TRANSACTION IES

Computing Visual Comfort Ratings For a Specific Interior Lighting Installation

By Sylvester K. Guth

THE EVALUATION of discomfort glare is an important design criterion in illuminating engineering. Extensive data and analyses[1] have provided the basis for the development of a new comprehensive visual comfort rating system[2] which includes a method for preparing general visual comfort probability (VCP) tables for standard conditions of room characteristics, luminaire arrangements and mounting heights, and illumination. It is expected that such tables for specific or typical luminaires will satisfy most of the requirements of the lighting designer by enabling him to select units which will provide a visually acceptable environment. However, there will be an occasional need for evaluating discomfort glare for luminaires whose luminance distribution or arrangement in a room do not correspond to those for which VCP tables are available. Furthermore, designers of lighting equipment may be interested in obtaining a rating for an experimental unit which is to be used in a special installation. In such cases it may be desirable to make individual computations to insure that the desired degree of visual comfort will be achieved.

The procedure for determining specific ratings as described in this paper parallels the one used for preparing general VCP tables.[2] The primary differences are that the standard uniform arrangement of luminaires is replaced by a specific layout, and the level of illumination will be that actually obtained. These will require the determination of certain values needed for obtaining solid angles, position indices and luminances for which predetermined factors are provided when preparing the tables. Nevertheless, the entire procedure is simple and straightforward, and can be performed with a slide rule or desk calculator, standard tables of squares and cubes of numbers and trigonometric functions, and graph paper. Charts and tables have been prepared in order to facilitate the determination of certain values.

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General Basis

Basically, the computation of a VCP rating involves a point-by-point method for determining a discomfort index for each luminaire within the field of view and combining them in an appropriate manner to obtain the overall rating of the lighting system. It takes into consideration the significant factors which influence discomfort glare: room size and sur-

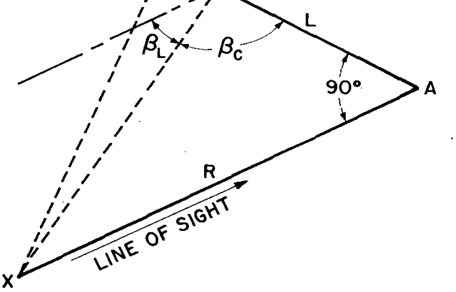


Figure 1. Illustrating how the position of a luminaire (S) with respect to the point of observation (X) can be specified in terms of readily determined distances and angles.

face reflectances; illumination level; luminaire type, size and light distribution; number, location and orientation of luminaires; and luminance of the entire field of view. The procedure outlined in this paper is essentially mathematical in that the various factors are computed from the physical and photometric characteristics of the room and luminaire. In this respect it differs from the predominantly graphical spherical perspective procedure reported by Bradley and Logan.[3] Both procedures require the determination of the same factors; if these are obtained with equal accuracy the resultant ratings will be identical. As a matter of interest, the present procedure makes use of certain predetermined spherical perspective data for computing the average field luminance.

The determination of VCP ratings requires the computation of the index of sensation M for each luminaire within the field of view, using the basic glare formula:

$$M = \frac{L_s Q}{P\, F^{0.44}} \qquad (1)$$

where

L_s = average luminance of luminaire,
Q = function of visual size of luminaire,
P = position index, and
F = average luminance of entire field of view.

The function Q is expressed in terms of the solid angle ω_s subtended by each luminaire:

$$Q = 20.4\omega_s + 1.52\omega_s^{0.2} - 0.075 \qquad (2)$$

Table I,* which provides values of Q for a limited range of ω_s, eliminates the need for using Equation (2).

The values of L_s, ω_s and P in Equations (1) and (2) are functions of the physical and photometric characteristics of the luminaire and of the geometry of the lighting installation. Fig. 1 illustrates how the location of the luminaire can be specified in terms of several readily determined distances and angles:

V = height of luminaire above eye level;
L = distance to the side, normal to the line of sight;
R = distance down the room, parallel to the line of sight;
D = direct distance from observation point to center of luminous area;
θ = photometric angle from nadir;
β_L = horizontal angle for lengthwise orientation of luminaire; and
β_C = horizontal angle for crosswise orientation of luminaire.

*Tables I, II and III as shown are abbreviated versions.

Table I—Function of Solid Angle

$$Q = 20.4\omega + 1.52\omega^{0.2} - 0.075$$

ω	0	1	2	3	4	5	6	7	8	9
					RANGE: 0.00010 to 0.00099					
0.0001	0.168	0.173	0.177	0.182	0.186	0.189	0.193	0.196	0.200	0.203
0.0002	0.206	0.209	0.212	0.214	0.217	0.219	0.222	0.224	0.227	0.229
0.0003	0.231	0.233	0.236	0.238	0.240	0.242	0.244	0.246	0.247	0.249
0.0004	0.251	0.253	0.255	0.256	0.258	0.260	0.261	0.263	0.264	0.266
0.0005	0.268	0.269	0.271	0.272	0.274	0.275	0.276	0.278	0.279	0.281
0.0006	0.282	0.283	0.285	0.286	0.287	0.289	0.290	0.291	0.292	0.294
0.0007	0.295	0.296	0.297	0.298	0.300	0.301	0.302	0.303	0.304	0.305
0.0008	0.306	0.308	0.309	0.310	0.311	0.312	0.313	0.314	0.315	0.316
0.0009	0.317	0.318	0.319	0.320	0.321	0.322	0.323	0.324	0.325	0.326
					RANGE: 0.0010 to 0.0099					
0.001	0.327	0.337	0.345	0.354	0.362	0.370	0.377	0.384	0.391	0.398
0.002	0.404	0.411	0.417	0.423	0.429	0.435	0.440	0.446	0.451	0.457
0.003	0.462	0.467	0.472	0.477	0.482	0.487	0.492	0.497	0.501	0.506
0.004	0.510	0.515	0.519	0.524	0.528	0.533	0.537	0.541	0.545	0.550
0.005	0.554	0.558	0.562	0.566	0.570	0.574	0.578	0.582	0.586	0.590
0.006	0.594	0.598	0.601	0.605	0.609	0.613	0.617	0.620	0.624	0.628
0.007	0.631	0.635	0.639	0.642	0.646	0.649	0.653	0.656	0.660	0.663
0.008	0.667	0.670	0.674	0.677	0.681	0.684	0.688	0.691	0.694	0.698
0.009	0.701	0.704	0.708	0.711	0.714	0.718	0.721	0.724	0.728	0.731
					RANGE: 0.0100 to 0.0199					
0.010	0.734	0.737	0.741	0.744	0.747	0.750	0.753	0.757	0.760	0.763
0.011	0.766	0.769	0.772	0.776	0.779	0.782	0.785	0.788	0.791	0.794
0.012	0.797	0.800	0.804	0.807	0.810	0.813	0.816	0.819	0.822	0.825
0.013	0.828	0.831	0.834	0.837	0.840	0.843	0.846	0.849	0.852	0.855
0.014	0.858	0.861	0.864	0.867	0.870	0.873	0.876	0.878	0.881	0.884
0.015	0.887	0.890	0.893	0.896	0.899	0.902	0.905	0.908	0.910	0.913
0.016	0.916	0.919	0.922	0.925	0.928	0.930	0.933	0.936	0.939	0.942
0.017	0.945	0.948	0.950	0.953	0.956	0.959	0.962	0.964	0.967	0.970
0.018	0.973	0.976	0.978	0.981	0.984	0.987	0.990	0.992	0.995	0.998
0.019	1.001	1.003	1.006	1.009	1.012	1.014	1.017	1.020	1.023	1.025

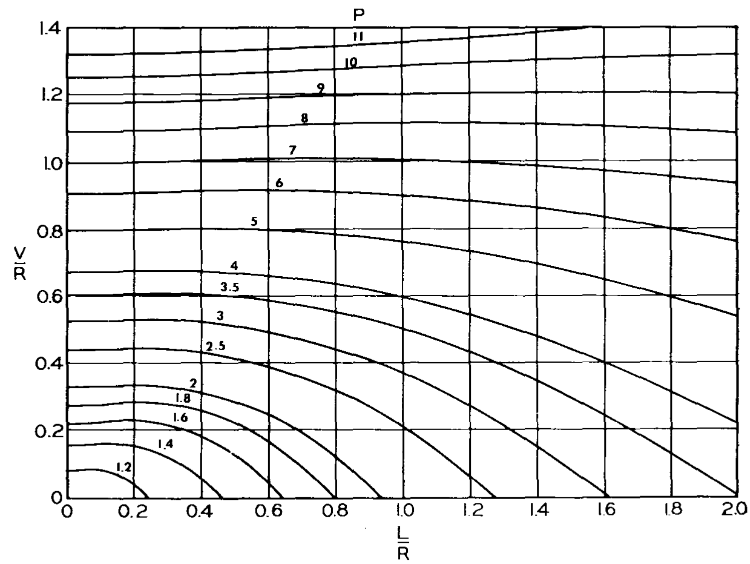


Figure 2. Chart for determining the position index P of luminaires in terms of V/R and L/R.

The observation point X is located four feet above the floor and four feet in front of the center of the rear wall.

The distance D and the angles θ, β_L and β_c can be expressed as functions of L, V and R:

$$D^2 = V^2 + L^2 + R^2 \qquad (3)$$

$$\cos\theta = \frac{V}{D} \qquad (4)$$

$$\tan\beta_L = \cot\beta_c = \frac{L}{R} \qquad (5)$$

In addition, the position index P is plotted in terms of V/R and L/R as shown in Fig. 2.

The solid angle ω_s subtended by the luminaire is equal to

$$\omega_s = \frac{A_p}{D^2} \qquad (6)$$

where A_p is the projected area as seen from the observation point. For luminaires of which the horizontal bottom area* is the potential source of glare, this can be written as

$$\omega_s = \frac{A\cos\theta}{D^2} \qquad (7)$$

Combining Equations (4) and (7),

$$\omega_s = A\frac{V}{D^3} \qquad (8)$$

The luminance L_s of the luminaire at each location in a room is a function of the angles θ and β_L or β_c, depending upon its orientation. The angle β is measured from the lengthwise axis of the luminaire (see Fig. 1).

The field luminance F used in Equation (1) is the average of the wall, ceiling, floor and luminaire luminances weighted in accordance with the solid angle subtended by each:

$$F = \frac{L_w\omega_w + L_{fc}\omega_f + L_{cc}(\omega_c - \Sigma\omega_s) + \Sigma L_s\omega_s}{5} \qquad (9)$$

in which

L_w = wall luminance,
L_{fc} = floor cavity luminance,
L_{cc} = ceiling cavity luminance,
ω_w = solid angle subtended by walls,
ω_f = solid angle subtended by floor,
ω_c = solid angle subtended by ceiling,
$\Sigma\omega_s$ = total solid angle subtended by luminaires, and
$(\omega_c - \Sigma\omega_s)$ = net ceiling solid angle, excluding luminaires.

The denominator in Equation (9) represents the total solid angle subtended by the field of view. All luminances are in footlamberts and solid angles in steradians. The solid angles of the surfaces of specific sizes of rooms have been predetermined and tabulated; those for intermediate sizes can be obtained by interpolation. A portion of the extensive table for the solid angles of room surfaces is shown in Table II.

The luminances of the room surfaces are computed from luminance coefficients and a form of the lumen method formula,[4]

$$\text{Room surface luminance} = \frac{\text{Total lamp lumens} \times \text{luminance coefficient}}{\text{floor area}} \qquad (10)$$

Luminance coefficients of room surfaces for any luminaire may be computed in accordance with an extension of the zonal-cavity method.[5] Values for several typical types of luminaires have been published.[4]

Having determined all the values required for using Equation (1), the individual indices of sensation

*Any luminaire can be converted into an "effective horizontal luminous area" which can be dealt with in the manner outlined. However, until a standard IES procedure has been adopted for determining projected areas of other types of luminaires, this method is temporarily limited to troffers, luminous ceilings and opaque-sided luminaires.

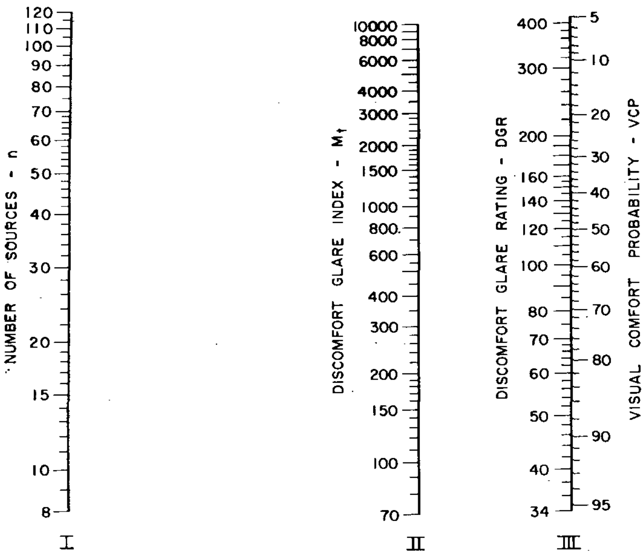


Figure 3. A nomogram for computing visual comfort probabilities (VCP). Procedure: Draw a line from the number n of luminaires on scale I through the discomfort glare index M_t on scale II and extend it to scale III; read off VCP on scale III.

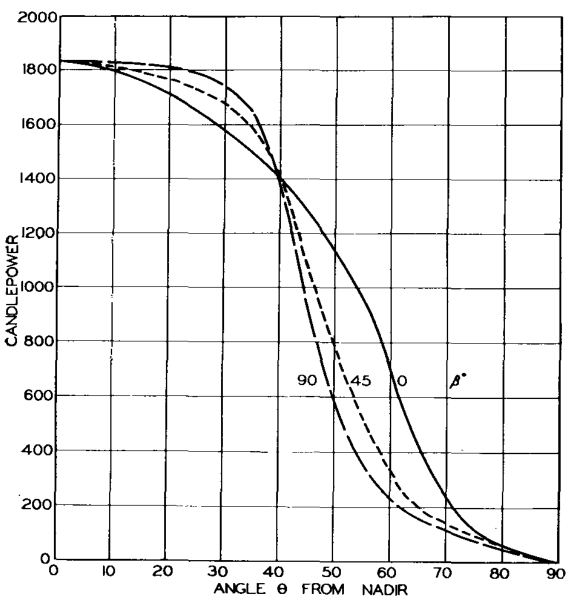


Figure 4. Candlepower distribution curves for the luminaire used in the illustrative calculations.

are computed and totaled to obtain M_t. The discomfort glare rating (DGR) is computed from

$$\text{DGR} = M^a{}_t \qquad (11)$$

and

$$a = n^{-0.0914} \qquad (12)$$

where n is the number of luminaires in the field of view. The DGR is converted into a visual comfort probability (VCP). However, the nomogram shown in Fig. 3 eliminates the need for using the exponential Equations (11) and (12) and permits computing the VCP directly.

Several work sheets have been devised to systematize and facilitate the computations. These will be discussed in detail as the step-by-step procedure is outlined.

Table II—Solid Angles of Room Surfaces for 40-Foot-Wide Rooms and a Ceiling Height of Ten Feet

ROOM WIDTH	ROOM LENGTH	FLOOR	WALLS	CEILING
40	15	2.022	1.958	1.020
	20	2.190	1.536	1.274
	30	2.318	1.240	1.442
	40	2.358	1.146	1.496
	60	2.398	1.056	1.546
	80	2.410	1.022	1.568
	100	2.422	1.002	1.576

Lighting Data

The luminaire selected for these illustrative calculations is a two-lamp recessed troffer with a clear configurated glass bottom having the photometric characteristics shown in Fig. 4. It is convenient to plot the candlepower distribution curves on rectangular coordinates in order to facilitate selecting values for specific angles. The luminaire was chosen because the candlepower distribution—and hence the average luminance at various viewing angles—was asymmetrical; lengthwise values at most of the direct glare zone angles are considerably higher than the crosswise values. It was assumed to be installed in a 40-foot-square room with a ten-foot ceiling in the pattern illustrated in Fig. 5. This particular arrangement of luminaires provides both lengthwise and crosswise orientations as seen from the observation point X. Certain required information about the luminaire and the room are given in parts 1 and 2 of Work Sheet A, which also is used for some of the calculations. The coefficient of utilization and initial footcandle level are given in part 3.

Since the lighting layout is symmetrical with respect to the line of sight, calculations need be made for only the left half of the room. For convenience,

Work Sheet A

For computing mean field luminance F and visual comfort probability (VCP)

1. Luminaire Description

Two-lamp, 40-watt, two- by four-foot recessed troffer with clear configurated glass bottom. 3200-lumen lamps; 7.5 square feet luminous area.

2. Room

a. Dimensions:	length	40 feet	width	40 feet	height	10 feet
b. Cavity ratios:	RCR	1.88	CCR	0	FCR	0.62
c. Reflectances:	walls	0.50	ceiling	0.80	floor cavity	0.20
d. Luminance coefficients:	walls	0.18	ceiling cavity	0.13	floor cavity	0.20
e. Solid angles:	walls ω_w	1.146	ceiling ω_c	1.496	floor ω_f	2.358
			luminaires $\Sigma\omega_s$	0.388		
			net ceiling ω_c $\Sigma\omega_s$	1.108		

3. Initial Illumination

a. Coefficient of utilization:	0.71
b. Footcandles (initial)	182

4. Field Luminance (initial)

a. Room surfaces:	walls	46.1	ceiling	38.3	floor	36.4
b. Weighted luminances:	walls $L_w\omega_w$			52.8		
	net ceiling $L_c(\omega_c-\Sigma\omega_s)$			42.5		
	luminaires $\Sigma L_s\omega_s$			131.5		
	floor $L_f\omega_f$			85.8		
			Total	312.6		
			Field luminance	62.5		
			$F^{0.44}$	6.17		

5. Visual Comfort Probability

a. Total index of sensation, M_t	383
b. Number of luminaires in field of view, n	54
c. Visual comfort probability, VCP	81

Work Sheet B

For computing factors used for determining luminances, position indices and solid angles

1 UNIT No.	2 V	3 L	4 R	5 V^2	6 L^2	7 R^2	8 D^2	9 D	10 D^3	11 V/R	12 L/R	13 V/D	14 θ	15 β_L	16 β_c	17 V/D^3
1	6	14	33	36	196	1089	1321	36.4	48229	0.182	0.424	0.165	81	—	67	0.000124
2		10	33		100	1089	1225	35.0	42875	0.182	0.303	0.171	80	—	73	0.000140
3		6	33		36	1089	1161	34.1	39652	0.182	0.182	0.176	80	—	80	0.000151
4		17	32		289	1024	1349	36.7	49431	0.187	0.531	0.163	81	28	—	0.000121
5		3	32		9	1024	1069	32.7	34966	0.187	0.094	0.183	79	5	—	0.000172
6		17	28		289	784	1109	33.3	36926	0.214	0.607	0.180	80	31	—	0.000162
7		3	28		9	784	829	28.8	23888	0.214	0.107	0.208	78	6	—	0.000251
8		10	27		100	729	865	29.4	25412	0.222	0.370	0.204	78	—	70	0.000236
9		10	25		100	625	761	27.6	21025	0.240	0.400	0.217	77	—	68	0.000285
10		17	24		289	576	901	30.0	27000	0.250	0.708	0.200	77	35	—	0.000222
11		3	24		9	576	621	24.9	15438	0.250	0.125	0.241	76	7	—	0.000387
12		17	20		289	400	725	26.9	19465	0.300	0.850	0.223	77	40	—	0.000308
13		3	20		9	400	445	21.1	9394	0.300	0.150	0.284	74	9	—	0.000639
14		14	19		196	361	593	24.4	14527	0.316	0.737	0.246	76	—	54	0.000413
15		10	19		100	361	497	22.3	11090	0.316	0.526	0.269	74	—	62	0.000541
16		6	19		36	361	433	20.8	8999	0.316	0.316	0.288	73	—	72	0.000567
17		14	13		196	169	401	20.0	8000	0.462	1.077	0.300	73	—	43	0.000753
18		10	13		100	169	305	17.5	5359	0.462	0.770	0.343	70	—	52	0.00112
19		6	13		36	169	241	15.5	3724	0.462	0.462	0.387	67	—	65	0.00161
20		17	12		289	144	469	21.7	10218	0.500	1.417	0.277	74	55	—	0.000587
21		3	12		9	144	189	13.7	2571	0.500	0.250	0.438	64	14	—	0.00233
22		17	8		289	64	389	19.7	7645	0.750	2.124	0.305	72	65	—	0.000785
23		3	8		9	64	109	10.4	1125	0.750	0.375	0.577	55	21	—	0.00533
24		10	7		100	49	185	13.6	2515	0.857	1.428	0.441	64	—	35	0.00239
25		10	5.25		100	28	164	12.8	2097	1.143	1.905	0.469	62	—	28	0.00286
26		17	5.25		289	28	353	18.8	6645	1.143	3.240	0.319	71	73	—	0.000903
27		3	5.25		9	28	73	8.5	614	1.143	0.572	0.706	45	30	—	0.00977

these have been numbered as shown in Fig. 5. Values of the index of sensation M are computed for only those luminaires or portions thereof which lie within the field of view. This limit on the ceiling is indicated by the dashed line which is 53 degrees above the horizontal line of sight. For practical purposes, the distance R_L forward from the observation point is determined from

$$R_L = 0.75\ V \qquad (13)$$

For a ten-foot mounting height, R_L is equal to 4.5 feet. Thus, only portions of luminaires 25, 26 and 27 are used; 28 to 32 are completely excluded.

Computational Procedure

Step 1—Determination of basic dimensional factors. a. On a copy of Work Sheet B enter the unit numbers in column 1.

b. Enter in the appropriate columns values of V, L and R which are obtained from the scale drawing of the lighting layout shown in Fig. 1. It should be noted that the distance R for units 25, 26 and 27 is measured to the center of the portion that is within the field of view.

c. Calculate the values for all the remaining columns in accordance with the respective headings. Equations (3), (4) and (5) are used for obtaining D, θ, β_L and β_c. The last two are determined for the appropriate luminaires as indicated.

When Work Sheet B is completed, it contains all the values needed for determining the luminaire luminances L_s, solid angles ω_s, and the position indices P.

Step 2 — Luminaire luminance L_s. a. Candlepower values at each five-degree angle θ from 40 to 90 degrees for the three photometric planes are obtained from Fig. 4 and listed in the appropriate columns of Work Sheet C.

For most luminaires, photometric data in three vertical planes—0 degree (parallel to lamps), 45 and 90 degrees (normal to lamps)—are sufficient. In some cases, when the distribution is markedly asymmetrical, it may be necessary to have such data for two or more additional planes.

b. Compute the average luminance L_s at each angle θ and each horizontal plane angle β from

$$L_s = \frac{\pi\ (\text{cp})}{A \cos \theta} \qquad (14)$$

For the luminaire used in this example, the luminous area A is equal to 7.5 square feet. The resultant values of L_s are given in the appropriate columns of Work Sheet C.

c. Plot the luminaire luminance L_s *vs* the angle β for each angle θ as shown on Work Sheet D.

d. Using the corresponding pairs of angles θ and β given in columns 14, 15 and 16 of Work Sheet B, obtain the average luminance for each luminaire from Work Sheet D (by interpolation, if necessary). Enter

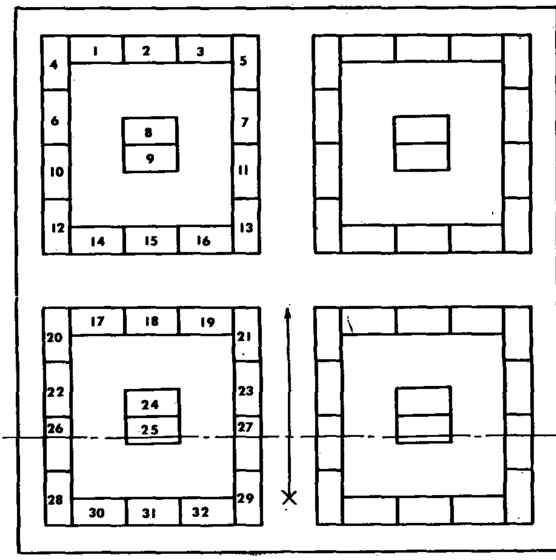


Figure 5. The lighting layout used for the illustrative calculations. The observation point is at X and the horizontal line of sight is indicated by the arrow. The dashed line represents the limit of the field of view on the ceiling.

these in column 2, Work Sheet E. For example, the angles θ and β_L for luminaire 21 are 64 and 14 degrees respectively; the resulting luminance of 326 footlamberts is indicated by the X on Work Sheet D.

Step 3—Solid angle ω_s *and function* Q. a. Enter the actual luminous area A of the luminaire in column 3, Work Sheet E. Since only portions of luminaires 25, 26 and 27 are within the field of view, the proportional areas for these units are as shown.

b. Compute the solid angle ω_s subtended by each luminaire using Equation (8) and the values of V/D^3 given in column 17, Work Sheet B, and enter in column 4, Work Sheet E.

Work Sheet C

For calculation of average luminance distribution of luminaire

ANGLE FROM NADIR	HORIZONTAL ANGLE β					
	0		45		90	
θ	cp	L_s	cp	L_s	cp	L_s
40	1400	766	1410	772	1370	750
45	1270	753	1080	640	940	557
50	1130	736	790	515	590	384
55	960	701	540	394	370	270
60	690	578	340	285	240	201
65	420	416	200	198	160	159
70	240	294	145	178	120	147
75	115	186	100	162	86	139
80	70	169	62	149	54	130
85	31	149	28	135	25	120
90	0	0	0	0	0	0

c. Using Table I, obtain the function Q for each solid angle ω_s and enter in column 5, Work Sheet E. Table I is used in the same way as logarithm tables, interpolating where necessary.

Step 4—Position index P. Using the values of L/R and V/R (columns 11 and 12 on Work Sheet B) and Fig. 2, determine the position index P for each luminaire and enter in column 6, Work Sheet E.

Step 5—Field luminance F. a. Using Table II, which includes only a portion of the extensive tables covering a wide range of room sizes and mounting heights, obtain the solid angles subtended by the room surfaces and enter in part 2e, Work Sheet A.

b. The sum of column 4, Work Sheet E, represents the total luminaire solid angle in the left half of the room. This value is doubled and entered in part 2e, Work Sheet A. The net ceiling solid angle is equal to that of the entire ceiling minus the luminaires.

c. The room surface (cavity) luminance coefficients are entered in part 2d, Work Sheet A.

While specific coefficients were not available for the luminaire used in these calculations, values have been estimated by a comparison of several sources of such information.[4, 6] Even though these values may not be precise, they will serve to illustrate how the computations are made.

d. Using Equation (10), the ceiling cavity, floor cavity and wall luminances are calculated and are given in part 4a, Work Sheet A. It should be noted that a floor cavity reflectance of 0.20 has been used; this is in accordance with the zonal-cavity method. In this example, the luminaires are recessed troffers and hence the ceiling cavity reflectance is equal to that of the ceiling, namely 0.80.

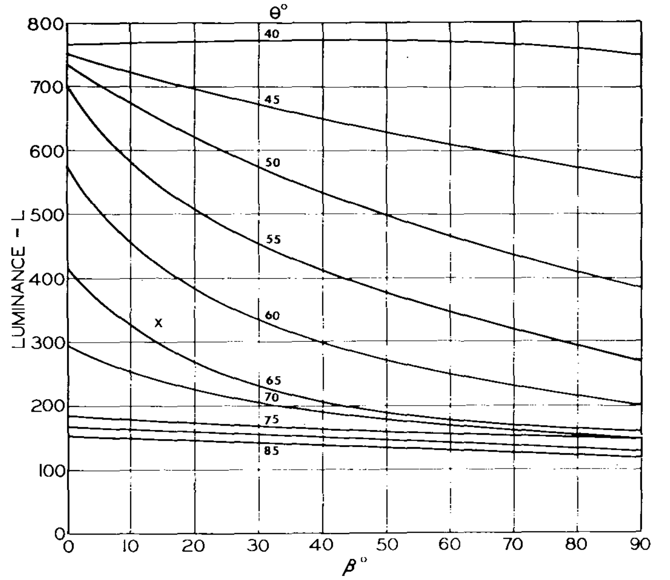
e. Compute the weighted luminances of the room surfaces by multiplying the solid angles by the respective luminances and enter them in part 4b, Work Sheet A.

f. Compute the weighted luminance of each luminaire by multiplying L_s by ω_s (columns 2 and 4, Work Sheet E) and enter them in column 7. Twice the sum of column 7 yields the total weighted luminance of all the luminaires in the room; this is entered as $\Sigma L_s\omega_s$ in part 4b, Work Sheet A.

g. Divide the sum of the weighted luminances by 5 to obtain the average field luminance F.

h. Using Table III, which is an abbreviated version of the complete table of the exponential function, determine $F^{0.44}$ by interpolation. Enter this in part 4b, Work Sheet A and in column 8, Work Sheet E.

Work Sheet D



The family of curves obtained from plotting luminance L_s vs β for each angle θ (data from Work Sheet C). The X represents the point for luminaire 21.

Step 6—Computation of M. All the factors needed for solving Equation (1) for each luminaire now are available on Work Sheet E. The individual indices of sensation are computed and entered in column 9. Twice the sum of column 9 is entered as M_t in part 5a, Work Sheet A. This is the index of sensation for the entire room.

Table III—Function of Field Luminance, $F^{0.44}$

F	$F^{0.44}$
50	5.59
51	5.64
52	5.69
53	5.74
54	5.78
55	5.83
56	5.88
57	5.92
58	5.97
59	6.01
60	6.06
61	6.10
62	6.15
63	6.19
64	6.23
65	6.28
66	6.32
67	6.36
68	6.40
69	6.44
70	6.48

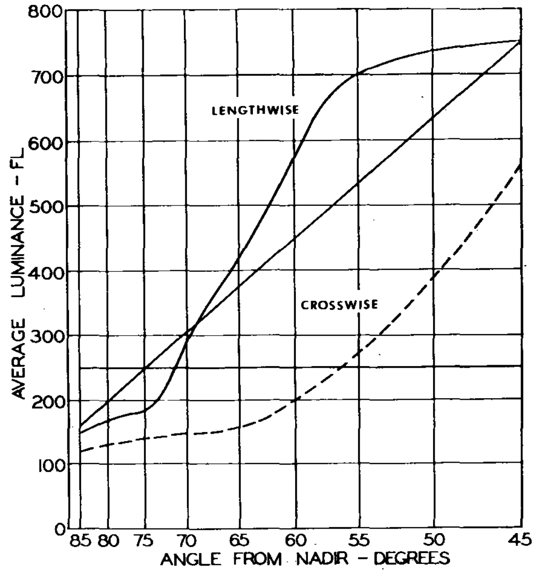


Figure 6. A scissors curve plot of the average luminances of the luminaire used in the illustrative calculations.

Step 7 — Computing visual comfort probability (VCP). a. Determine the total number of luminaires or portions thereof within the field of view. In this example it is twice the number listed on Work Sheet B—*i.e.*, a total of 54 luminaires. Enter this number in part 5b, Work Sheet A.

b. The nomogram shown in Fig. 5 permits computation of the visual comfort probability (VCP) directly and eliminates the need for using Equations (11) and (12). The procedure is: Draw a line from the number n of sources on scale I through the discomfort glare index M_t on scale II and extend it to scale III; read off the VCP on scale III. For this example, the resulting visual comfort probability is 81, which indicates a very high probability that this lighting system will not produce discomfort; it should be very satisfactory.

Comparison with Scissors Curve

The primary purpose of this paper is not to compare the ratings obtained with this new computational procedure with those obtained by other methods. In fact, the luminaire was selected without any consideration of how it might be rated. However, it is inevitable that such comparisons will be made, especially with the scissors curve. Therefore the average luminance data have been plotted as shown in Fig. 6. The solid and dashed curves represent the lengthwise and crosswise average luminance distributions, respectively. The straight diagonal line indicates the maximum permissible luminances at various angles between 45 and 85 degrees. It is evident that this luminaire complies with the scissors curve for crosswise orientation. However, when mounted lengthwise the luminances between 45 and 72 degrees will not pass this criterion. On the other hand, the detailed computations indicated a VCP of 81 which is considered to be very acceptable.

A study of the layout (Fig. 5) and the angles θ (column 14, Work Sheet B) indicates that most of the luminaires are viewed at angles greater than 70 degrees, at which the luminances are well below the limiting line. Furthermore, even when oriented lengthwise, many of the luminaires are viewed at angles for which crosswise luminances are the major contributing factor. A comparison of the average luminances given in Work Sheet C indicates that those in the 45-degree vertical plane also would lie below the limiting scissors curve line. From the data for individual luminaires (Work Sheet E) it is seen that luminaires 21, 23 and 27 are the brightest and have the highest values of M, and thereby contribute materially to the total index of sensation. However, when

Work Sheet E

For computation of indices of sensation M

1 UNIT No.	2 L_s	3 A	4 ω_s	5 Q	6 P	7 $L_s\omega_s$	8 $F^{0.44}$	9 M
1	138	7.5	0.000930	0.320	1.62	0.13	6.17	4.4
2	137		0.001050	0.332	1.52	0.14		4.8
3	134		0.001130	0.339	1.47	0.15		5.0
4	155		0.000908	0.318	1.76	0.14		4.5
5	170		0.001290	0.353	1.49	0.22		6.5
6	155		0.001220	0.347	1.92	0.19		4.5
7	170		0.001880	0.397	1.56	0.32		7.0
8	143		0.001770	0.389	1.67	0.25		5.4
9	148		0.002140	0.413	1.74	0.32		5.7
10	159		0.001660	0.381	2.17	0.26		4.5
11	178		0.002920	0.458	1.69	0.52		7.8
12	174		0.002310	0.424	2.54	0.40		4.7
13	195		0.004790	0.545	1.87	0.93		9.2
14	158		0.003100	0.457	2.41	0.49		5.0
15	160		0.004060	0.513	2.13	0.65		6.2
16	158		0.005000	0.554	1.95	0.79		7.3
17	172		0.005620	0.579	3.46	0.97		4.7
18	177		0.008400	0.681	3.05	1.49		6.4
19	168		0.012100	0.800	2.72	2.03		8.0
20	162		0.004400	0.528	4.10	0.71		3.4
21	326		0.017500	0.959	2.81	5.70		18.0
22	162		0.005890	0.590	6.10	0.95		2.5
23	500		0.040000	1.540	4.55	20.00		27.4
24	238		0.017900	0.970	6.00	4.26		6.2
25	300	5.63	0.016100	0.919	8.50	4.83		5.3
26	158	2.81	0.002540	0.437	8.90	0.40		1.3
27	673	2.81	0.027500	1.227	8.50	18.51		15.7
Total			0.194108			65.75		191.4
Room total			0.388216			131.50		382.8

these luminances are considered together with their respective position indices—*i.e.,* L_s/P—it is evident that they are not excessive. For example, L_s/P for luminaires 1 and 27 are 85 and 79, respectively; the luminances for the equivalent sources viewed directly are very nearly the same. Of course, the larger size of the latter accounts for its higher value of M.

This new method takes into account the actual luminance, visual size and position of each luminaire in a lighting installation. As seen in Fig. 6, the relatively low crosswise luminances—and also those in the 45-degree plane, which are not plotted—more than compensate for the somewhat higher luminances of a very few luminaires that may be viewed at near-lengthwise angles. It should be pointed out that the ratios of maximum to average luminances of this luminaire do comply with the scissors curve requirement: All the ratios are 3 to 1 or less, with the majority being less than 2 to 1.

Conclusion

The computational procedure outlined in this paper may seem rather involved. However, it is necessary to include all the significant factors when rating a luminaire in the environment in which it is to be used. The rating will not be truly representative if any of them are excluded. Fortunately, tables for typical luminaires will eliminate the need for making individual calculations except in a few cases. But even when specific calculations are made, the availability of charts and tables considerably facilitates such calculations.* They can be made by nontechnical people. As a matter of interest, the calculations presented in this paper required only a little over an hour. This should be considered time well spent to insure that a proposed system will be visually acceptable.

References

1. Guth, S. K.: "A Method for the Evaluation of Discomfort Glare," ILLUMINATING ENGINEERING, Vol. LVIII, p. 351 (May 1963).
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4. *IES Lighting Handbook,* Fourth Edition, Illuminating Engineering Society, New York (1966).
5. Jones, B. F. and Jones, J. R.: "Using the Zonal-Cavity System in Lighting Calculations," Part IV, ILLUMINATING ENGINEERING, Vol. LIX, p. 556 (October 1964).
6. "Brightness Distribution in Rooms," Committee Report, ILLUMINATING ENGINEERING, Vol. XLII, p. 180 (February 1947).

*The author has a limited number of copies of the charts and tables which can be made available to those interested in making VCP calculations.

Conference Paper Discussion

Discussion of this paper will be published in a subsequent issue of IE, together with the author's rebuttal.

Discussion of all Conference Papers is now due. Written discussion for publication with the papers should be submitted without delay (**one copy** to Ruby Redford, ILLUMINATING ENGINEERING, 345 East 47th St., New York, N. Y. 10017; **one copy** to J. N. Robertson, Chairman, Papers Committee, Dept. of Water & Power, P.O. Box 111, Los Angeles, Calif. 90054; **one copy** to the author(s); and **one copy** to the Discussion Coordinator). Discussion Coordinators are as follows:

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