IES Transaction

Measurement of the Contrast Rendition Factor For Pencil Handwritten Tasks

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THE AUTHOR recently reported[1] the conceptual framework of a new and more complete method to be used in specifying levels of interior illumination on the basis of visual performance criteria, which is intended to replace in time the author's earlier method[2] in current use by the Society. The new method takes account of five factors which influence the difficulty of a visual task and hence the level of illumination to be specified, in addition to the intrinsic task variables such as size of detail, luminance and chromatic contrast and legibility which were included in the visual task evaluation aspect of the original method. The new variables are: (a) the informational requirement of the task; (b) the angle at which the task is viewed; (c) the level of task object contrast in an actual environment, which depends upon the degree of veiling reflections present; (d) the level of task image contrast which depends upon the degree of disability glare in the environment; and (e) the level of visual performance capability in the presence of transitional adaptation, which depends upon the luminance non-uniformities in the actual environment.

The earlier paper examined in some detail the effects of informational requirements and viewing angle upon the difficulty of a prototype pencil handwritten task. It also included study of the validity of physical methods for measuring the level of task object contrast, to provide a means of making quantitative allowance for the veiling reflection effects of real luminous environments. It was shown that measurement of the flux contrast of prototype pencil targets could be used to describe the visual difficulty of pencil handwritten tasks under realistic lighting systems, provided the following precautions were taken: (a) the pencil target used for physical measurements had to be matched in specularity to the pencil task used for visual assessment; and (b) the luminous environment could not exceed a criterion measure of lighting directionality. The presence of greater lighting directionality than the criterion leads to localized veiling reflection effects within different parts of the visual task. These cause the visual difficulty of the task to bear a complex relation to the physical contrast of the task which depends upon both the informational requirement and the viewing angle.

This work seemed to provide the basis for development and use of at least the portions of the new and more complete method involving the level of informational requirements, the viewing angle, and the effects of veiling reflections.

The experiment which seemed to provide a validation of physical measurements of task object contrast involved only two lighting systems, and these were not realistic but were chosen for convenience in making measurements with the Visual Task Evaluator. (One involved three rows of luminaires, but the ceiling was covered with translucent light panels rather than acoustic tile. The other involved a translucent ceiling interrupted by the three rows of luminaires. The systems were alternated by turning on either the luminaires or the translucent ceiling.) Two pencil targets were used for the physical measurements, one involving multiple dots and the other crosshatched lines. There was a suggestion in the data that the

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Table I—Values of the Task Specularity Index (TSI)

	Viewing Angle (degrees)				
Target	10	25	40	50	60
D30.4.2	1.581	1.795	1.860	1.935	1.885
L37.4.2	1.560	1.745	1.855	1.957	2.179
C48.4.1	1.549	1.734	1.884	2.079	2.552
C48.4.2	1.558	1.742	1.856	2.075	2.402
C48.4.3	1.535	1.736	1.845	2.059	2.398
C48.4.4	1.522	1.724	1.838	2.008	2.439
C48.4.5	1.585	1.819	1.895	2.120	2.560
Average C48. targets	1.550	1.751	1.864	2.068	2.470

multiple-dot target assessed visual difficulty of the task better than the crosshatched linear target.

Since it is imperative that a completely valid procedure be used to measure the effects of veiling reflections, further study has been devoted to this problem. The matter of the most valid pencil target for use in physical measurements of task object contrast has been pursued a great deal farther, and measurements have been made under a wide variety of realistic lighting installations.

New Validation Experiments

As was reported in the earlier paper,[1] the author studied the physical properties of 76 pencil handwritten samples made by sixth-grade students from Toronto. The critical property was found to be specularity, as described by a Task Specularity Index (TSI). The value of TSI is merely a ratio of the flux contrast of a pencil sample under the generally diffuse illumination of a Portable Illumination Reference Box, divided by the flux contrast of the same sample illuminated by a single row of simulated luminaires in the Interior Lighting Simulator. The values of flux contrast were measured with the laboratory model Visual Task Photometer (VTP) in which a gravity-loaded photometric aperture insured that precisely the same area of the task was measured at each viewing angle. Pencil strokes were found to differ in TSI depending upon their orientation with respect to the plane which included the line-of-sight and the row of luminaires. Strokes parallel to the plane are designated longitudinal whereas those perpendicular to the plane are designated transverse. Words such as "ark" and "saw" were found to have relatively equal numbers of longitudinal and transverse strokes and had an average TSI at the 25-degree viewing angle of 1.750. The 28 ark samples had an average TSI value of 1.760 at 25 degrees. These samples were later studied at 40 degrees and the average value of TSI was found to be 1.870.

Values of TSI for the multidot target D30.4.2 and the crosshatched linear target L37.4.2 used in the earlier study are reported in Table I for viewing angles ranging from 10 degrees-60 degrees. We note that these targets appear quite equal in specularity. They are both considered satisfactorily matched to the 76 handwritten samples at the 25-degree and 40-degree viewing angles at which these later were measured.

With specularity so closely matched, how could one of these targets assess the visual difficulty of a pencil handwritten visual task better than the other? The targets obviously differ with regard to radial symmetry, the multidot target being radially symmetric whereas the linear crosshatched target obviously has only two orthogonal directions of pencil lines represented. Since real pencil writing has nearly all orientations of lines, we might expect the lack of radial symmetry of the crosshatched linear target to create difficulty as it seemed to do. While the multidot target has radial symmetry, there appear to be two problems with its use: (a) the use of dots rather than lines does not seem realistic; and (b) there is no way to use the multidot target to evaluate the directionality of the lighting installation. This second disadvantage is a severe one, since we must evaluate lighting directionality in order to assure the validity of physical measurements as a substitute for visual assessment. Accordingly, a third type of pencil target was sought. The use of concentric pencil rings was immediately suggested since they have great realism and also radial symmetry. The need for a measure of lighting directionality was satisfied by use of a special narrow rotatable aperture slot mounted just above a second concentric ring target produced on the same piece of background paper used for the first concentric ring target. The slot was cut in a piece of background paper and thus revealed only the portions of the concentric ring target beneath the open slot. When the slot is rotated into a longitudinal orientation, the revealed pencil lines are short arcs of the concentric

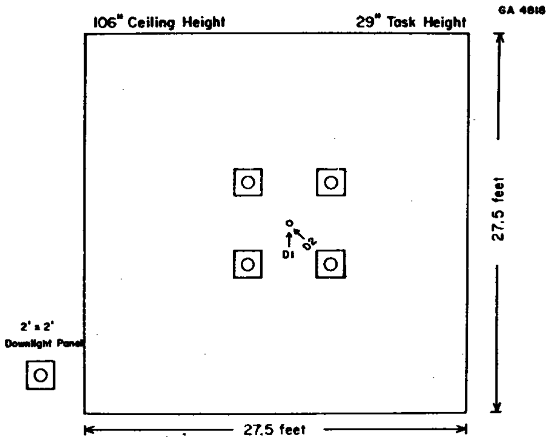

Figure 1. Lighting layout for downlight installation showing two test locations.

circles oriented principally transversely. When the slot is rotated to other angles, the revealed pencil lines are short arcs oriented in other directions. Thus, lighting directionality may be measured by recording flux contrast for a variety of orientations of the slotted mask.

The concentric-ring targets were introduced into the Interior Lighting Simulator under the conditions used in the earlier experiments[1] so that lighting directionality criteria could be established. The Lighting Directionality Factor (LDF) was redefined as the ratio of the maximum divided by the minimum flux contrast value found at different orientations of the slotted mask on each target. A separate LDF limit was set for each concentric ring target since they were not of precisely equal specularity. These values were set slightly larger than the values measured with three rows of simulated luminaires, as before.

Experimentation with lead hardness, pressure and tip curvature as before lead us to a recipe for concentric ring targets of the desired specularity. Measurements of TSI for a set of five of these targets are contained in Table I. The average values agree well with the design values at 25-degree and 40-degree viewing angles and with the values for all viewing angles for the other two targets.

These seven targets were used to measure flux contrast under a variety of different lighting systems. Task contrast was indicated by the Contrast Rendition Factor (*CRF*), defined as the flux contrast under a given lighting condition divided by the flux contrast in our laboratory double-hemisphere. Values of *CRF* were measured at 25 degrees and 40 degrees with: (a) three rows of luminaires on eight-foot centers; (b) full translucent ceilings; (c) a luminous wall; (d) a set of four downlights. It was found that the values of *CRF* obtained with the different test objects were indeed different.

First, a method was developed to compensate for the differences in *CRF* obtained with the different concentric-ring targets. Compensation factors were found which corrected the values of *CRF* obtained with each of these targets to the average value obtained with all five. Compensation was achieved quite satisfactorily with each concentric-ring target by an equation of the type

$$CRF' = k_1 CRF + k_2 CRF^2 \qquad (1)$$

where *CRF* is the measured value in each case, and *CRF'* is the corrected value approximating the average value for all five targets. Values of k_1 varied from .960 to 1.070 and values of k_2 from +.040 to —.070 for the different targets. The corrections are in fact very small, usually amounting to only .003 or .004 in the value of *CRF*, which represents no more than a 0.5 per cent correction.

Once the data were corrected in the manner indicated, values of *CRF* obtained with the five concentric-ring targets were found to agree with each other very closely. However, data for the multidot and cross-hatched targets obviously disagreed with each other and with the data obtained with the concentric-ring targets. What was needed was a validation experiment to determine which values of *CRF* properly assessed the visual difficulty of a pencil task viewed under the different lighting systems. The data obtained under the different lighting conditions were scrutinized to pinpoint the most likely condition to use for this purpose. Since precision of Visual Task Evaluator data is relatively poor, validation experiments will be most successful when the largest possible differences exist between the values of *CRF* obtained with the different targets. This was found to be the case with the downlight installation.

The layout is shown in Fig. 1. Four downlights were located at the corners of a six-foot square. When the target was placed in the center of the square and viewed from the D2 direction, a luminaire was at the direct specular angle when the viewing angle was 32 degrees from vertical. This condition was not used, but angles of 25 degrees and 40 degrees are located very near the specular angle. Measurements of the concentric-ring targets was limited to the use of target C48.4.1 only, with the values of *CRF* corrected in accordance with the appropriate equation (1) to approximate the average values obtained with all five targets. Ratios of the value of *CRF* in position D2 divided by *CRF* in position D1 were as follows at 25 degrees: .850 for C48.4.1; .735 for D30.4.2; and .775 for L37.4.2. At 40 degrees, the values were .788 for C48.4.1; .680 for D30.4.2; and .803 for L37.4.2. Not only were the differences among the targets very large, but the pattern of differences was not the same at the two viewing angles. These seemed to be excellent conditions for a valida-

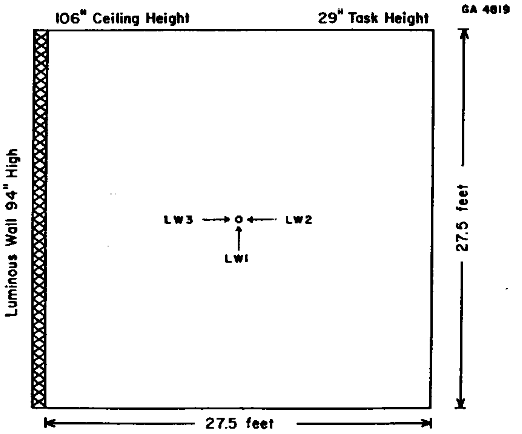

Figure 2. Lighting layout for luminous wall installation showing three test locations.

tion experiment. However, before proceeding, the slotted mask technique was used to assess the lighting directionality, and it was found that the value of the Lighting Directionality Factor (LDF) fell below the criterion value.

Measurements of task visibility was made with the pencil task used previously (W37-1) using the Visual Task Evaluator. The orientation was changed back and forth from D1 to D2. A total of 400 measurements were made in all, 100 at each position at each 25-degree and 40-degree viewing angle. The ratios of $\tilde{C}$ obtained in position D2 divided by $\tilde{C}$ in position D1 were as follows: .855 at 25 degrees and .785 at 40 degrees. It seems quite clear that the concentric ring targets possess validity. Accordingly, these targets were made available to four investigators in addition to the author* for studying veiling reflections.

One aspect of the use of these targets remained theoretically troublesome. Values of TSI were measured with the gravity-loaded aperture which includes precisely the same concentric rings regardless of the viewing angle at which measurements are made. All pracitcal use of these targets involves use of a laboratory or commercial Pritchard photometer, equipped with a fixed photometric aperture which includes different portions of a concentric-ring target depending on the viewing angle. In principle, use of other than the same complete concentric rings should distort the values of CRF since the correct balance between longitudinal and transverse strokes will only be achieved at 0-degree viewing angle. At larger viewing angles, perspective foreshortening will add increasingly more transverse-like arcs to the concentric rings measured at 0 degrees, and this alteration in the balance between longitudinal and transverse strokes should alter the target specularity and the value of CRF.

It is possible to eliminate this bias by constructing special elliptical photometric apertures, one for each viewing angle, which compensate for perspective foreshortening and insure that the same full concentric rings are measured at each viewing angle. A set of such apertures was fabricated, and measurements were made with target C48.4.1 with the regular and special photometric apertures under different lighting installations. Measurements were restricted to the 60-degree viewing angle where the effect should be greatest. The same lighting installations were used as in the last validation experiment. In this case, the largest difference between the values of CRF obtained with the regular and special aperture was found with the luminous wall installation. The layout is shown in Fig. 2. The greatest difference was found by dividing the CRF found in position LW3 by the value found in position LW2. With the regular photometric aperture, the ratio was 1.53. It was 1.62 with the special photometric aperture. Measurements of lighting directionality with the slotted mask showed that the value of the Lighting Directionality Factor fell within allowable limits as before. A total of 200 Visual Task Evaluator measurements were made, 100 for each position. The ratio of the value of $\tilde{C}$ obtained in position LW3 divided by the value in position LW2 was 1.63. This reveals that values of CRF obtained with the special photometric aperture are the valid measures of the difficulty of visual tasks as one might expect.

New CRF Survey

With a valid target and measuring technique at hand, it seemed appropriate to survey values of CRF for a wide variety of lighting conditions. It also seemed appropriate to study the three different pencil targets under a variety of conditions to establish the degree to which a compensation technique to correct out differences in CRF values obtained with the different targets could be developed. The concentric-ring target was studied with both the special and the regular photometer apertures with the same objective.

The two lighting layouts used in the validation experiments were used again. In the case of the luminous wall, a third test direction was used (LW1). Other lighting installations are shown in Figs. 3-6. There are five test locations with the fixture layout, two with the translucent ceiling layout, five with the coffered-ceiling layout, and two with the wall-mounted fixture layout. All these lighting layouts were made within the test room at the Institute used in the earlier study. The 28-ft by 28-ft room features a full luminous plenum and a suspended grid system which

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*Foster K. Sampson, Grant Davidson, J. W. Griffith, and J. E. Kaufman.

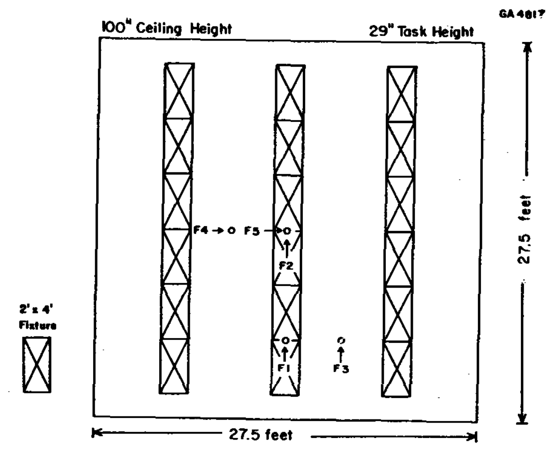

Figure 3. Lighting layout for fixture installation showing five test locations.

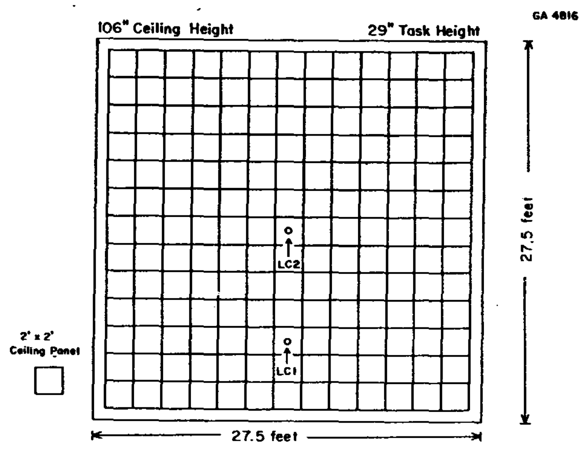

Figure 4. Lighting layout for translucent ceiling installation showing two test locations.

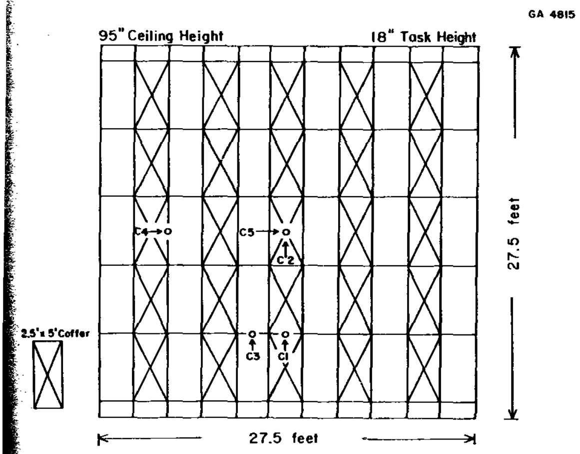

Figure 5. Lighting layout for coffered-ceiling installation showing five test locations.

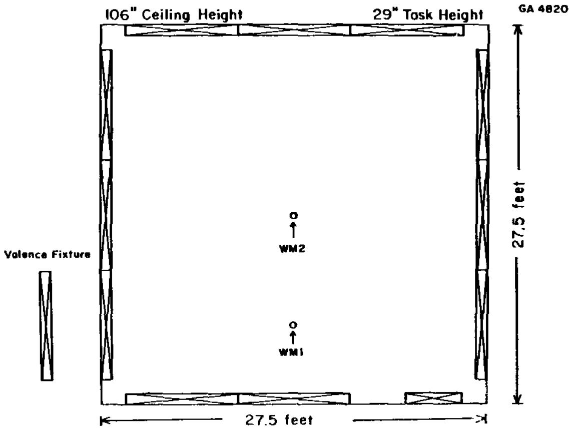

Figure 6. Lighting layout for valance fixture installation showing two test locations.

permits use of any layout of two-foot by two-foot translucent or opaque panels. Beneath that, metal tracks are mounted which can hold two-foot by four-foot flush-mounted fixtures. The ceiling height is 106 inches above the floor. A second grid system was suspended below all this to accommodate the coffered-ceiling systems, with the ceiling panels mounted 95 inches above the floor. The full luminous wall was covered with removable panels when the wall was not in use. The valance fixtures were mounted approximately 79 inches above the floor and 27 inches below the opaque ceiling. Test room reflectances were as follows: walls 48.3 per cent, floor 18.1 per cent, opaque ceiling tile 85.2 per cent, translucent ceiling tile 70.4 per cent. The Visual Task Photometer was used as in the earlier study. It was mounted at different heights above the floor so that the test plane was kept approximately constant at about 77 inches.

Four fixure lighting materials were used: (a) white diffusers; (b) plastic prismatic lenses; (c) diffuser multilayer polarizers; and (d) prismatic multilayer polarizers. Three materials were used in the full translucent ceiling: (a) double diffuser panels; (b) translucent plastic eggcrate louvres; and (c) double multilayer polarizer panels. Four lighting installations were used with the coffered-ceiling: (a) single lamp units with standard plastic refractors; (b) double lamp units with standard plastic refractors; (c) single lamp units with low-brightness plastic refractors; and (d) double lamp units with low-brightness plastic refractors. Thus, there were 53 combinations of lighting installation and test position. A set of data consisted of measurements of flux

Table II—Values of the Contrast Rendition Factor (CRF)

10° Viewing Angle

Test Condition	C48.4.1 (S)	C48.4.1	D30.4.2	L37.4.2
D1	.950	.950	1.022	.959
D2	.944	.944	.993	.917
LW1	1.044	1.044	1.049	1.101
LW2	1.085	1.085	1.059	1.093
LW3	1.042	1.042	1.058	1.061
F1	.831	.831	.816	.826
F2	.859	.859	.849	.851
F3	.997	.997	1.050	1.021
F4	1.001	1.001	1.029	.987
F5	.862	.862	.898	.912
LC1	.919	.919	.939	.925
LC2	.927	.927	.950	.935
C1	.913	.912	.912	.898
C2	.898	.898	.902	.910
C3	.928	.928	.976	.942
C4	.920	.920	.942	.922
C5	.884	.884	.912	.921
WM1	1.048	1.048	1.055	1.058
WM2	1.102	1.102	1.082	1.105

contrast for each of the four target conditions, at each of five viewing angles. Thus, the total survey included 1,060 measurements of flux contrast. A value of CRF was computed from each using the flux contrast values obtained in the laboratory double-hemisphere as the reference base.

Preliminary measurements revealed the need for several refinements in the measurement technique. First, it was found that alignment of the photometric apertures with the concentric-ring targets was unexpectedly critical. The technique was adopted that alignment was checked and adjusted at each viewing angle separately, using a six-minute photometric aperture centered on the central dot in the concentric-ring target. Sphere calibrations were performed again with this method of alignment and were found

Table III—Values of the Contrast Rendition Factor (CRF)

25° Viewing Angle

Test Condition	C48.4.1 (S)	C48.4.1	D30.4.2	L37.4.2
D1	.886	.886	.990	.921
D2	.755	.754	.732	.716
LW1	1.039	1.039	1.053	1.079
LW2	1.020	1.020	1.019	1.040
LW3	1.025	1.025	1.048	1.040
F1	.807	.807	.809	.816
F2	.832	.832	.838	.841
F3	.984	.984	1.060	1.011
F4	.908	.908	.949	.902
F5	.950	.950	1.013	.977
LC1	.902	.902	.945	.911
LC2	.916	.916	.959	.927
C1	.861	.861	.872	.870
C2	.884	.884	.908	.898
C3	.913	.913	.979	.938
C4	.890	.890	.919	.896
C5	.906	.906	.954	.920
WM1	1.066	1.066	1.078	1.058
WM2	1.079	1.079	1.081	1.063

Table IV—Values of the Contrast Rendition Factor (CRF)

40° Viewing Angle

Test Condition	C48.4.1 (S)	C48.4.1	D30.4.2	L37.4.2
D1	1.000	1.000	1.060	1.027
D2	.785	.783	.726	.823
LW1	1.060	1.060	1.068	1.082
LW2	.956	.956	.966	.950
LW3	1.041	1.041	1.064	1.061
F1	.855	.855	.858	.865
F2	.869	.869	.866	.874
F3	1.010	1.010	1.077	1.030
F4	.903	.903	.928	.932
F5	1.000	1.000	1.040	.994
LC1	.928	.928	.967	.942
LC2	.949	.949	.980	.958
C1	.922	.919	.928	.922
C2	.915	.916	.927	.922
C3	.957	.959	1.011	.973
C4	.906	.906	.930	.923
C5	.921	.922	.944	.935
WM1	1.087	1.087	1.076	1.061
WM2	1.041	1.041	1.036	1.010

to differ in some cases from those obtained by less accurate methods of alignment.

The slot aperture mounted over the second concentric-ring target was found to yield erroneous values of LDF under some lighting geometries, due to shadows produced by the thickness of the paper mask and its slight separation from the target. Accordingly, special slot apertures were made to mount in the photometer. These may be rotated without being removed from the photometer. A separate aperture is required for each viewing angle to compensate for the foreshortening effects, and these were fabricated.

Investigators other than the author do not have the laboratory double-hemisphere available for their use. Rather, they must depend upon the Portable Illumination Reference Box to check their sphere reference values. This is especially important in view

Table V—Values of the Contrast Rendition Factor (CRF)

50° Viewing Angle

Test Condition	C48.4.1 (S)	C48.4.1	D30.4.2	L37.4.2
D1	1.073	1.065	1.119	1.071
D2	.905	.870	.868	.907
LW1	1.105	1.087	1.075	1.098
LW2	.867	.849	.902	.867
LW3	1.096	1.065	1.068	1.076
F1	.908	.875	.882	.893
F2	.927	.899	.905	.913
F3	1.062	1.046	1.099	1.050
F4	.991	.973	1.005	.989
F5	1.032	1.013	1.039	1.004
LC1	.976	.954	.987	.964
LC2	.999	.981	1.010	.989
C1	.966	.948	.958	.944
C2	.982	.957	.968	.966
C3	1.007	.994	1.036	.998
C4	.961	.941	.968	.952
C5	.982	.957	.983	.973
WM1	1.115	1.097	1.089	1.064
WM2	.988	.966	.977	.958

Table VI—Values of the Contrast Rendition Factor (CRF)

60° Viewing Angle

Test Condition	C48.4.1 (S)	C48.4.1	D30.4.2	L37.4.2
D1	1.151	1.131	1.141	1.080
D2	1.041	.995	1.013	.979
LW1	1.136	1.108	1.080	1.085
LW2	.702	.690	.778	.726
LW3	1.140	1.057	1.081	1.075
F1	.939	.891	.908	.900
F2	.986	.942	.954	.936
F3	1.108	1.083	1.110	1.056
F4	1.046	1.016	1.042	.999
F5	1.076	1.044	1.055	1.016
LC1	1.004	.976	1.007	.971
LC2	1.065	1.024	1.039	1.001
C1	1.003	.969	.977	.954
C2	1.045	1.005	1.006	.980
C3	1.057	1.031	1.060	1.012
C4	.999	.965	.992	.960
C5	1.039	1.006	1.020	.990
WM1	1.103	1.076	1.062	1.027
WM2	.905	.884	.900	.890

of the alignment problem. In effect, each investigator must "calibrate out" his particular alignment method. The original model Reference Box was found to change contrast calibration when lamp blackening occurred at the ends of the fluorescent lamps, thus changing the light distribution within the cavity. The Reference Boxes were improved by the insertion of a diffuser to serve as a secondary source, and recalibrated against the large sphere. Of course, the author did not use the Reference Box, but he referred his flux contrast measurements directly to the laboratory double-hemisphere.

For our present purposes, the data may be consolidated by averaging the values of CRF obtained with different lighting materials, since these do not produce greatly different CRF values. The resulting data are presented in Tables II to VI, each for a different viewing angle. Data for each test target are presented for each of the 19 combined installations—test positions illustrated by Figs. 1 to 6. The use of the special photometric apertures with target C48.4.1 is indicated by the (S) after the target notation.

It will be of interest to evaluate the results of the two validation experiments in terms of these new CRF data. With respect to the D2/D1 comparison, CRF values from Tables III and IV give ratios as follows at 25 degrees: .852 for C48.4.1 (S); .851 for C48.4.1; .740 for D30.4.2; and .778 for L37.4.2. At 40 degrees, the values were: .785 for C48.4.1 (S); .783 for C48.4.1; .685 for D30.4.2; and .801 for L37.4.2. With respect to the LW3/LW2 comparison. CRF values from Table VI give 1.625 for C48.4.1 (S) and 1.534 for C48.4.1. These new data confirm our earlier conclusion that measurement of flux contrast with concentric-ring targets using the special photometric apertures alone possesses validity.

The values of CRF in Tables II-VI show clearly that the measurement of flux contrast with the concentric-ring target with the regular photometric aperture gives results equivalent to those obtained with the special apertures except at 50-degree and 60-degree viewing angles. Presumably, the effect of inclusion of additional arcs of essentially longitudinal orientation is simply too small to be measured at smaller angles. This is a fortunate outcome since investigators other than the author have made measurements with the regular aperture at viewing angles of 25 degrees and 40 degrees. However, yet untested conditions may involve invalidities at the smaller viewing angles, so that the use of the special apertures is certainly to be recommended. The differences in CRF for the regular and special apertures do not lend themselves to any obvious compensation equation.

The differences between the CRF values obtained with targets D30.4.2 and L37.4.2 and those obtained with target C48.4.1 using the special aperture are very large indeed, and seemingly very erratic. These differences far exceed measurement errors, which do not exceed ±.0005 in the original value of flux contrast or ±.003 in the computed value of CRF. The two nonstandard targets yielded 84 values of CRF less than the corresponding value for the standard target, and 106 values greater. There is clearly no possible way in which a compensation equation can be devised. The differences must be understandable in terms of the particular profiles of response of these targets to single rays arising from different points in space above the target, profiles such as the author reported some years ago.[3] Clearly, these targets must not be used for measurements of the veiling reflection effects of luminous environments of interest, since the results do not possess validity with respect to the difficulty of pencil-handwritten tasks.

Conclusions

It appears that a valid procedure has been found for assessment of the difficulty of pencil-handwritten visual tasks by physical measurement of the flux contrast of special pencil targets. This should mean that the Society can modify its current procedure for specification of interior illumination levels on the basis of visual performance criteria to include the effect of loss of task contrast due to veiling reflections in actual luminous environments. It may also be possible for use to be made now of the information contained in the author's paper[1] concerning the effects of informational requirements and viewing angle upon task difficulty.

Continued effort should be devoted to the development of procedures making possible the inclusion of the recognized effects of disability glare and transitional adaptation, so that the author's more complete system can be used in full as soon as possible.

References

1. Blackwell, H. R., "A More Complete Quantitative Method for Specification of Interior Illumination Levels on the Basis of Performance Data," ILLUMINATING ENGINEERING, Vol. 64, April 1969, p. 289.
2. Blackwell, H. R., "Development and Use of a Quantitative Method for Specification of Interior Illumination Levels on the Basis of Performance Data," ILLUMINATING ENGINEERING, Vol. 54, June 1959, p. 317.
3. Blackwell, H. R., "A General Quantitative Method for Evaluating the Visual Significance of Reflected Glare, Utilizing Visual Performance Data," ILLUMINATING ENGINEERING, Vol. 58, April 1963, p. 161.

DISCUSSION

G. P. WAKEFIELD:* This is the kind of scientific research that can probably do the greatest good for office and school attendants, as well as IES. It is an attempt to measure our seeing task problems in a reliable manner. Once this technique has been established and accepted by IES it can then provide a measure, and subsequently aid in the development of improved lighting systems, which is our ultimate goal.

If this basic material is a potential foundation to build on, it certainly should be studied and discussed thoroughly before anything else is done. Suppose then, we test the consistency of instrumentation and validity of measure with the things we already know about good lighting, and gauge this paper accordingly. With this as a premise, let us first examine the luminous ceiling LC-1 and LC-2 with C48.4.1 (S) and C48.4.1 targets. The CRF of each is in the accompanying table.

We are assuming that the white diffuser is a perfect diffuser of uniform luminance and free of lamp images. If this is so (as it should be to be a test luminous ceiling), why should a variance of .008 be indicated between LC-1 and LC-2? The reflected luminance is the same in both locations.

Is this variance a reading error by the operator and does it suggest a ± tolerance? Or is the variance of .008 an influence created by the proximity of the wall since LC-1 is two feet six inches from the wall and LC-2 is in the center of the room. Here could be a clue, for the locale variable would change the directional flux pattern of the task illumination. Logic would then justify a better CRF for LC-2 as the figures indicate.

It is difficult to justify the same CRF for C48.4.1 (S) and C48.4.1 targets as shown at three different viewing angles; namely, 10°, 25° and 40°. This macrometer consistency is certainly questionable with a light measuring instrument. Is this possible? If this is actually so, and if these measurements can be duplicated, we have the ideal tool for future lighting progress.

At viewing angles of 50° and 60°, inconsistencies come to light that totally upset our gradual configuration as suggested in viewing angles 10°, 25° and 40°.

To eliminate the location variance, let us examine the CRF at the center of the room—LC-2 with different viewing angles:

10°	25°	40°	50°	60°
.927	.916	.949	.999	1.065

The .916 at 25° must be in error or else .927 at 10° is out of step.

Table I

Viewing Angle	10°		25°		40°		50°		60°	
	X	O	X	O	X	O	X	O	X	O
LC-1	.919	.919	.902	.902	.928	.928	.976	.954	1.004	.976
LC-2	.927	.927	.916	.916	.949	.949	.999	.981	1.065	1.024
Variance	.008	.008	.014	.014	.021	.021	.023	.027	.061	.048

X Target C48.4.1 (S)
O Target C48.4.1

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Also, why does CRF increase with the viewing angle increasing? Wouldn't it be the same from the same ceiling luminance?

Possibly, here again, we are reading the influence of a directional flux pattern created by the changing viewing angle. It may well be a phenomenon we have never measured before.

If this is so, Dr. Blackwell has made a masterful contribution to the Science of Seeing!

Isaac Goodbar:* It is indeed very encouraging that, thanks to Dr. Blackwell's work, we finally seem to be coming up with a standard task that can be used by everybody, and which shows good correlation of results between physical and visual assessment.

This will eventually make possible the prediction of Contrast Rendition Factors by calculations, by means of a standard procedure always providing reliable results.

The importance of these calculations cannot be overemphasized. If we assume that all the tasks on the two left columns of Table III of the paper, for 25 degrees viewing angle, had always a luminance of 50 footlamberts (171 candelas per square meter) we find, using Dr. Blackwell's evaluation method based on relative contrast sensitivity, that the equivalent hemisphere luminance in the case WM2 is 95.4 footlamberts (327 candelas per square meter). Instead, in the case D2 it is only 9.4 footlamberts (32 candelas per square meter). This is a variation of more than 1 to 10, caused solely by changes in geometry.

This shows that it is not very useful to know how many footcandles we have on the task unless we also learn what the contrast rendition factor is. Dr. Blackwell mentions his use of a special double hemisphere. May I ask if the results obtained were compared with those that could be obtained in ordinary photometric spheres? This may be a good happy medium between using Dr. Blackwell's special double hemisphere which, as he says, is available only to him and using the Portable Illumination Reference Box (or shoebox as we used to call it).

Another question that puzzles me somewhat is why Dr. Blackwell found it necessary to correct the CRF values measured on different concentric ring tasks by means of a special formula (formula (1) of his paper) instead of just using ordinary averaging methods based on the theory of errors.

R. T. Dorsey:** This paper essentially answers the fundamental question of how to equate visual assessments of veiling reflections *versus* photometric assessments. I am satisfied that for a broad range of conditions, the concentric ring target will give realistic results.

I would like the data on Lighting Directionality Factor for the concentric ring target with the slotted mask in two orientations (for the work of our RQQ Subcommittee on Veiling Reflections).

While the paper is not directed at exploring the effects caused by different lighting systems, it is interesting to note four conclusions that can be drawn from the data reported.

1. The great effectiveness of side lighting reported by Griffith is confirmed.
2. The perimeter lighting system shows a high CRF (it remains to be determined how the VCP of the system behaves as a function of levels of illumination).
3. Downlights appear surprisingly good. While the data are far from conclusive, they indicate that the development of downlights with favorable candlepower distributions will be a major subject in the future.
4. Several studies so far have indicated the enormous effect of position and orientation of the observer. The data presented here indicate that perhaps our preliminary arbitrary location of the point of regard at the center of the back of the room may not be sufficient to give a realistic overall picture of the CRF of various systems.

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*Isaac Goodbar, P.E., Queens Village, N.Y.

**General Electric Co., Nela Park, Cleveland, Ohio.

W. B. DeLaney:* I would like to voice my compliments and thanks to Dr. Blackwell for his continued research and clarification of the "Veiling Reflections" concept.

It is indeed gratifying to hear him verifying and clarifying problems and terminology developed by me and other investigators in this field. I am particularly interested in his allusions to field measuring equipment, since I presented the Veiling Reflections Field Indicator (VRFI)[1] at the IES National Technical Conference in Montreal two years ago.

At that time, I maintained there was no pretense at the VRFI being equal to the more sophisticated and more expensive laboratory instrumentation. It was designed as a rough indicator for field use in the same way that a pocket light meter is a rough indicator of light levels that can be determined far more accurately with laboratory type instrumentation.

It was also stated at that time that changes in configuration would be feasible, and in fact encouraged, to bring about a better correlation with the laboratory findings.

My question is this: Having had a VRFI for examination and testing, what checks were made and what were the results? Secondly, what comments do you have on the future application of this technique as an extension of the laboratory measurements?

1. DeLaney, W. B., "A Simplified Field Indicator of Veiling Reflections," Illuminating Engineering, Vol. 63, March 1968, p. 111.

J. E. Kaufman:** Dr. Blackwell has again made a significant contribution by providing a needed tool for studying veiling reflections in visual tasks. With the new pencil target and modifications to the Visual Task Photometer, application research can quickly move ahead to give us the answers to the questions, "What are the most significant causes of veiling reflections" and "how can veiling reflections be reduced to a minimum or compensated for?" For example, the values of CRF in the tables already show the effects of layout of lighting equipment and worker-task position.

It should be pointed out, however, that this present target applies only to pencil handwriting. Although pencil handwriting is a significant task in classrooms and offices, there are other tasks to be considered. To study veiling reflections in relation to other tasks, other targets must be developed. Fortunately, Dr. Blackwell has shown the way.

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H. Richard Blackwell:* I appreciate the kind comments of the discussers and the care with which they have apparently read my manuscript. I agree emphatically with the general tone of the discussion, namely that we are coming very near the time when precise assessments can be made of veiling reflections effects so that the *Visual effectiveness* of lighting may be properly evaluated.

First, let us consider some aspects of the method used to measure CRF. Mr. Wakefield comments on the three-figure identity of values obtained with the regular and special photometric apertures for the 10°, 25° and 40° viewing angles, under the luminous ceiling, and asks if indeed such precision is possible. Let me assure him that these data were in fact obtained, and that indeed the measurement precision of CRF *can* be as good as ±0005. However, it is not always that good. Note that of the 57 pairs of values for the C48.4.1 (*S*) and C48.4.1 target measurements at the 10°, 25° and 40° viewing angle, 52 are identical to three figures whereas five vary by amounts up to .003. I do not believe the five differences are indeed significant so that these results suggest that measurement errors can reach .003. Remember that my measurement conditions were next to ideal. The power supply for the lamps was voltage-stabilized and the electronic equipment was in continuous use for weeks at a time.

Mr. Goodbar questions my formula (1) for correcting CRF values, suggesting that instead I should have used "ordinary averaging methods based on the theory of errors." I must have described my procedure badly. The corrections in question have nothing to do with measurement errors. Rather, the value of CRF obtained in a given lighting installation will vary with the specularity of the target used to measure CRF. As shown in Table I, the five class C48 targets varied somewhat in specularity. The correction equations were derived from measured values of CRF in different installations to compensate for the differences in target specularity so that different investigators using different targets on the same installation would obtain the same value of CRF.

Mr. Goodbar also suggests use of a regular photometric sphere instead of either my special double hemisphere or the little illumination reference box we have jokingly called the shoebox. Of course this may be done, if it is possible to place targets in the median plane of the photometric sphere, move them remotely from target to background position for measurements of flux contrast, and measure through each of a series of portholes in the sphere corresponding to the different viewing angles. But even if all this is possible, the flux contrast values obtained in the regular photometric sphere would have to be checked against those obtained in the special double hemisphere or one of the shoeboxes which have been checked against the double hemisphere since these are the criterion values for standard use. My own experience has shown that a regular photometric sphere does not necessarily produce a uniform hemisphere of illumination impinging upon a target mounted in a median plane within it, and may introduce stray light and hence contrast loss in the photometer due to excessive luminance of some point in the rear hemisphere behind the target.

Mr. Wakefield discusses the significance of the difference in CRF obtained in the two positions, *LC*1 and *LC*2 studied under the luminous ceiling installations. He observes that the values of CRF obtained at position *LC*2 are consistently greater than those obtained in position *LC*1. Mr. Wakefield expresses wonder as to whether the differences are significant or not and considers alternately what might be responsible for non-difference or difference. First, he states that the two values should be the same since "the reflected luminance is the same." Then he suggests that perhaps a difference might be related to differences in the "directional flux pattern of the task illumination." I can assure Mr. Wakefield that the difference is significant and that it *is* related to the pattern of flux reaching the task illumination. Veiling reflection effects have to be understood in terms of the summation of effects produced by each and every light ray reaching the task, as shown so fully in my Project No. 70[1] report. The differences in CRF between positions *LC*1 and *LC*2 are probably due principally to the difference in the amount of lighted ceiling extending beyond the task in the two cases. This explanation would predict that CRF would be greater in position *LC*2 than in position *LC*1, as is the case. This explanation would also predict that this difference would increase with viewing angle, which is also shown by the data. The smaller difference between *LC*2 and *LC*1 values at 60° with the target C48.4.1 is also predicted in these terms since the excess of transverse lines measured in this case would reduce the effect of the extent of lighted ceiling beyond the target.

In probing the data for verity, a procedure with which I heartily agree, Mr. Wakefield has also questioned the reversal in the trend of CRF values which occurs either at 10° or at 25°, depending upon how you look at the data. I am certain that this reversal is real and believe it can be explained in terms of two effects which work in opposite directions. One effect is related to the amount of light reflected from the rear wall which is occluded by the photometer "body-shadow." The light reflected from the wall creates high values of CRF. This light is least blocked at 10° and more blocked at all other viewing angles. The second and major effect is that the luminous ceiling of limited extent produces progressively less flux at *and beyond* the specular angle as viewing angle is increased, and progressively more flux this side of the specular angle. Light coming from this side of the specular angle is more beneficial than the light

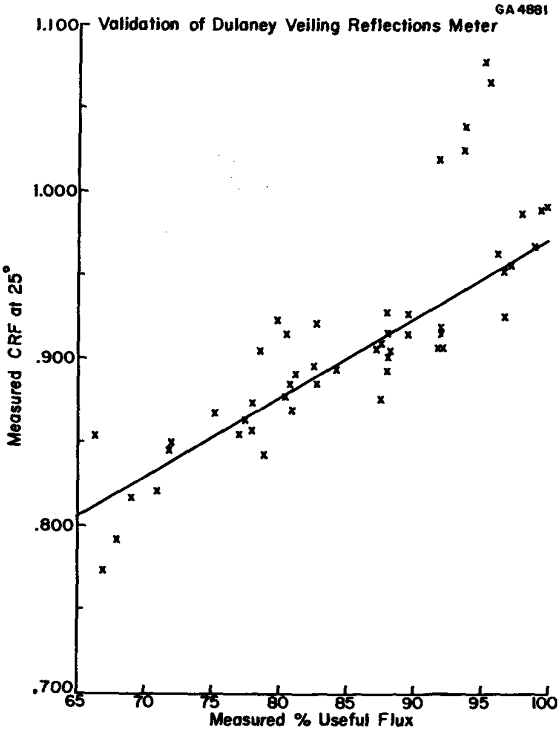

Figure A.

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*Author.

coming from beyond the specular angle so that the effect produces progressively greater CRF as viewing angle is increased. The reversal occurs because the two effects work in opposite directions. The plausibility of this explanation is supported by the fact that the reversal is less pronounced (.011 rather than .017) at position *LC*2 than at position *LC*1, where the effect of light reflected from the rear wall would be less. (I should point out that this analysis ignores the fact that none of our three luminous ceiling installations had the Lambertian distributions Mr. Wakefield assumes to exist, the departure being quite marked for both the multilayer polarizer and eggcrate louvre installations included in the average.)

With these technical matters out of the way, let us turn to what may be more interesting matters related to the differences in CRF found among different installations. As Mr. Goodbar points out, the differences in CRF reported in the paper correspond to highly significant differences in visual performance. One simple way to express this involves describing the level of visual performance made possible by a given lighting installation in terms of the luminance of our special double hemisphere producing the same level of visual performance. This is the meaning of the expression "equivalent hemisphere luminance" used by Mr. Goodbar. The standard visual performance data first adopted by the Society in 1959 may be used to compute Equivalent Sphere Luminance (ESL) in terms of the concept of Relative Contrast Sensitivity (RCS) first introduced by my wife and me.[2] The details of this calculation procedure will be described elsewhere. The results of such calculations are essentially what Mr. Goodbar reports for the wall-mounted valance lighting units and the downlights. (I obtain $ESL = 86.7$ footlamberts for *WM*2 and 9.34 for *D*2 with the actual luminance set at 50 footlamberts in each case). There is indeed almost a tenfold difference in the effectiveness of each unit of illumination produced by these two lighting geometries. Of course. overall evaluation of the two lighting systems requires that we take account of the luminous efficiency of each system in producing illumination, a well-known aspect of these lighting systems which runs in the opposite direction but not nearly by a factor of ten-to-one.

With regard to Mr. Dorsey's first comment, let me say that the values of the Lighting Directionality Factor for the concentric ring target all fell safely within the limits set by the validation experiment so that we may consider our measurements valid measures of target visibility.

Mr. Dorsey is quite correct in his conclusions that my values of CRF confirm the conclusion reported by Griffith as to the great effectiveness of sidelighting. Mr. Dorsey is also correct in his conclusions that my data show the great effectiveness of wall-mounted (perimeter) lighting, and also the importance of position and orientation of the test location. This last result indeed emphasizes the need for us to collect CRF data in a variety of locations under each installation of interest.

I do not agree with Mr. Dorsey's conclusion that "downlights appear surprisingly good" in light of the value of *ESL* for downlighting discussed above. As noted, in position *D*2 at 25°, downlights gave only 9.34 equivalent sphere footlamberts. If this is "surprisingly good," how bad did Mr. Dorsey expect downlights to be?

Mr. DeLaney asks what results I have obtained with the "Veiling Reflections Field Indicator" he so kindly lent me for study. As promised, I measured Per Cent Useful Flux with the VRFI in each installation and test position I used in my CRF survey. The data are presented in Fig. A, where the CRF I measured at the 25° viewing angle is plotted as a function of the value of Per Cent Useful Flux obtained with the VRFI. (The polarization filters in the VRFI were not used, since in my opinion they measure a quantity unrelated to the per cent vertical polarization from the multilayer polarizers involved in some of the installations.) The line is a visual fit to the data points. What can we conclude? First, it is certain that the VRFI measures something correlated with CRF. Second, it seems clear that the correlation is not as good as we might have hoped.

Examination of the individual data suggests that a VRFI of somewhat more sophisticated design might prove to be very valuable as a field measuring device. The present instrument compares total flux from the hemisphere above the task to total flux from everywhere but the "specular zone" for the 25° viewing angle. The device thus dichotomizes flux into two categories, flux coming from the specular zone and flux coming from anywhere else. What is needed is a device which places differential weight upon elements of flux coming from different portions of each of these two zones. To illustrate this need, note that the five data points in the figure which depart from the line to the greatest extent correspond to values of CRF greater than unity. Examination of the data in Table III shows that these five data points came from the luminous wall and the wall-mounted valance installations. The Project No. 70 report shows clearly that light from low angles far from the specular zone is especially beneficial to task contrast. If the VRFI had placed especially great positive weight on flux coming from these zones, the values of Per Cent Useful Flux would have correlated better with values of CRF.

Finally, Mr. Kaufman quite properly calls attention to the fact that all this work refers only to pencil handwritten tasks, and that we must now proceed to generalize our knowledge of the veiling reflections effect by considering other tasks. I heartily agree, and hope that my study can serve as a prototype for the further studies which are necessary if we are to develop a practical applications engineering evaluation of veiling reflection effects upon visual performance.

1. Blackwell, H. R., "A General Quantitative Method for Evaluating the Visual Significance of Reflected Glare Utilizing Visual Performance Data," ILLUMINATING ENGINEERING, Vol. 58, April Section I, 1963. p. 161.
2. Blackwell, H. R. and Blackwell, O. M., "The Effect of Illumination Quantity Upon the Performance of Different Visual Tasks," ILLUMINATING ENGINEERING, Vol. 63, April Section I, 1968, p. 143.