Veiling Reflection Control By Candlepower Distribution

IES TRANS-ACTION

I. Lewin and
J. W. Griffith

WE ARE entering a third era of illuminating engineering. The first era was concerned with providing adequate levels of illumination for performing the visual task. The second dealt with discomfort glare, its analysis, and the design of equipment to minimize its effects. The third era is the combination of these first two into an integrated system, providing adequate illumination, visual comfort, and the solution to the third problem of veiling reflections.

Achieving greater knowledge of veiling reflections, leading to the design of illumination systems for improving contrast rendition, has been one of the most important tasks facing the Illuminating Engineering Society.

RQQ Report No. 4, "A Method of Evaluating the Visual Effectiveness of Lighting Systems," indicates the importance of visual performance losses occurring as a result of specular reflections from the written task.[1] Knowledge of this subject has been progressing rapidly and although we were aware of the large contrast losses which occur with conventional systems of illumination, we were unable to compare various studies due to the lack of information on the effect of several important variables. Because of these unexplained variables, designers have been severely limited in their ability to engineer lighting systems to meet IES recommended levels of performance.

In a recent survey,[2] conducted under the joint sponsorship of the Educational Facilities Laboratories and Illuminating Engineering Research Institute, it was found that only one out of 18 electric lighting systems surveyed actually met IES recommendations based upon visual performance. In fact, approximately one third of the tested installations produced less than half of the 70 effective footcandles recommended by IES (750 effective lux), although the measured task illumination levels were in excess of 100 footcandles (1080 lux).

The authors felt that a thorough investigation of veiling reflections under controlled experimental conditions was required to determine the fundamental factors affecting task contrast.

Consequently, luminaires with a range of typical candlepower distributions were investigated at task locations traversing the entire installations. In addition, a system specifically designed to overcome veiling reflections was tested.

Test Facilities and Testing Procedure

The Illumination Systems Research Laboratory consists of a room measuring 24 by 32 feet, with a ceiling suspended at a height of nine feet. The reflectance of the walls is .65, that of the ceiling is .80, and the floor is .21. Daylight entering the room was negligible. The room contained simulated furniture in the form of small desks.

The power to all luminaires was supplied through a voltage regulator, and a photoelectric illumination meter was used at a fixed point throughout the tests to verify that no change in lamp output occurred. Prior to testing, all lamps were aged for 200 hours.

A Blackwell Visual Task Photometer[3] was used to measure all Contrast Rendition Factors, and a Blackwell concentric ring target, no. C48.4.4, was used as the visual task.[4] The recommended procedure was followed throughout.[5] Lighting Directionality Factors were measured for each installation tested and were found to be within the limits of acceptability in all cases.[5] The CRF measurements were made five times

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A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 14-17, 1970, Vancouver, B.C., Canada. AUTHORS: Respectively, Research Manager, Holophane Co., Inc., New York, N. Y., and Consulting Engineer, Dallas, Texas.

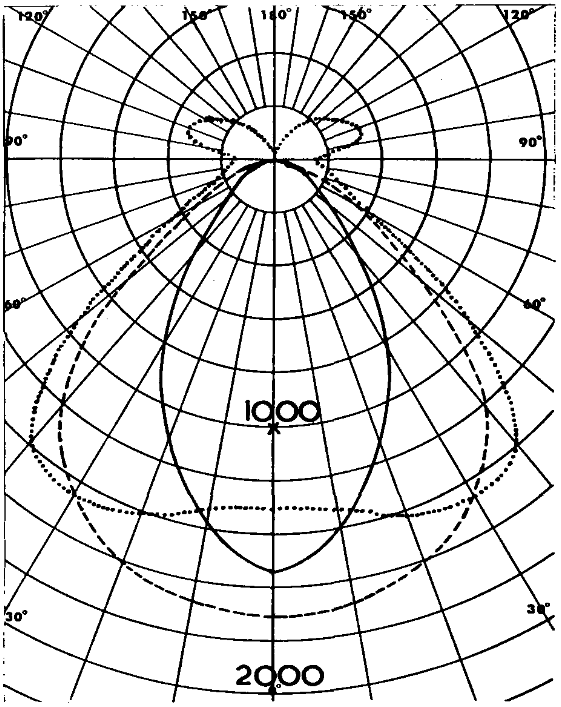


Figure 1. Candlepower distribution curves for conventional luminaires. Across-axis plane.

at each test location and the results averaged. Any readings which were obviously erroneous were discarded. The Pritchard Photometer was used to measure task illumination and task luminance, from which luminance factor was calculated at each point. The illumination measurements were checked by an accurate photoelectric meter.

Lighting Equipment Tested

Three conventional systems of illumination were tested initially. The light distribution curves for the three luminaires are shown by Fig. 1, representing narrow, medium and wide candlepower characteristics, spanning photometric distributions in common use today. To enable engineering comparisons, the total number of lamps in each installation was the same, with identical layouts of luminaires (Fig. 2).

Results

The first installation tested was that utilizing luminaires with the narrow candlepower distribution. Contrast Rendition Factor, task luminance and task illumination were measured at close intervals along a line traversing the length of the room, beneath the center row of luminaires. The results obtained, for the three viewing angles tested, are shown by Fig. 3.

Certain characteristics shown in Fig. 3 were found to be typical of all three installations, providing significant information on the variation of contrast loss within a room. As the distance between the point of measurement and the rear wall increased, there was a gradual increase in Contrast Rendition Factor. This is probably due to the relative increase in task illumination originating from luminaires behind the observer. This effect is overcome as the test position is moved further into the room, and CRF is constant until the front wall is approached. For a viewing angle of 10 degrees, there is initially a sharp drop in Contrast Rendition Factor. This presumably occurs at a position where part of the last luminaire in the row remains in the veiling reflection offending zone, but where mainly the front wall, which has low brightness only, lies outside the offending zone, and thus contributes little to offset the task veiling reflections. This results in a low CRF. As the viewing angle is increased to 40 degrees, the dip in the curve is eliminated, as the offending zone lies further in front of the test position. Thus the offending zone encompasses the front wall before the contribution to task illumination from outside the offending zone is reduced due to the front wall. Close to the front wall,

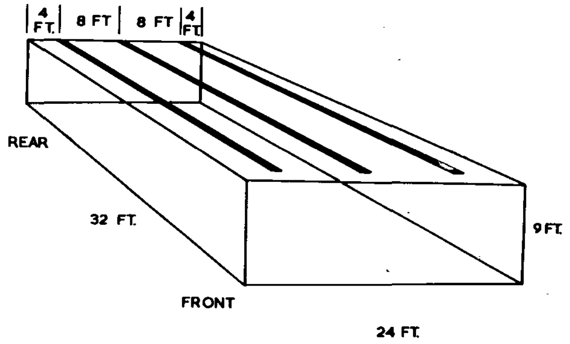


Figure 2. Diagram of Illumination Systems Research Laboratory.

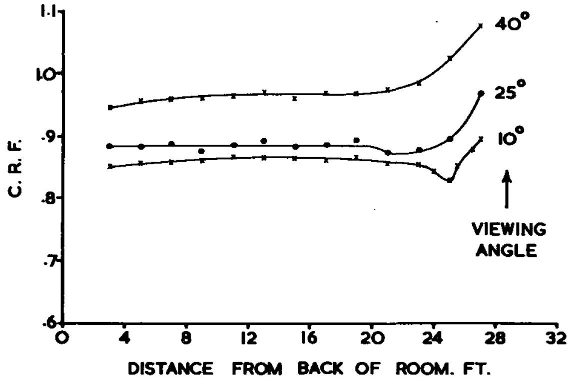


Figure 3. Contrast rendition factor variation along length of room. Narrow distribution fixtures, beneath center row.

for all three viewing angles, the absence of luminaires within the offending zones causes a large rise in Contrast Rendition Factor.

Results of a similar traverse midway between rows of luminaires are shown in Fig. 4. Similar characteristics may be noted, with the overall level of CRF being higher, as would be expected. The front wall dip and rise effects discussed above are reduced or eliminated, as luminaires do not lie within the offending zone at any point along the traverse.

Further traverses taken at intermediate positions gave the expected intermediate results.

Since equivalent visual performance within the working area is an essential aspect of good design, traverses were conducted across the room for evaluation of the problem. Fig. 5 shows the results of a traverse across the room center, where the flat portions of the curves shown in Figs. 3 and 4 exist, thereby typifying the CRF variation within the major working area.

It has been found by previous research that most visual tasks in offices and schools are conducted at viewing angles close to 25 degrees, and thus this viewing angle is becoming the accepted design standard.[1,6] For this reason, and to avoid the publication of an excessive amount of data, further results are presented for a viewing angle of 25 degrees only.

Fig. 6 gives a comparison of the Contrast Rendition Factor characteristics of the three conventional systems of illumination. It will be noticed that as the width of the polar distribution curve increases, the diversity of Contrast Rendition Factor decreases.

A Luminaire Evaluation System

Since Contrast Rendition Factor curves by themselves are meaningless to the engineer, the authors would like to discuss a concept whereby a luminaire in a system may be rated according to its suitability for meeting Equivalent Sphere Illumination criteria.[1] The importance of such a luminaire effectiveness rating lies in its ability to provide a means of comparing and selecting illumination systems for veiling reflection control. Also, as will be shown, the proposed evaluation system is in keeping with present engineering techniques involving Coefficients of Utilization.

The Coefficient of Utilization of a luminaire relates the mean horizontal task footcandles provided by that luminaire in a given room to the lamp lumens emitted. It is therefore a means of expressing the efficiency of that luminaire in terms of horizontal footcandles. The "Coefficient of Effectiveness" of a luminaire in a system is comparable in many ways to CU, except that the luminaire is rated in terms of the effective footcandles (Equivalent Sphere Illumination)[1] produced, rather than the horizontal footcan-

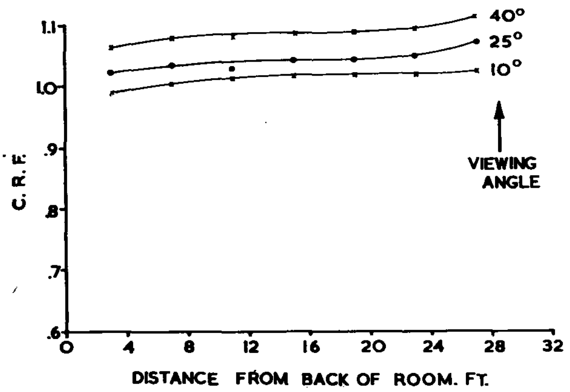


Figure 4. Contrast rendition factor variation along length of room. Narrow distribution fixtures, between rows.

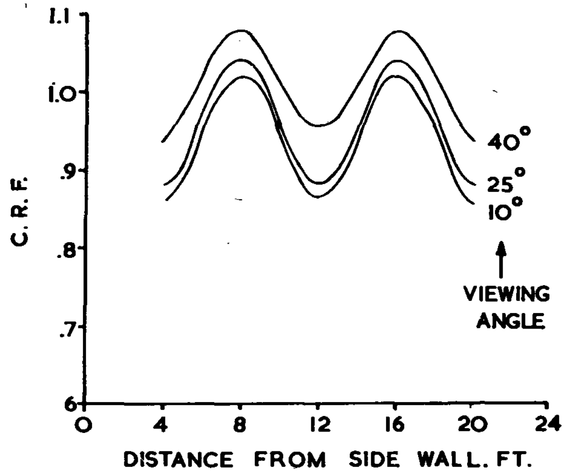


Figure 5. Contrast rendition factor variation across center of room. Narrow distribution fixtures.

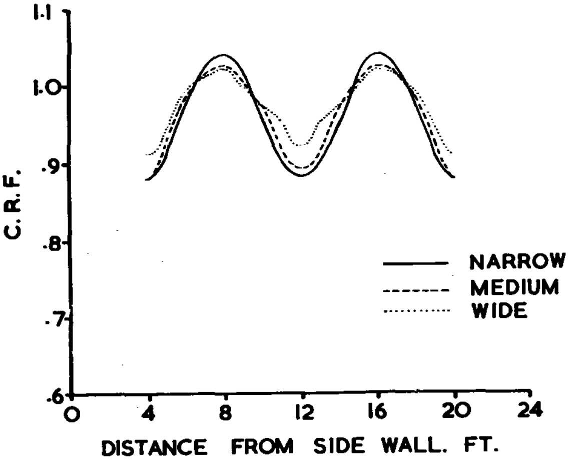
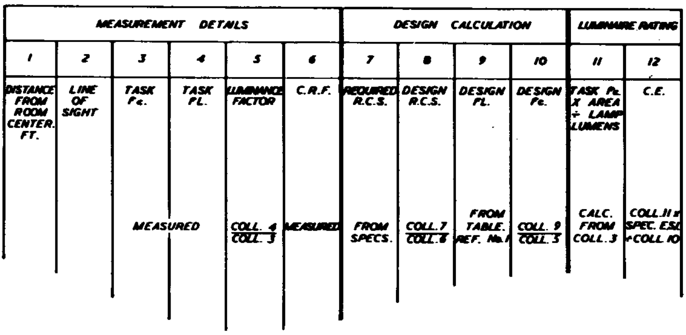


Figure 6. Contrast rendition factor variation across center of room. 25-degree viewing angle. Conventional systems.



MEASUREMENT DETAILS						DESIGN CALCULATION				LUMINAIRE RATING	
1	2	3	4	5	6	7	8	9	10	11	12
DISTANCE FROM ROOM CENTER. FT.	LINE OF SIGHT	TASK Fc.	TASK FL.	LUMINANCE FACTOR	C.R.F.	REQUIRED R.C.S.	DESIGN R.C.S.	DESIGN FL.	DESIGN Fc.	TASK Fc. X AREA ÷ LAMP LUMENS	C.E.
		MEASURED		$\frac{\text{COLL. 4}}{\text{COLL. 3}}$	MEASURED	FROM SPECS.	$\frac{\text{COLL. 7}}{\text{COLL. 6}}$	FROM TABLE. REF. No. 1	$\frac{\text{COLL. 9}}{\text{COLL. 5}}$	CALC. FROM COLL. 3	COLL. 11 × SPEC. ESI ÷ COLL. 10

Figure 7. Calculation of co-efficient of effectiveness.

dles. The use of Coefficient of Effectiveness thus will allow the selection of luminaires on the basis of the true visual performance which will be accomplished, fully taking veiling reflections into account.

Fig. 7 illustrates the calculation of Coefficient of Effectiveness, (CE), and Table I gives an illustrative example. The table can be divided into three sections. The first section involves the use of test laboratory measurements, which in the near future may be superseded by values obtained from a predetermination system. Section two covers the design calculations, while section three calculates the luminaire rating in terms of Coefficient of Effectiveness.

Unlike Coefficient of Utilization, Coefficient of Effectiveness will change with task location and direction of view, for any given viewing angle, due to alteration of Contrast Rendition Factor. These two factors are noted therefore in columns 1 and 2. The measured values for task illumination and task luminance are entered in columns 3 and 4, luminance factor being calculated from column 4 ÷ column 3 and entered in column 5. CRF is noted in column 6.

The entry in column 7 will depend upon the specifiactions with which we are concerned. In the case of a classroom, for instance, the required Equivalent Sphere Illumination would be 70.0 effective footcandles (750 effective lux) to meet IES specifications. This would give a value for the corresponding task luminance of 50.40 fL (172.6 cd/m^2), using a typical task reflectance value of 0.72. The Relative Contrast Sensitivity provided by a luminance of 50.40 fL is 67.20. taken from the RCS/luminance table contained in RQQ Report No. 4.[1] This value is entered in column 7, and is the Relative Contrast Sensitivity which must be provided to give the 70 effective footcandles (750 effective lux).

Dividing the required RCS (col. 7), by CRF (col. 6), gives the value of Relative Contrast Sensitivity to which we must design to overcome the effect of veiling reflections and provide the required Equivalent Sphere Illumination. This is noted in column 8. Using this value and the RCS/luminance curve,[1] will give the task luminance which must be provided to meet the specification. The horizontal footcandles (lux) which must be designed, column 10, can be obtained by dividing the design task luminance (col. 9) by the luminance factor (col. 5).

The Coefficient of Effectiveness can be calculated from:

$$CE = \frac{\textit{horizontal footcandles} \times \textit{room area}}{\textit{lamp lumens}} \times \frac{\textit{required ESI}}{\textit{fc to provide required ESI}}$$

The above factor [horizontal footcandles (lux) times room area divided by lamp lumens] is essentially the Coefficient of Utilization. We can apply this to the specific task location by using the actual task footcandle (lux) level. The value is entered in column 11. Multiplying column 11 by [Required Equivalent Sphere Illumination divided by Horizontal footcandles (lux) needed to provide required Equivalent Sphere Illumination] gives the Coefficient of Effectiveness, column 12.

The authors believe that the Coefficient of Effectiveness is a natural further development beyond RQQ Report No. 4.[1] This report details the calculation of Equivalent Sphere Illumination and Lighting Effectiveness Factor, which are a means of evaluating an existing installation. Coefficient of Effectiveness, however, allows the engineer to determine his lighting requirements for meeting given criteria, and therefore is a design tool for providing systems to meet Equivalent Sphere Illumination specifications. Furthermore, it can be used to evaluate existing installations also, for if the value in column 3 (measured task illumination) exceeds the value in column 10 (design illumination) the Equivalent Sphere Illumination specification has been met.

Application of the Evaluation System

The importance of both Contrast Rendition Factor and also measured horizontal footcandle (lux) in determining the Coefficient of Effectiveness is apparent. Fig. 8 shows the variation in measured foot-

Table I—Example Calculation of Coefficient of Effectiveness

Measurement Details						Design Calculation				Luminaire Rating	
Dist. from Room Center (ft)	Line of Sight	Task Illumination fc (lux)	Task Luminance fL (cd/m²)	Luminance Factor	CRF	Required RCS	Design RCS	Design Luminance fL (cd/m²)	Design Illumination fc (lux)	Illumination × area ÷ lamp lumens	CE
0	Along	115 (1240)	95 (325)	.826	.892	67.20	75.24	122.78 (420.40)	148.64 (1599.4)	.678	.319
1	axis	114 (1230)	93 (318)	.816	.917	"	73.28	97.56 (334.04)	119.56 (1286.5)	.672	.393
2	"	110 (1180)	88 (301)	.800	.973	"	69.06	62.16 (212.83)	77.70 (836.1)	.649	.585
3	"	106 (1140)	85 (291)	.802	1.006	"	66.80	48.10 (164.69)	59.98 (645.4)	.625	.729
4	"	105 (1130)	83 (284)	.790	1.029	"	65.31	40.44 (138.47)	51.19 (550.8)	.619	.846
5	"	109 (1170)	89 (305)	.817	1.018	"	66.01	43.75 (149.80)	53.55 (576.2)	.643	.841
6	"	110 (1180)	90 (308)	.818	.986	"	68.15	56.30 (192.77)	68.83 (740.6)	.649	.660
7	"	113 (1220)	92 (315)	.814	.929	"	72.34	87.14 (298.37)	107.05 (1151.9)	.667	.436

candles (lux) corresponding to the CRF characteristics shown in Fig. 6.

In order to obtain uniformity of effectiveness, losses due to low contrast rendition factors could be offset by a substantial increase in the corresponding illumination level at that point. However, with conventional systems of illumination, the large contrast losses beneath rows of luminaires are not offset, and therefore a great variation in Coefficient of Effectiveness results (Fig. 9).

Solving the Problem

Past research has shown that light striking the visual task from the side can virtually eliminate veiling reflections,[7] suggesting that a luminaire having a distribution curve similar to that shown in Fig. 10 would provide high Contrast Rendition Factors.

The application of such a photometric distribution would be as illustrated in Fig. 11, such that twin beams of light are emitted from each luminaire, so that illumination falls on the task from the side (Fig. 12). In this way, the veiling reflections will be cast away from the observer rather than in his direction of view, while providing a high level of task illumination and luminance.

For optimum contrast rendition, a particular requirement of this form of luminaire is that a radically different form of candlepower distribution in a plane along the lamp axis should be provided, such as shown in Fig. 13. In this way luminaires in the veiling reflection offending zone, above and in front of the observer, will throw very little light towards the task, and will not cause the veiling reflections experienced with conventional systems of illumination. This form of along-axis distribution has the further benefit of providing very low luminaire brightness for normal viewing.

While this concept is not new,[8, 9] it has not been fully scientifically investigated in the past.

A system of fluorescent luminaires as described above was installed in the Illumination Systems Research Laboratory. As these luminaires were

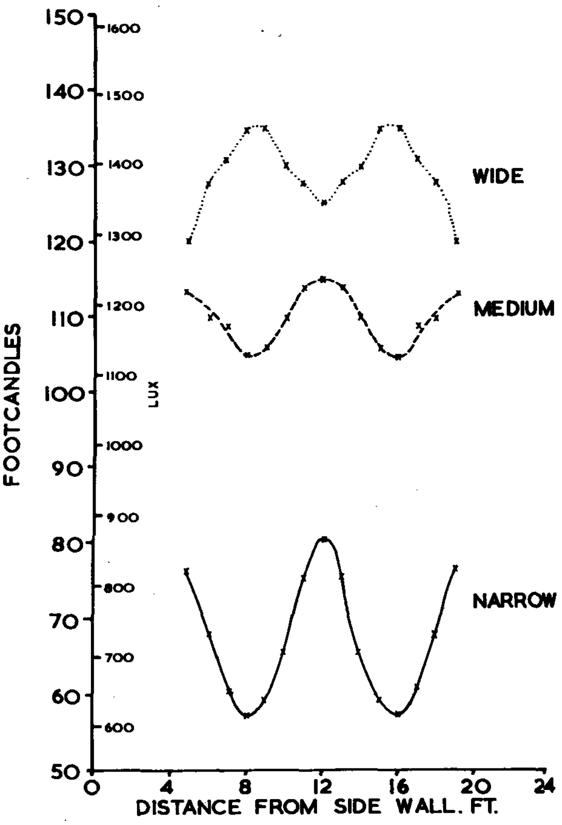


Figure 8. Illumination variation across center of room. Conventional systems.

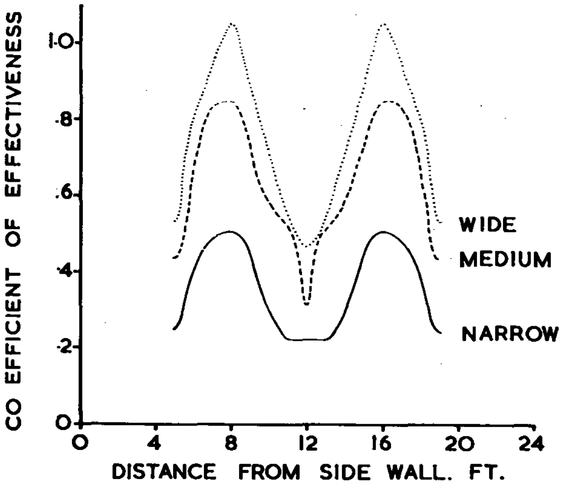


Figure 9. Co-efficient of effectiveness characteristics across center of room. Conventional systems.

equipped with single lamps, six rows were used in order to be equivalent on a lumen basis to the three rows of conventional twin-lamp luminaires.

Fig. 14 compares the Contrast Rendition Factors obtained with the twin-beam system of illumination to the characteristics shown earlier in the paper. The anticipated increase in contrast rendition is immediately apparent. Furthermore, the horizontal footcandle distribution obtained with the system is practically flat, Fig. 15, and for the same number of lamps, the illumination is considerably higher than all three conventional installations.

The Coefficient of Effectiveness values for the twin-beam system were calculated. Superimposing the coefficient of Effectiveness characteristic upon the curves for the conventional systems produces Fig. 16, which indicates the desirability of this type of candlepower distribution, in terms of both magnitude and uniformity of effectiveness.

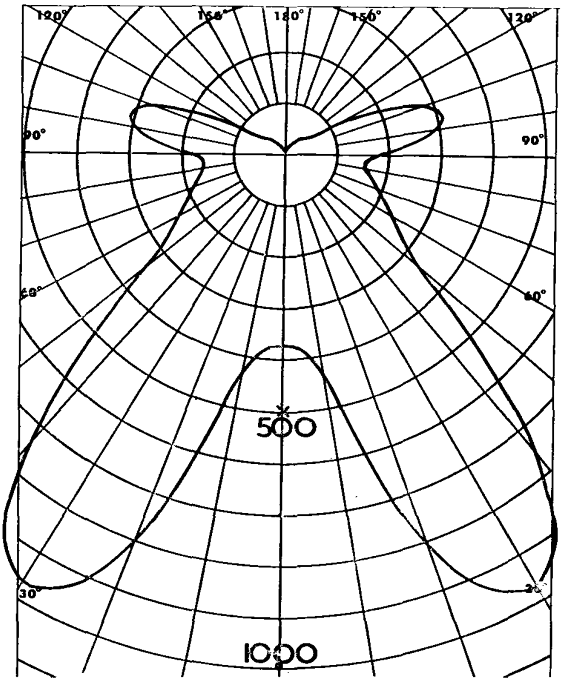


Figure 10. Candlepower distribution curve for twin-beam luminaire. Across—axis plane.

In planning illumination systems for visual performance, the critical design point occurs at the position of minimum effectiveness, as this will be the worst viewing position in the room. Table II, column 2, indicates the minimum values of coefficient of effectiveness for the four illumination systems tested. The twin-beam distribution of illumination exhibits a minimum effectiveness of 1.8, 2.6 and 3.7 times that of the wide, medium and narrow distribution systems, respectively.

When designing conventional illumination systems, uniformity of illumination is considered satisfactory if the ratio of maximum to minimum footcandles (lux) is less than 1.3, or 1.5. A ratio may be derived

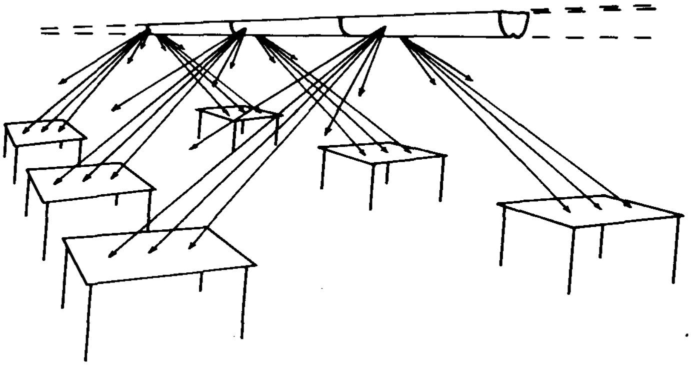


Figure 11. Twin-beam system of illumination.

Table II—Maximum to Minimum Ratio Coefficient of Effectiveness

System	Min. CE	Max. CE	Max./Min. CE Ratio
Twin-beam	.830	.956	1.15
Narrow	.223	.505	2.26
Medium	.319	.850	2.66
Wide	.468	1.052	2.25

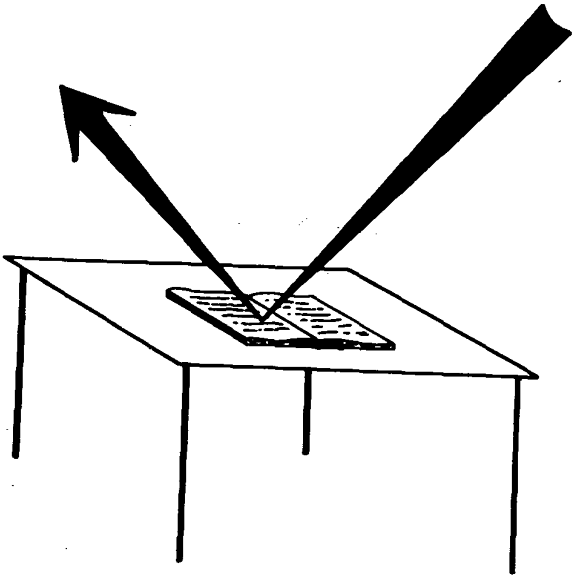


Figure 12. Specular reflection from visual task cast away from observer. Twin-Beam system.

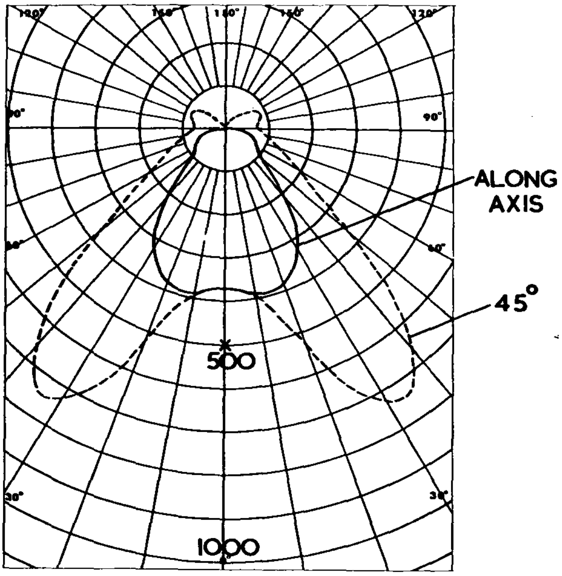


Figure 13. Candlepower distribution curve for twin-beam luminaire. Diagonal and long-axis plane.

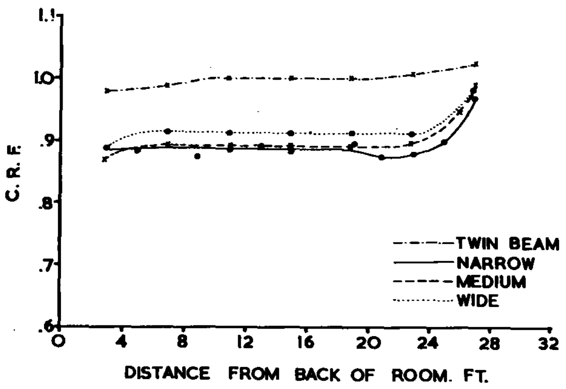


Figure 14. Contrast rendition factor variation along length of room. All systems, beneath center row.

by dividing the minimum value of coefficient of effectiveness for a system into the maximum CE for that system, which will indicate the uniformity of effectiveness. This was carried out for the four systems analyzed in this paper, results being given in Table II. The results indicate that a desirable uniformity of Equivalent Sphere Illumination will be provided by the twin-beam system, yet not with the conventional systems.

Other Considerations

The problem with which we were concerned was to develop and evaluate an illumination system for veiling reflection control, which satisfied also discomfort glare and esthetic considerations.

Careful control of the candlepower distribution curve is required with a twin-beam system of illumination. Should an observer turn his line of sight from the normal viewing direction, which is along the line of axis of the luminaires, it is important that control of veiling reflections and of discomfort glare is maintained.

For crosswise viewing, it is required that the across-axis distribution curve should cut back sharply above the main candlepower spread, and have low candlepower at angles in the discomfort glare zone. The fact that this can be achieved is verified by the across-axis luminance values for the twin-beam illumination system, which are similar throughout the range to those produced by conventional illumination systems. The same holds true for lines of sight intermediate between across and along the axis. As previously mentioned, the very low candlepower values for the along-axis plane ensure extremely low luminance for viewing in line with the luminaires. Discomfort glare control therefore is achieved for all lines of sight.

The magnitude of the candlepower from each

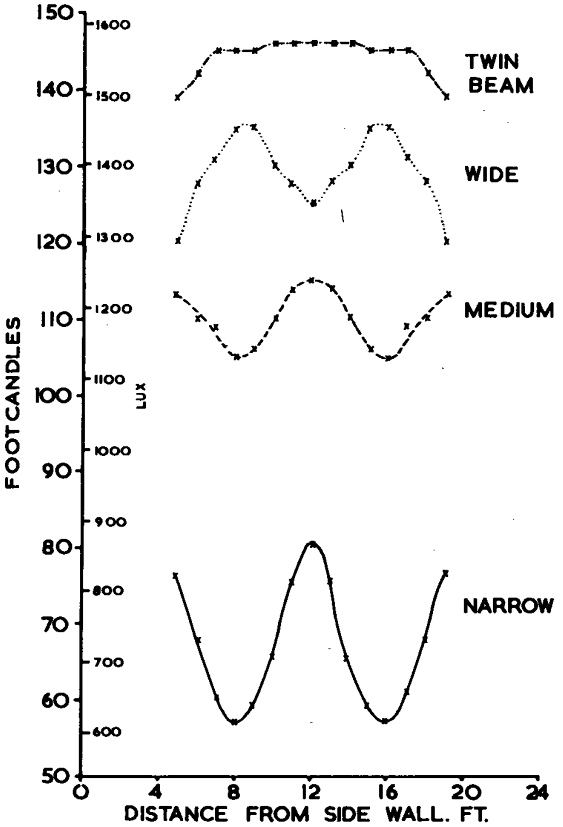


Figure 15. Illumination variation across center of room. All systems.

individual luminaire, and the degree of spread of candlepower in the two beams, must be carefully designed. Correct balance of these two factors will ensure that for crosswise viewing, the light incident upon the visual task will originate not from a single luminaire, but from a combination of many luminaires producing overlapping illumination characteristics. Because of this, the proportion of light on the task coming from outside the veiling reflection offending zone will always be great, and therefore, even in the case of an across-axis line of sight, veiling reflection control superior to that of conventional systems can be achieved.

A further comment of interest was made by numerous persons who viewed the twin-beam system of illumination. The general viewing conditions in the room appeared to be substantially improved, due to the increased clarity of objects. This is caused probably by the increased level of vertical illumination, producing superior modeling. This may be compared

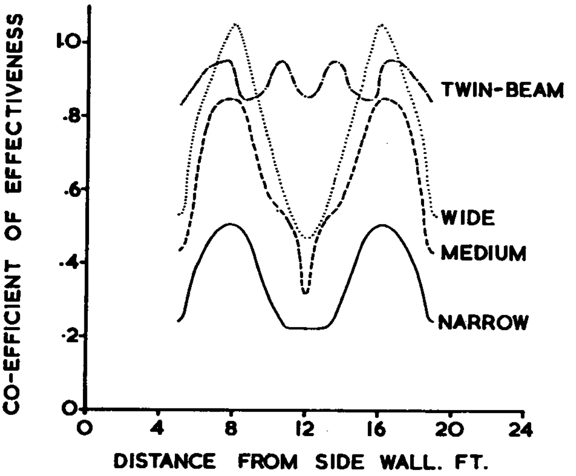


Figure 16. Co-efficient of effectiveness characteristics across center of room. All systems.

to the effect of a sunny day in comparison to that of an overcast sky. We have, however, no way of numerically assessing important visual effects such as this, and future research in this area seems to be desirable.

Conclusion

Veiling reflections have marred the quality of illumination systems in the past. As the authors have indicated, however, contrast losses may effectively be controlled by the use of candlepower distributions not found with conventional lighting equipment. We believe that the future of the lighting industry lies in this direction.

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Discussion of this IES Conference paper may be sent to IES headquarters, attention of the editor. A copy should be sent to the authors for their reply.