study. In typical lighting design practice, an office space is modeled in a simulation tool without furniture partitions, and a partition factor is applied which effectively accounts for the reduction in light levels from the partitions. In this case, the lighting values from the simulation tend to be more even across the space. In this study, the furniture partitions and overhead storage units were explicitly modeled in the simulation tool, which lead to wider ranges in the average/minimum, average/maximum and maximum/minimum ratios due to shadowing compared to the partition factor method. A review of design methods, including addressing shadowing on the work surface, criteria, and tools, including a comparison to field measurements of lighting quality, is indicated.

- The basic 2 x 4 parabolic luminaire, LM-1, and the 2 x 2 parabolic luminaire, LM-3, did not consistently meet the luminaire luminance criteria when the furniture layouts changed.

Unacceptable above-criteria luminaire luminance occurred in LM-1 and LM-3 in both lighting schemes LS-1 and LS-2. High luminaire luminance can cause glare in VDT screens and uncomfortably bright areas in the ceiling plane.

- Average vertical illuminance criteria were more likely to be exceeded in the combined task-ambient lighting scheme, LS-1.

Attempting to provide both task and ambient lighting from only ceiling-based luminaires causes design criteria to come into conflict. In LS-1, achieving adequate average horizontal illuminance often resulted in above-criteria average vertical illuminance.

REFERENCES

IESNA, 1996, IESNA Lighting Handbook, Eighth Edition. Illuminating Engineering Society of North America.

Steelcase, 2000, Life Cycle Comparisons of Direct and Indirect Lighting for Offices. Unpublished research report. Steelcase North America.

Table 2 Luminaire scorecard for LS-1, CH-1, layout LO-1

LS-1, CH-1	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	√	X	X	√	X	√	NA
LM-2	√	X	X	√	√	√	NA
LM-3	√	X	X	√	X	√	NA
LM-4	√	X	X	√	√	√	NA
LM-5	√	X	X	√	√	√	√
LM-6	√	X	X	√	NA	√	√
LM-7	X	X	X	X	NA	√	X

Note: Luminaire LM-7 cannot meet criteria at this time due to the fact that T-5 ballasts are available in a limited number of ballast factors.

Table 3 Luminaire scorecard for LS-1, CH-1, changing LO-1 to layouts LO-2, LO-3, and LO-4

LS-1, CH-1	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	X	X	X	√	X	√	NA
LM-2	X	X	X	√	√	√	NA
LM-3	X	X	X	X	X	√	NA
LM-4	X	X	X	√	√	√	NA
LM-5	X	X	X	X	√	√	X
LM-6	X	X	X	X	NA	√	X
LM-7	X	X	X	X	NA	√	X

Note: Luminaire LM-7 cannot meet criteria at this time due to the fact that T-5 ballasts are available in a limited number of ballast factors

.

Table 4 Luminaire scorecard for LS-1, CH-2, layout LO-1

LS-1, CH-1	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	√	X	X	√	X	√	NA
LM-2	√	X	X	√	√	√	NA
LM-3	√	X	X	√	X	√	NA
LM-4	√	X	X	√	√	√	NA
LM-5	√	X	X	√	√	√	√
LM-6	√	X	X	√	NA	√	√
LM-7	√	X	X	√	NA	√	X

Table 5 Luminaire scorecard for LS-1, CH-2, changing LO-1 to layouts LO-2, LO-3, and LO-4

LS-1, CH-2	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	X	X	X	X	X	√	NA
LM-2	X	X	X	√	√	√	NA
LM-3	√	X	X	√	X	√	NA
LM-4	X	X	X	√	√	√	NA
LM-5	X	X	X	√	√	√	X
LM-6	X	X	X	X	NA	√	X
LM-7	X	X	X	X	NA	√	X

Table 6 Luminaire scorecard for LS-2, CH-1, layout LO-1

LS-1, CH-1	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	√	X	X	√	X	√	NA
LM-2	√	X	X	√	√	√	NA
LM-3	√	X	X	√	X	√	NA
LM-4	√	X	X	√	√	√	NA
LM-5	√	X	X	√	√	√	√
LM-6	√	X	X	√	NA	√	√
LM-7	√	X	X	√	NA	√	X

Table 7 Luminaire scorecard for LS-2, CH-1, changing LO-1 to layouts LO-2, LO-3, and LO-4

LS-2, CH-1	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	X	X	X	√	X	√	NA
LM-2	√	X	X	√	√	√	NA
LM-3	√	X	X	√	X	√	NA
LM-4	X	X	X	√	√	√	NA
LM-5	√	X	X	√	√	√	X
LM-6	√	X	X	√	NA	√	X
LM-7	√	X	X	√	NA	√	X

Table 8 Luminaire scorecard for LS-2, CH-2, layout LO-1

LS-1, CH-2	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	√	X	X	√	X	√	NA
LM-2	√	X	X	√	√	√	NA
LM-3	√	X	X	√	X	√	NA
LM-4	√	X	X	√	√	√	NA
LM-5	√	X	X	√	√	√	√
LM-6	√	X	X	√	NA	√	√
LM-7	√	X	X	√	NA	√	X

Table 9 Luminaire scorecard for LS-2, CH-2, changing LO-1 to layouts LO-2, LO-3, and LO-4

LS-2, CH-2	Horizontal Illuminance			Vertical Illuminance	Luminaire Luminance	Ceiling Luminance	
	Avg	Avg/Min	Avg/Max	Avg		Max	Max/Min
LM-1	√	X	X	√	X	√	NA
LM-2	√	X	X	√	√	√	NA
LM-3	√	X	X	√	X	√	NA
LM-4	X	X	X	√	√	√	NA
LM-5	√	X	X	√	√	√	X
LM-6	X	X	X	√	NA	√	X
LM-7	X	X	X	√	NA	√	X