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The Effect of Luminaire Type and Spacing on Visibility Levels in Unobstructed Spaces

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Abstract—**The study examines how luminaire type and spacing affect task contrast and visibility in unobstructed office spaces. The Lumen-Micro program was used to calculate visibility levels in a model open-office space as a function of luminaire candlepower distribution, fixture spacing, and illuminance level. Three representative luminaires were parametrically examined: a lensed troffer, a high-performance parabolic, and a high-performance uplight. Small differences in average task visibility levels were observed for the different luminaires and fixture spacings examined, but these differences were slight compared with variability within an installation. The study indicates that if one does not know the location of the task *a priori*, then it is not possible to achieve consistently high visibility levels throughout a space without resorting to lighting solutions that are intrinsically inefficient.**

Introduction

ONE GOAL of illuminating engineering should be the design of lighting systems that can provide consistently high task visibility regardless of where a task might be located within a working space. A general solution to this design problem would clearly be of benefit because in many situations, the designer has no *a priori* knowledge of where the occupants will be located relative to the lighting system and the task stations. In speculative building projects, even the type of task is rarely known during the design phase. Ceiling-mounted luminaires on a uniform grid are the usual approach to this design problem. This paper focuses on the use of ceiling-mounted lighting systems for providing good visibility throughout unobstructed spaces.

Background

To appreciate the complexity of this problem, one must first realize that task visibility is a complicated function of a number of variables. Worse yet, there is considerable debate within the lighting community as to which metric best characterizes the visibility of a task. In this paper, we avoid the use of equivalent sphere illumination (ESI), which has been deprecated by the Illuminating Engineering Society of North America (IESNA), and following [1], use instead the natural logarithm of the visibility level ln(VL) to express task visibility. It is convenient to express the visibility level (VL) as a product of two functions: the contrast rendition factor (CRF) and a relative contrast sensitivity function. CRF is the ratio of the task contrast under the lighting condition being studied to the contrast obtained under a reference lighting condition (sphere illumination). CRF is a function of the type of task (i.e., the specular and diffuse reflectances of the task detail and surround) and the location of the lights relative to the task and the observer's viewpoint. It is essentially a relative measure of the lighting system's ability to produce contrast at a specified task location independent of the actual illuminance level. VL then, is the product of CRF and the relative contrast sensitivity—a function that characterizes how the eye's sensitivity to contrast varies with adaptation luminance. VL therefore includes not only the physical contrast (as might be measured by a luminance meter) but also the psychophysical portion of visibility.

Previous research on the applicability of visibility to lighting design [2], [3] has focused on the variability of CRF with respect to the observer's position in the room and the type of lighting installation. These detailed studies have shown that the most important determinants of CRF are the position of the observer with respect to the task and lights and the specularity of the task. As expected, low CFR's occurred when a light (or lights) was in the "offending zone" but were fairly high otherwise. The degree of task specularity was also found to strongly affect CRF; tasks without specularity showed consistently high CRF's regardless of position, but such tasks are not realistic. It was also found that the variability of CRF's (for tasks with some specularity) as a function of position within a given installation was large compared with differences between installations.

Using the previous studies as a point of departure, the objective of this paper is to examine how CRF and ln(VL) vary for a broader range of lighting variables and to compare the variability of ln(VL) within an installation to visibility changes brought about by varying the overall illuminance level.

Methods

We used the Lumen-Micro program to compute point-by-point illuminance and contrast values for a model open-office space. The output tables were then further analyzed to extract quantities of interest. All calculations of CRF and ln(VL) assume the standard pencil task viewed at 25°. Lumen-Micro does not allow varying the angle of view and does not treat the effect of obstructions within the space. Nonetheless, these

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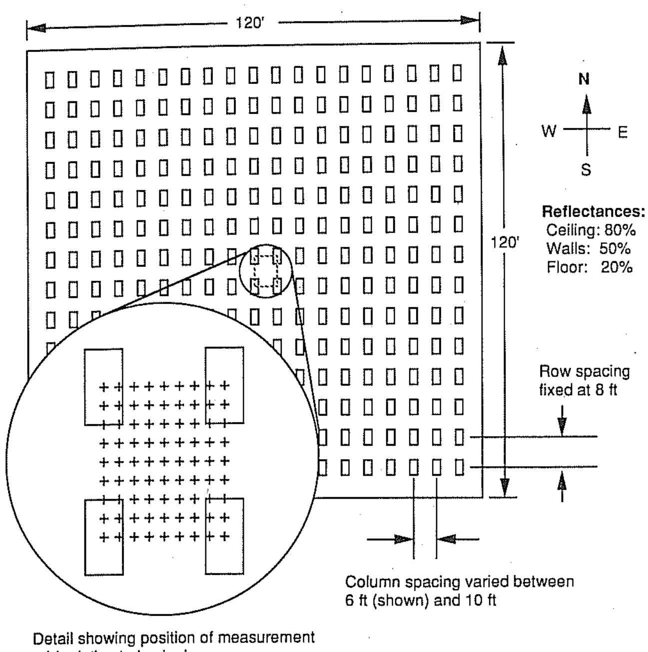

Fig. 1. Plan view of modeled open-office area. Lighting calculations were performed at the 81 grid points shown in the detail. The corners of the measurement grid were always directly below luminaire centers with the actual spacing between points varied proportionally with the luminaire spacing.

limitations are not overly restrictive as long as the results are not generalized to situations where it does not apply.

Model

We modeled an 120 × 120-ft open-office space with a 9-ft high ceiling and typical reflectances (Fig. 1). The modeled space was intended to represent an open-planned space in which the walls are sufficiently far removed from the area of evaluation that the influence of the walls on the lighting calculations may be neglected. We considered various lighting layouts consisting of different luminaires arranged in rectangular grids. We varied the fixture spacing in the east–west direction (6, 8, and 10 ft) but kept the row spacing in the north–south direction fixed at 8 ft.

To reduce compute time, we restricted the lighting calculations to a rectangular area, as shown in Fig. 1. Within a given layout, results from this measurement grid can be considered representative of other parts of the room that are not close to the walls. To insure that results could be meaningfully compared between systems with different luminaire spacings, the dimensions of the measurement grid were allowed to vary with the luminaire spacing. Thus, illuminance and contrast were always calculated on a grid of 9 by 9 points (a total of 81 points), regardless of the fixture spacing by varying the physical distance between the points so that the corner points of the measurement grid were always directly below the center of a luminaire.

Each layout was designed to provide an average of 84 fc over the measurement area. By choosing appropriate candlepower multipliers for each run, we assured that all the examined layouts provided the same average illuminance regardless of fixture spacing.

Luminaire Types

We selected three twin-lamp luminaires for analysis: a 2 × 4 lensed troffer, a 2 × 4 large-cell parabolic, and an indirect luminaire. The photometric reports from the luminaire manufacturers give the fixture efficiencies of the lensed, parabolic, and indirect luminaire as 73.2, 74.4, 77.7%, respectively. The parabolic fixture displays the classical "batwing" candlepower distribution perpendicular to the lamp axis. The indirect luminaire is representative of a modern efficient uplight with a relatively wide candlepower distribution, allowing it to be mounted only 2 ft below the ceiling plane. The other luminaires were recessed and ceiling mounted.

Analysis

Lumen-Micro actually calculates contrast rather than VL (or CRF) directly. In order to examine VL distributions, it was necessary to convert the contrast values to CRF and ln(VL). CRF was computed simply by dividing the contrast tables from Lumen-Micro by the equivalent sphere contrast (0.1675). ln(VL) was computed using [1], [4]

$$VL = C_{eq} {}^* \mathrm{CRF} {}^* a^* \left\{ \left[\frac{b}{(p^*E)} \right]^{.4} + 1 \right\}^{-2.5} \qquad (1)$$

where C_{eq}, which is the equivalent contrast, is defined as the contrast of a reference target of equal visibility to the target of interest. The terms a and b are fitted constants (a = 16.847 and b = 0.4784 for a 20-year old observer) and ρ is the reflectivity of the task (ρ = 0.846). Varying E in the above expression allows one to compute VL at any adaptation level given values of CRF.

RESULTS

Table I lists the various luminaires and spacings examined and gives the calculated mean and standard deviations for the illuminance values over the measurement grid. In addition, we have listed the particular candlepower (CP) multiplier used for each configuration to achieve the listed average illuminance. Since we have kept average illuminance constant for each of the base runs while varying the luminaire spacing over a broad range, the candlepower multiplier may be as large as 1.26 or as small as 0.73. We did not model the indirect luminaire at 10 × 8 spacing since this would require an unrealistically high CP multiplier.

The standard deviation in illuminance given in Table I is a reasonably useful measure of how much the point-by-point illuminance values vary about the mean illuminance. None of the lighting systems exhibited significant nonuniformity in illuminance, indicating that the spacing-to-mounting-height recommendations were not exceeded for any examined system. As expected, illuminance variability tends to increase (i.e., uniformity decreases) as the fixture spacing is increased. Note also that there is relatively little difference in the standard deviation for the lensed and parabolic fixtures. The indirect lighting system shows the most uniform illuminance, as expected.

TABLE I
MEAN ILLUMINANCE AND UNIFORMITY FOR THREE LUMINAIRE SYSTEMS AT VARYING SPACINGS

System	Luminaire Type	Luminaire Spacing (col × row)	Candlepower Multiplier	Mean[a] Illuminance	Std Dev Illuminance
$L6 \times 8$	Lensed	6 × 8	0.77	84.1	1.7
$L8 \times 8$	Lensed	8 × 8	1.03	84.1	1.7
$L10 \times 8$	Lensed	10 × 8	1.26	84.1	4.7
$P6 \times 8$	Parabolic	6 × 8	0.73	84.1	1.9
$P8 \times 8$	Parabolic	8 × 8	0.98	84.1	2.3
$P10 \times 8$	Parabolic	10 × 8	1.22	84.1	1.8
$I6 \times 8$	Indirect	6 × 8	0.92	84.1	0.4
$I8 \times 8$	Indirect	8 × 8	1.23	84.1	0.6

[a] 81 data points

TABLE II
MEAN CONTRAST RENDITION FACTOR AND LN(VL) FOR THREE LUMINAIRE SYSTEMS AT VARIOUS SPACINGS AND LIGHT LEVELS EAST FACING DIRECTION

System	Mean[a] Illuminance (fc)	Mean CRF	Std Dev CRF	Mean ln(VL)	StdDev ln(VL)
$L6 \times 8$	84	0.93	0.05	2.05	0.05
$L6 \times 8$	42	0.93	0.05	1.96	0.05
$L6 \times 8$	21	0.93	0.05	1.84	0.05
$L6 \times 8$	8.4	0.93	0.05	1.64	0.05
$L8 \times 8$	84	0.93	0.07	2.05	0.07
$L8 \times 8$	42	0.93	0.07	1.96	0.07
$L8 \times 8$	21	0.93	0.07	1.84	0.07
$L8 \times 8$	8.4	0.93	0.07	1.63	0.07
$L10 \times 8$	84	0.93	0.08	2.05	0.09
$L10 \times 8$	42	0.93	0.08	1.96	0.09
$L10 \times 8$	21	0.93	0.08	1.84	0.09
$L10 \times 8$	8.4	0.93	0.08	1.64	0.09
$P6 \times 8$	84	0.94	0.04	2.06	0.04
$P6 \times 8$	42	0.94	0.04	1.97	0.04
$P6 \times 8$	21	0.94	0.04	1.85	0.04
$P6 \times 8$	8.4	0.94	0.04	1.65	0.04
$P8 \times 8$	84	0.94	0.05	2.05	0.06
$P8 \times 8$	42	0.94	0.05	1.93	0.06
$P8 \times 8$	21	0.94	0.05	1.84	0.06
$P8 \times 8$	8.4	0.94	0.05	1.63	0.06
$P10 \times 8$	84	0.94	0.07	2.06	0.07
$P10 \times 8$	42	0.94	0.07	1.97	0.07
$P10 \times 8$	21	0.94	0.07	1.85	0.07
$P10 \times 8$	8.4	0.94	0.07	1.64	0.07
$I6 \times 8$	84	0.98	0.01	2.1	0.01
$I6 \times 8$	42	0.98	0.01	2.01	0.01
$I6 \times 8$	21	0.98	0.01	1.89	0.01
$I6 \times 8$	8.4	0.98	0.01	1.69	0.01
$I8 \times 8$	84	0.98	0.01	2.1	0.01
$I8 \times 8$	42	0.98	0.01	2.01	0.01
$I8 \times 8$	21	0.98	0.01	1.89	0.01
$I8 \times 8$	8.4	0.98	0.01	1.69	0.01

[a] 81 data points

Contrast Rendition Factor

Table II lists the mean and standard deviations of CRF and ln(VL) over the entire measurement grid for all the examined luminaires and spacings for the observer looking east. Table III lists equivalent results for the observer looking north. Tables II and III also list the CRF's and ln(VL)'s for different average illuminance levels.[1] These values were calculated by applying (1) to the Lumen-Micro contrast and illuminance tables computed for the 84-fc cases and varying E appropriately. Note that the CRF's for a given luminaire and spacing do not vary with illuminance since CRF is intensity independent. For a given luminaire, the average CRF's do not vary significantly as a function of fixture spacing. However, the standard deviation in CRF's increase with increasing fixture spacing. The average CRF's for the lensed luminaire are lowest, followed closely by the parabolic fixture. The indirect luminaire consistently shows the highest CRF with the smallest standard deviation. For the observer looking north (i.e., parallel to the lamp axis), the mean CRF for the indirect luminaire system is unity with very little variance.

Contour plots showing how CRF varies over the measurement grid are presented in Fig. 2 for an observer looking east and in Fig. 3 for an observer looking north. (By symmetry,

[1] Different average illuminances can be achieved with currently available lighting control hardware that dim entire circuits of fluorescent lights over a relatively large range.

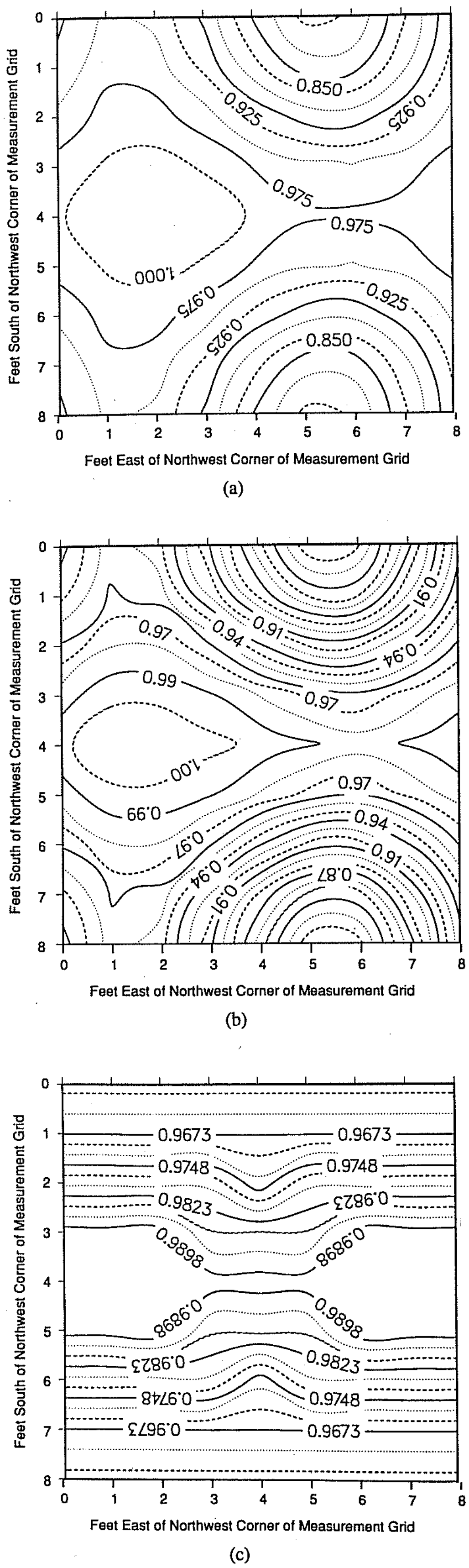

Fig. 2. Contour plots showing lines of equal CRF for (a) lensed troffer, (b) parabolic luminaire, and (c) indirect lighting for an observer facing east. The luminaire spacing is 8 × 8 with luminaires directly over each corner of the plots. The luminaire lamp axes are oriented vertically with respect to the plots.

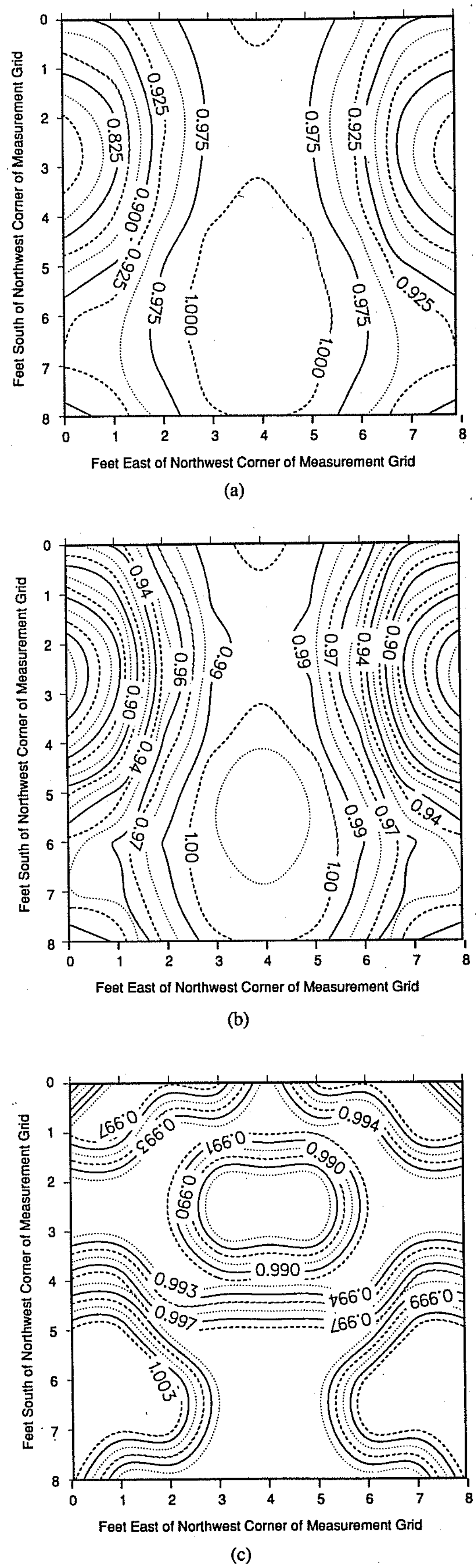

Fig. 3. Contour plots showing lines of equal CRF for (a) lensed troffer, (b) parabolic luminaire, and (c) indirect lighting for an observer facing north. The luminaire spacing is 8 × 8 with luminaires directly over each corner of the plots. The luminaire lamp axes are oriented vertically with respect to the page.

TABLE III
MEAN CONTRAST RENDITION FACTOR AND LN(VL) FOR THREE LUMINAIRE SYSTEMS AT VARIOUS SPACINGS AND LIGHT LEVELS NORTH FACING DIRECTION

System	Mean[a] Illuminance (fc)	Mean CRF	Std Dev CRF	Mean ln(VL)	Std Dev ln(VL)
$L6 \times 8$	84	0.94	0.04	2.06	0.05
$L6 \times 8$	42	0.94	0.04	1.97	0.05
$L6 \times 8$	21	0.94	0.04	1.85	0.05
$L6 \times 8$	8.4	0.94	0.04	1.64	0.05
$L8 \times 8$	84	0.93	0.07	2.05	0.08
$L8 \times 8$	42	0.93	0.07	1.95	0.08
$L8 \times 8$	21	0.93	0.07	1.84	0.08
$L8 \times 8$	8.4	0.93	0.07	1.63	0.08
$L10 \times 8$	84	0.93	0.09	2.05	0.1
$L10 \times 8$	42	0.93	0.09	1.9	0.1
$L10 \times 9$	21	0.93	0.09	1.84	0.1
$L10 \times 8$	8.4	0.93	0.09	1.63	0.09
$P6 \times 8$	84	0.96	0.03	2.08	0.03
$P6 \times 8$	42	0.96	0.03	1.98	0.03
$P6 \times 8$	21	0.96	0.03	1.87	0.03
$P6 \times 8$	8.4	0.96	0.03	1.67	0.03
$P8 \times 8$	84	0.95	0.05	2.07	0.06
$P8 \times 8$	42	0.95	0.05	1.98	0.06
$P8 \times 8$	21	0.95	0.05	1.86	0.06
$P8 \times 8$	8.4	0.95	0.05	1.66	0.05
$P10 \times 8$	84	0.94	0.08	2.06	0.09
$P10 \times 8$	42	0.94	0.08	1.97	0.09
$P10 \times 8$	21	0.94	0.08	1.85	0.09
$P10 \times 8$	8.4	0.94	0.08	1.65	0.09
$I6 \times 8$	84	1.0	0.01	2.12	0.01
$I6 \times 8$	42	1.0	0.01	2.03	0.01
$I6 \times 8$	21	1.0	0.01	1.91	0.01
$I6 \times 8$	8.4	1.0	0.01	1.7	0.01
$I8 \times 8$	84	1.0	0.01	2.12	0.01
$I8 \times 8$	42	1.0	0.01	2.03	0.01
$I8 \times 8$	21	1.0	0.01	1.91	0.01
$I8 \times 8$	8.4	1.0	0.01	1.71	0.01

[a] 81 data points

CRF's for the viewer looking west will be identical for the observer looking east and similarly for the south and north.) These figures show the location of areas of low CRF relative to the luminaire grid. (The center of a fixture is always immediately above the corners of the plots, which are oriented so that the lamp axes runs north–south and vertically with respect to the orientation of the page). For the lensed and parabolic luminaires, areas of low CRF occur where the observer is immediately in front of a luminaire looking in the direction of the luminaire. CRF's are low here because the luminaire is in the "offending zone," thereby greatly reducing contrast. Other than at these low spots, CRF's generally approach unity. In fact, for the observer between luminaires, especially when light comes from behind, CRF's exceed one. This "sweet spot" is more pronounced for the observer facing north because of the difference in candlepower distribution perpendicular and parallel to the lamp axis. For the indirect luminaire, CRF's are consistently high and do not exhibit the low "valleys" observed for the direct lighting systems.

Although Figs. 2 and 3 clarify where contrast rendition is good or poor relative to the luminaires, it is also useful to ask what percentage of the working area is within a particular range of CRF, that is, if one is equally likely to be at any given location in the space, what is the probability of obtaining a CRF within some small range? This question can be more easily answered by observing the probability distribution of CRF for the various luminaires and spacings examined. Figs. 4 and 5 are histograms showing the probability of obtaining a CRF within some small range over the range of observed CRF's. CRF's below 0.7 were not observed for any of the cases examined, nor did any exceed 1.07. For the lensed and parabolic fixtures, we find that the distribution of CRF's becomes somewhat broader as fixture spacing increases even though the mean CRF does not change significantly. At the widest spacing, one observes more "outliers," particularly at lower CRF. At the same time, there are more CRF's above one that counteract the lower values. (A CRF of one simply means that the task contrast is the same as it would have been under the reference sphere lighting condition.)

The standard deviation in CRF increases with wider spacings because the fixtures are assumed to be brighter (we adjusted CP multipliers and thus brightness so that different fixtures at different spacings would achieve the same illuminance). The low CRF's encountered when the luminaire is in the offending zone will be even lower with wide spacing because the fixture causing the veiling reflection will be brighter and therefore cause more overall contrast reduction. On the other hand, because the distance between fixtures increases with wider spacing, there will be areas between luminaires with CRF's somewhat higher than 1.

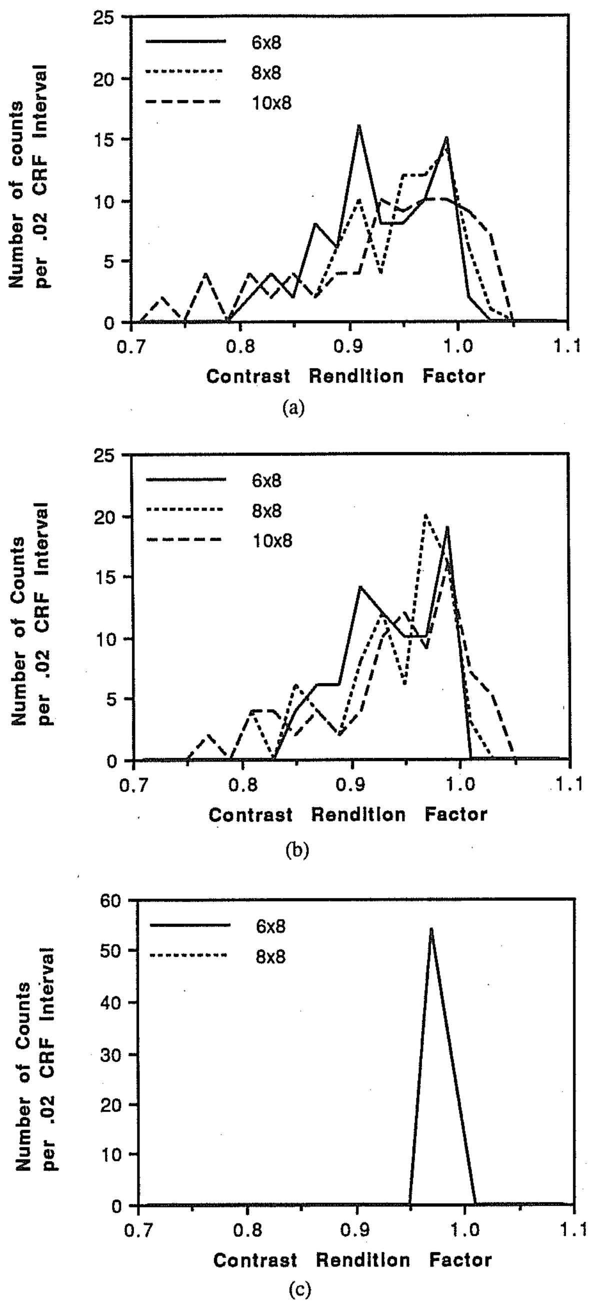

Fig. 4. Probability distributions of CRF for (a) lensed troffer, (b) parabolic luminaire, and (c) indirect lighting for an observer facing east.

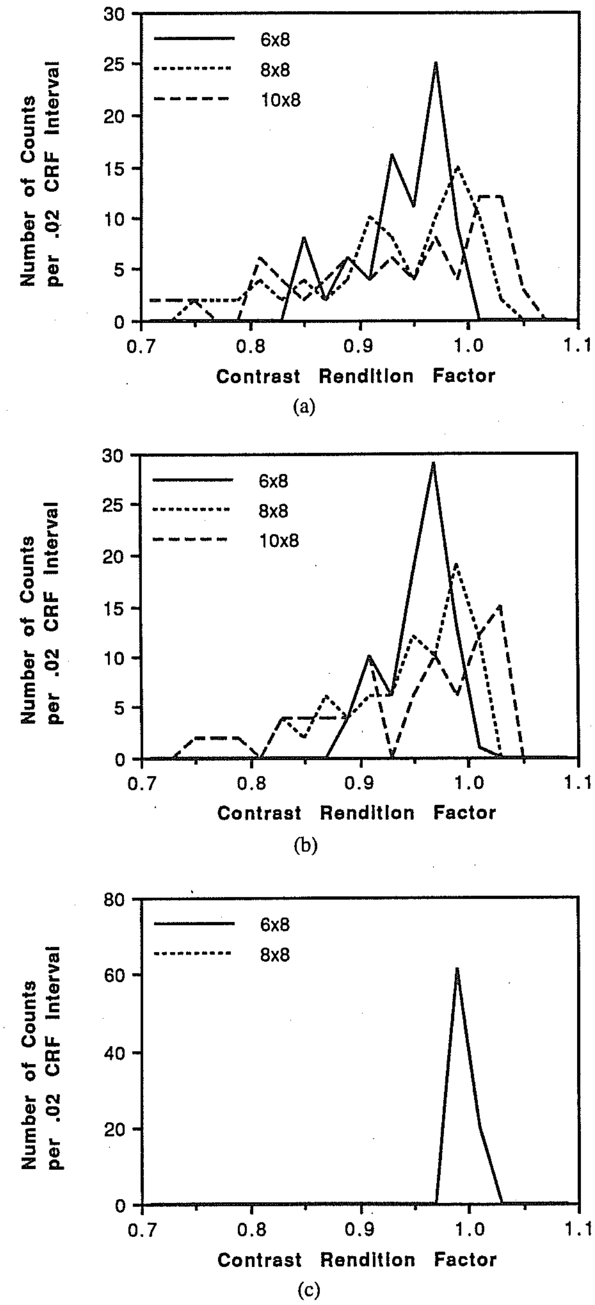

Fig. 5. Probability distributions of CRF for (a) lensed troffer, (b) parabolic luminaire, and (c) indirect lighting for an observer facing north.

Visibility Levels

As described earlier, contrast rendition by itself is insufficient to determine task visibility. To examine task visibility, we must consider ln(VL); which is a function that takes into account how the eye's sensitivity to contrast varies with adaptation level. Task visibility levels, expressed as ln(VL), are given in Tables II and III for the east and north viewing directions. Although there are small differences in the details, several general patterns can be seen from the ln(VL) results. The lensed and parabolic lighting layouts achieve a mean ln(VL) of roughly 2.05 (at 84 fc). At an arbitrary task location, the ln(VL) may vary 0.07 about that mean value. What is the significance of this variability in ln(VL)? By way of comparison, we note that the difference in average ln(VL) between the lensed and parabolic fixtures is considerably less than the variability in ln(VL) as a function of position. On the other hand, reducing a lighting layout's average illuminance from 84 to 42 fc reduces the average ln(VL) by slightly less than 0.1 ln(VL) units—somewhat more than the variability of ln(VL) within a given layout. Stated another way, the amount of variability of ln(VL) within an installation is roughly equal in magnitude to the change in ln(VL) brought about by halving the design illuminance level.

For the indirect lighting layouts, the mean ln(VL) was between 2.1 and 2.12 (at 84 fc) with a standard deviation of only 0.01. In other words, if we use indirect lighting, we can achieve high ln(VL)'s regardless of our location in the room or viewing direction. Because the mean ln(VL) value for the indirect case is higher than that of the lensed and parabolic lighting layouts at the same illuminance level, it would seem to be the best lighting arrangement. Unfortunately, this comparison is flawed. To achieve the same average illuminance as the direct lighting cases at the same fixture spacing, we had to assume a candlepower multiplier that was 20% larger than the CP required for the direct lighting layouts. For equally efficient lamp/ballast systems, this would require a higher lighting power density for the indirect lighting system to achieve the same average illuminance as the direct lighting layouts with commensurately higher operating costs. If we assume, instead, the same power density for direct and indirect systems alike (by using a CP multiplier of 1.0 instead of 1.26 for the indirect case), the mean ln(VL) for the indirect case drops to 2.07 ($\pm$ 0.01). Since this is within a standard deviation of the mean for the direct lighting cases, we seem to be back where we started. The improvements in ln(VL) due to indirect lighting are essentially counterbalanced by the reduction in illuminance that occurs because light must first be bounced off the ceiling.

The relationship between average illuminance level and ln(VL) for all the 8 × 8 lighting layouts is shown in Fig. 6 for the east and north viewing directions. At a given illuminance level, ln(VL) is higher for the indirect case than for either of the direct layouts, but the variability in ln(VL) as a function of position for the direct cases largely overwhelms this difference. At lower light levels (i.e., 20 fc), halving the average illuminance significantly reduces ln(VL). This would indicate that at lower illuminance levels, errors in light level provision are more important than at higher light levels.

Discussion

The variability in ln(VL) as a function of position within a given installation was found to be large compared with the differences in mean ln(VL) between installations. The results would indicate that it is difficult to provide good visibility globally with a uniformly arranged overhead lighting system. Indirect lighting was found to provide consistently high ln(VL)'s with little variance but only by sacrificing efficiency. Luminous ceilings are another method for achieving high visibility levels throughout a space, but these systems likewise are relatively inefficient. Visibility is a very localized phenomenon, and it would seem to be difficult to optimize it globally. This would tend to confirm the observations of Slater [2] and Boyce [3]. One interesting result, though, was the insensitivity of mean ln(VL) to luminaire spacing. This has some economic implications because the lighting layouts with wider fixture spacing also require fewer fixtures. Because the first costs of the system with fewer luminaires are less, it will also be more economical overall; it can provide the same mean ln(VL) as a system with higher first cost. Of course, this assumes that there exist lamp/ballast/fixture systems that can provide light outputs that are comparable with the candlepower multipliers we have used in the analysis. From a practical standpoint, a high candlepower multiplier implies a) high lamp lumen rating, b) high ballast factor, and c) optimum temperature performance. Existing lamp/ballast systems that can achieve luminaire lumen outputs commensurate with the highest CP multiplier (1.26) we have used in this study are available but require high lumen output lamps (3450 lumen rating, for example) and electronic ballasts with sufficiently high ballast factor. At any rate, if one is to benefit from providing the same average visibility level with fewer fixtures, then low output lamps (such as 35-W lamps) should be avoided, and higher output lamps (such as standard 40-W or T-10 lamps) should be used instead.

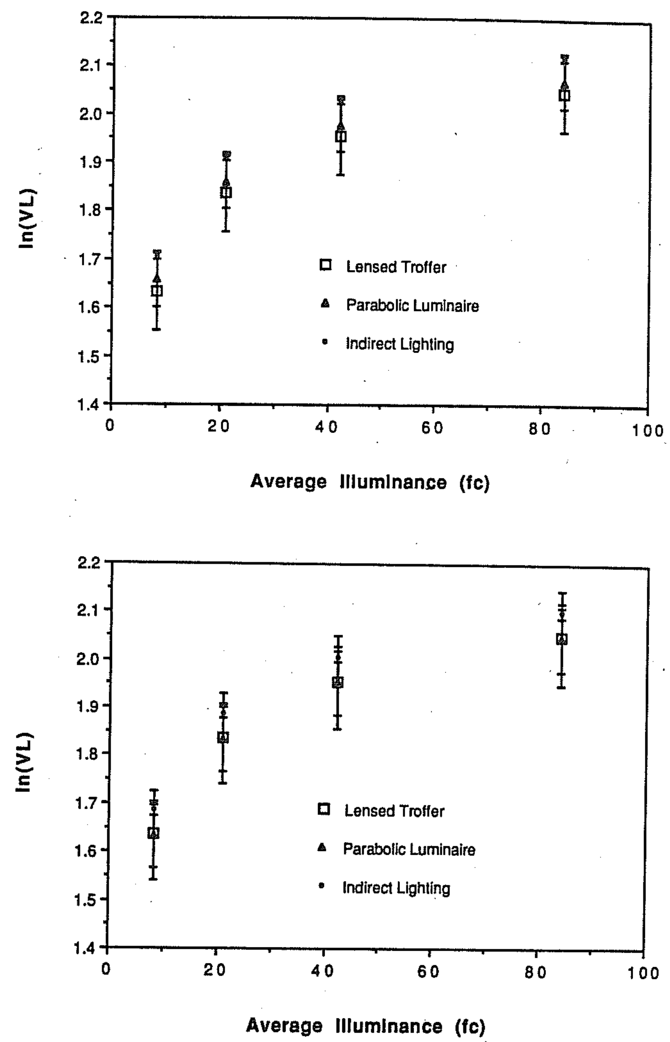

Fig. 6. Mean ln(VL) as a function of illuminance for the lensed, parabolic, and indirect lighting systems at 8 × 8 spacing for the east and north viewing directions. The standard deviations of the data points about the mean are shown as error bars.

Since it is apparently difficult to assure good visibility everywhere and still maintain the high efficiency of a direct lighting system, it is fruitful to identify those features of a lighting installation that lead to good or poor CRF. Since low CRF's occur at predictable locations (i.e., when the luminaire is in the "offending zone"), one solution is simply to locate people away from these areas. Clearly, this requires good communication between the lighting engineer and interior decorator—an all-too-infrequent occurrence in most building projects. Nonetheless, if areas of poor CRF can be avoided, one reasonable approach is to use fewer fixtures that are both brighter *and* smaller. Since the extent of the area of low CRF is determined by the physical size of the luminaire (or strictly speaking, the angular subtense of the luminaire as seen by the observer), smaller fixtures will result in smaller "offending zones." If the fixtures are also brighter, then one can use fewer of them to achieve the same illuminance level. This should result in a proportionally larger area with good visibility. Of course, the visibility in the poor locations will be even lower under these circumstances, but this would not be a problem if these areas are avoided as discussed above.

For an obstructed space such as that treated here, visibility could be optimized by running the task stations in columns between the columns of luminaires with the occupants facing north or south. These zones between luminaire columns have high CRF values usually exceeding those levels found with indirect lighting systems. On the other hand, if uniformly high CRF values are required at all locations in a space, then indirect lighting systems would appear to be a good solution.

This study has restricted itself to the standard pencil task at a 25° viewing angle, but other studies [2] have shown that as long as the paper task has some specularity, the type of task (pen, pencil, xerox copy, etc.) does not significantly affect CRF (or VL). One task that is clearly different, though, is the visual display tube (or VDT), but the "visibility" of this relatively new task cannot be analyzed effectively with existing commercial lighting software. Future research should address this task, perhaps using the next generation of lighting calculation software that can effectively model the visual task in all its detail and complexity.

The results of this study indicate that it may not be possible to efficiently assure good visibility regardless of viewer location and orientation by choosing a particular overhead lighting system. This does not imply, though, that all such attempts at optimization are fruitless for all types of lighting design strategies. For example, if the overhead lighting system is tunable (i.e., the light output of individual luminaires can be independently controlled), it may be possible to optimize task visibility locally, especially if there are no nearby tasks. Finally, placing lights nearer the task using task lights generally allows one to optimize local conditions, especially if the position of the light can be adjusted.

Conclusion

We found that there were small differences in average task visibility levels for different luminaires and fixture spacings but that these differences were insignificant compared with variability within an installation. This indicates that if one does not know the location of the task *a priori*, then it may not be possible to achieve consistently high visibility levels throughout a space with an overhead lighting system without resorting to solutions that are intrinsically inefficient.

Acknowledgment

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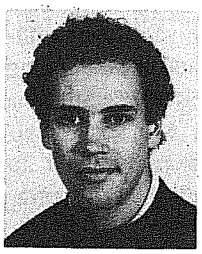

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