Coefficients of Utilization for Luminaires with Concentrating Distributions

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The currently used Lumen Method of calculating interior illumination was developed by Harrison and Anderson[1] during the period between 1915 and 1920. It is an empirical method based upon the results of experiments with typical luminaires of that time in rooms of various sizes and surface reflectances. Most luminaires of that day had rather broad downward distributions with less than half of the direct component flux in the 0-40° zone (flux ratio less than 50 per cent). Therefore, when new materials, processes, and design techniques made it possible to obtain more concentrating downward distributions, the method of calculating the coefficients of utilization used in the Lumen Method was no longer applicable for all luminaires. By extrapolation the basic data were extended to a 65 per cent flux ratio,[2] but this was far short of the requirements since some modern luminaires have flux ratios of over 90 per cent.

The need for additional accurate data has long been recognized[3] and other studies have been initiated to provide information that is applicable for all distributions. One of these has resulted in the Interflection Method,[4] which has been used as the basis for computing the data for the reflected components presented in this paper. The Interflection Method itself, however, was not carried to a conclusion so that it could be used directly to calculate coefficients of utilization. Also, the Interflection Method assumes that the working plane is located one-fourth of the distance from the floor to the ceiling. In the ordinary use of the Method this assumption will lead to considerable error in high bay lighting installations. However, the error can be largely eliminated by calculating separately the flux that strikes the working plane directly, as is done in this paper.

The real need is for a method of calculating coefficients of utilization that more fully recognizes differences in distribution of light flux from present day equipment. It would then be possible to provide more accurate coefficients of utilization for use in the familiar Lumen Method formulas.

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Basic Method

To satisfy this need the authors are proposing a method of calculating coefficients of utilization that considers the ultimate disposition of the flux from every 10° zone instead of using an arbitrary wide zone of 40° as a criterion. The flux in each 10° zone (0°-10°, 10°-20°, etc.) that strikes the work plane directly is determined, and to that is added the flux that reaches the work plane by interreflection. The ratio of the total flux reaching the work plane to the lamp lumens is the coefficient of utilization.

Development of the Method

This method was developed by assuming specific symmetrical luminaire locations in a square room representing each room index. Then, for each luminaire location in a given room size, the percentage of the lumens in each of the 10° zones that strike the working plane directly was calculated (see Fig. 1 for approximate method of making calculation). By averaging the percentages for a given zone for all the luminaires, an average percentage

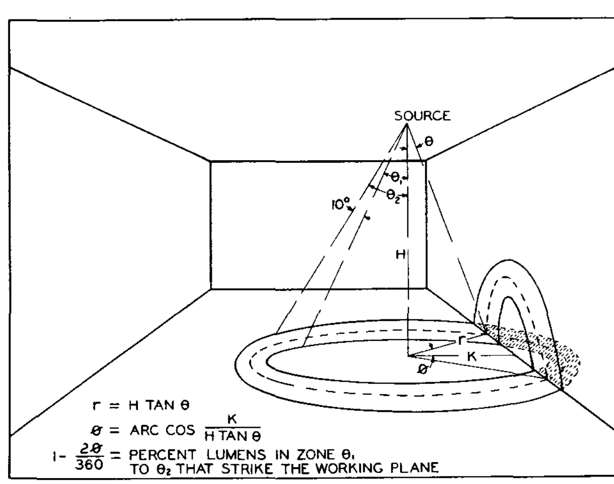

Figure 1. The flux in any zone that strikes the work plane directly is equal to the total lumens in the zone minus the lumens that strike the wall.

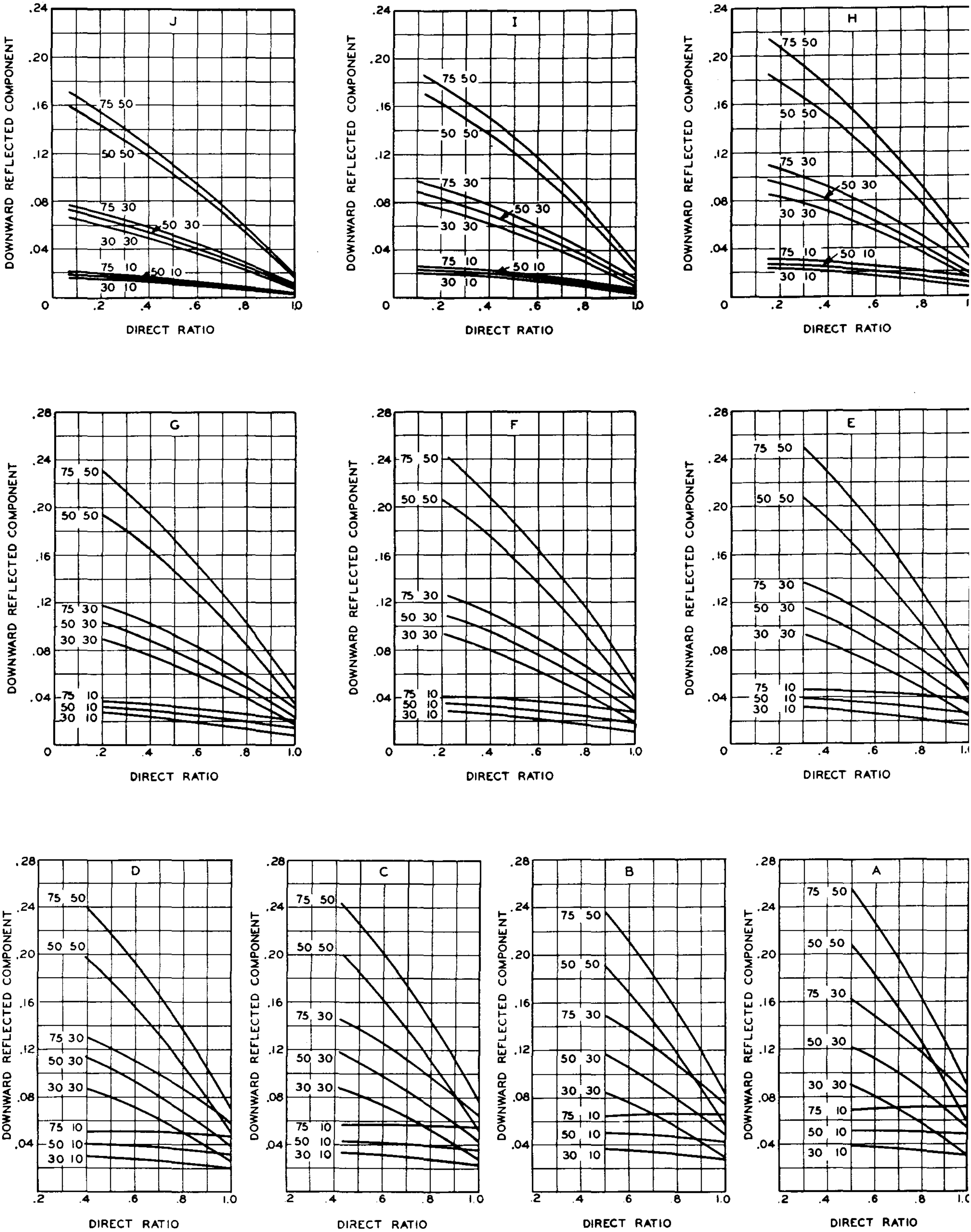

Figure 2. Downward reflected component plotted against direct ratio for each room index. The figures accompanying each curve denote the ceiling and wall reflectances.

for that zone was obtained. Such average figures, called zonal multipliers, have been prepared for each 10° zone for rooms of room index A through J, and are presented in Table I. They are in no

TABLE I.

Zone (Deg.)	J	I	H	G	F	E	D	C	B	A
				Zonal Multipliers 0° to 90°						
0-10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10-20	.72	.79	.81	.85	.88	.91	.92	.94	.95	.96
20-30	.57	.67	.73	.79	.83	.87	.89	.91	.93	.94
30-40	.34	.50	.56	.64	.69	.77	.82	.85	.88	.91
40-50	.16	.36	.49	.57	.64	.72	.78	.81	.86	.88
50-60	.03	.12	.28	.39	.48	.60	.67	.72	.78	.83
60-70	—	—	.05	.21	.31	.43	.52	.59	.69	.77
70-80	—	—	—	—	—	.11	.22	.32	.47	.60
80-90	—	—	—	—	—	—	—	—	.04	.14

way influenced by the distribution of the luminaire, but they are effective for all luminaires. To apply the method to a specific luminaire the luminaire lumens in each zone are multiplied by the appropriate zonal multiplier. The sum of these products for a specific room index, when divided by the total downward (0°-90°) lumens of the luminaire, is the percentage of downward lumens that strike the work plane directly. This quantity will be referred to as the *Direct Ratio.*

The percentage of downward luminaire lumens that are reflected from the room surfaces to the working plane (*Downward Reflected Component*) is directly related to the Direct Ratio in a given room. This relationship is illustrated in Fig. 2 where the Downward Reflected Component (obtained from interflection data) is plotted against the Direct Ratio for a wide range of distributions. A series of curves is given for each room index and combination of room surface reflectances. From these curves it is a simple matter to obtain the Downward Reflected Component for any Direct Ratio.

An indication of the accuracy of the method of calculation and calculating procedure (see Fig. 3) can be illustrated by assuming an area to be lighted is 48 feet square and 42½ feet high, and has 30 per cent ceiling and 10 per cent wall reflectances. Calculations were made for two widely different luminaire distributions by the conventional method, the zonal method proposed herein, and the point-by-point method. The point-by-point footcandle values cannot be converted to a coefficient of utilization or utilization factor because there is no indication of the magnitude of the flux reflected to the working plane. It can, however, be expressed as the direct ratio by merely multiplying by the area and dividing by the total luminaire lumens. In this manner a direct comparison can be made between the point-by-point method and the zonal

1000-WATT CONCENTRATING LUMINAIRE

ZONE	ZONAL LUMENS	ZONAL MULTIPLIER	PRODUCT
0°-10°	3005	1.00	3005
10°-20°	5580	.72	4020
20°-30°	3125	.57	1782
30°-40°	2310	.34	785
40°-50°	1180	.16	189
50°-60°	129	.03	4
60°-70°	40	—	—
70°-80°	—	—	—
80°-90°	—	—	—
TOTAL	15369		9785

$$\text{DIRECT RATIO} = \frac{9785}{15369} = .635$$

$$\text{C.U.} = \frac{15369}{21000^*}(.635+.01) = .47$$

* LAMP LUMENS - 21000

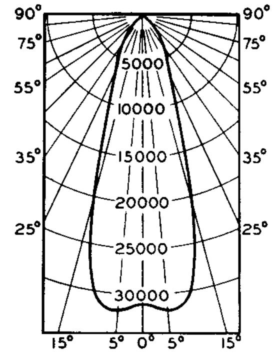

Figure 3. Calculation of the coefficient of utilization for a "J" room. The downward reflected component is .01 for 30% ceiling and 10% wall reflectances.

system proposed by the authors (see Table II). The point-by-point calculations were made for the points stipulated as measuring points in the I.E.S. Procedure for Determining Horizontal Footcandle Levels.[5]

An analysis of Table II indicates that in a high narrow room the Harrison-Anderson Method gives too low a value for direct concentrating luminaires and too high a value for direct luminaires having a rather broad distribution such as that of a typical industrial fluorescent unit. The zonal method data is actually based on nine luminaires in a "J" room so it checks closely with the point-by-point method.

Extending the Method to All Distributions

Although this method of calculating coefficients was developed primarily for direct luminaires, it soon became apparent that it was also applicable to distributions in which part or all of the light was directed upward.

For other than totally direct luminaires, the Direct Ratio and Downward Reflected Component are obtained as outlined in the preceding paragraphs, but their sum is multiplied by the ratio of the downward luminaire lumens to the total lamp lumens. This product is the *Downward Coefficient.*

To obtain a comparable *Upward Coefficient*, the percentage of upward (90°-180°) luminaire lumens that strike the ceiling (*Ceiling Ratio*) is obtained

TABLE II.

Method of Calculation	Concentrating Distribution Utilization Factor	Concentrating Distribution Direct Ratio	Wide Distribution Utilization Factor	Wide Distribution Direct Ratio
Harrison-Anderson	.51	—	.35	—
Zonal Method	.645	.635	.270	.255
Point-by-Point*	—	.645	—	.258
Point-by-Point**	—	.676	—	.270

*Assumes 9 sources are installed.
**Assumes 4 sources are installed.

by the use of zonal multipliers for each 10° zone by the same technique as was used to obtain the Direct Ratio (see Table III). This *Ceiling Ratio* is

TABLE III.

Zone (Deg.)	Room Index J	I	H	G	F	E	D	C	B	A
	Zonal Multipliers 90° to 180°									
90-100	—	—	—	—	—	.04	.14	.22	.33	.40
100-110	—	—	.10	.22	.32	.47	.60	.67	.76	.81
110-120	.20	.34	.43	.52	.59	.69	.77	.82	.89	.93
120-130	.37	.50	.60	.67	.72	.78	.83	.88	.91	.94
130-140	.56	.66	.72	.78	.81	.86	.88	.91	.94	.95
140-150	.63	.71	.77	.82	.85	.88	.91	.94	.96	.97
150-180	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

used only as the means of obtaining the *Upward Utilization Factor* from a series of curves in which Upward Utilization Factor is plotted against Ceiling Ratio (Fig. 4). Since the Upward Utilization Factor represents the percentage of upward *luminaire* lumens that is reflected to the working plane, it must be multiplied by the ratio of the upward luminaire lumens to the total lamp lumens to obtain the Upward Coefficient. (This would be the coefficient of utilization for a totally indirect luminaire.)

The sum of the Downward Coefficient and the Upward Coefficient is the Coefficient of Utilization for a luminaire that distributes the light both downward and upward.

Step-by-Step Procedure

The steps to be followed in computing the coefficient of utilization are:

(For totally direct luminaires, step 1 only; for totally indirect luminaires, step 2 only; for all others, steps 1, 2, and 3.)

1. Determine the Downward Coefficient as follows:
   a. Multiply the zonal lumens in each 10° zone from 0° to 90° by the respective zonal multiplier obtained from Table I.
   b. Add the results of step a.
   c. Divide the sum obtained in b. by the total luminaire lumens emitted downward. This is the Direct Ratio.
   d. From the appropriate curve of Fig. 2, determine the Downward Reflected Component for the Direct Ratio obtained in step c.
   e. Add the Direct Ratio and the Downward Reflected Component. This is the Downward Utilization Factor.
   f. Multiply the Downward Utilization Factor by the per cent of lamp lumens emitted downward by the luminaire. This is the Downward Coefficient. (If the luminaire is totally direct this is the coefficient of utilization.)
2. Determine the Upward Coefficient as follows:
   a. Multiply the zonal lumens in each 10° zone from 90° to 180° by the respective zonal multiplier obtained from Table III.
   b. Add the results of step a.
   c. Divide the sum obtained in step b. by the total luminaire lumens emitted upward. This is the Ceiling Ratio.
   d. From the appropriate curve of Fig. 4, determine the Upward Utilization Factor for the Ceiling Ratio obtained in step c.
   e. Multiply the Upward Utilization Factor by the per cent of lamp lumens emitted upward by the luminaire. This is the Upward Coefficient. (If the luminaire is totally indirect this is the coefficient of utilization.)
3. Add the Downward Coefficient (step 1. f.) and the Upward Coefficient (step 2. e.). This is the coefficient of utilization for a luminaire that is neither totally direct nor totally indirect.

Conclusions

While the method described herein does require a change in the method of calculating coefficients of utilization, the user of the Lumen Method *does not* have to change his method of making lighting calculations. The time required to calculate a complete set of coefficients of utilization by this zonal method is only slightly longer than by the conventional method. Certainly the greater accuracy obtained more than justifies the small amount of additional work which must be performed only once for each luminaire. Too frequently it is necessary for the lighting engineer, after carefully following all of the rules, to make excuses for inaccurate predictions. More accurate coefficients would explain the discrepancy on many occasions. Sometimes factors as improper voltage, non-typical lamps, inaccurate meter reading, and misjudged room surface reflectances result in errors, but often the coefficient of utilization is faulty.

While extensive, carefully controlled illumination tests have not yet been made to verify the coefficients obtained by this new method, the direct ratios have been spot-checked by the point-by-point method and have been found to be accurate. The authors feel this method can be used with confidence for calculating the coefficients for luminaires that direct the major part of their flux downward. To obtain comparable accuracy for the flux directed upward, the theoretical upward utilization factor curves shown in Fig. 4 should probably be lowered slightly (approximately 5 per cent) to compensate for light that is absorbed by the luminaire after being reflected off the ceiling (see last paragraph of the Appendix), even though some (perhaps complete) compensation is made in the determination of the Ceiling Ratio (see Appendix). This source of error is inherent in any system of calculating coefficients and the magnitude of the error depends on the characteristics of the luminaire and the number installed in a given area.

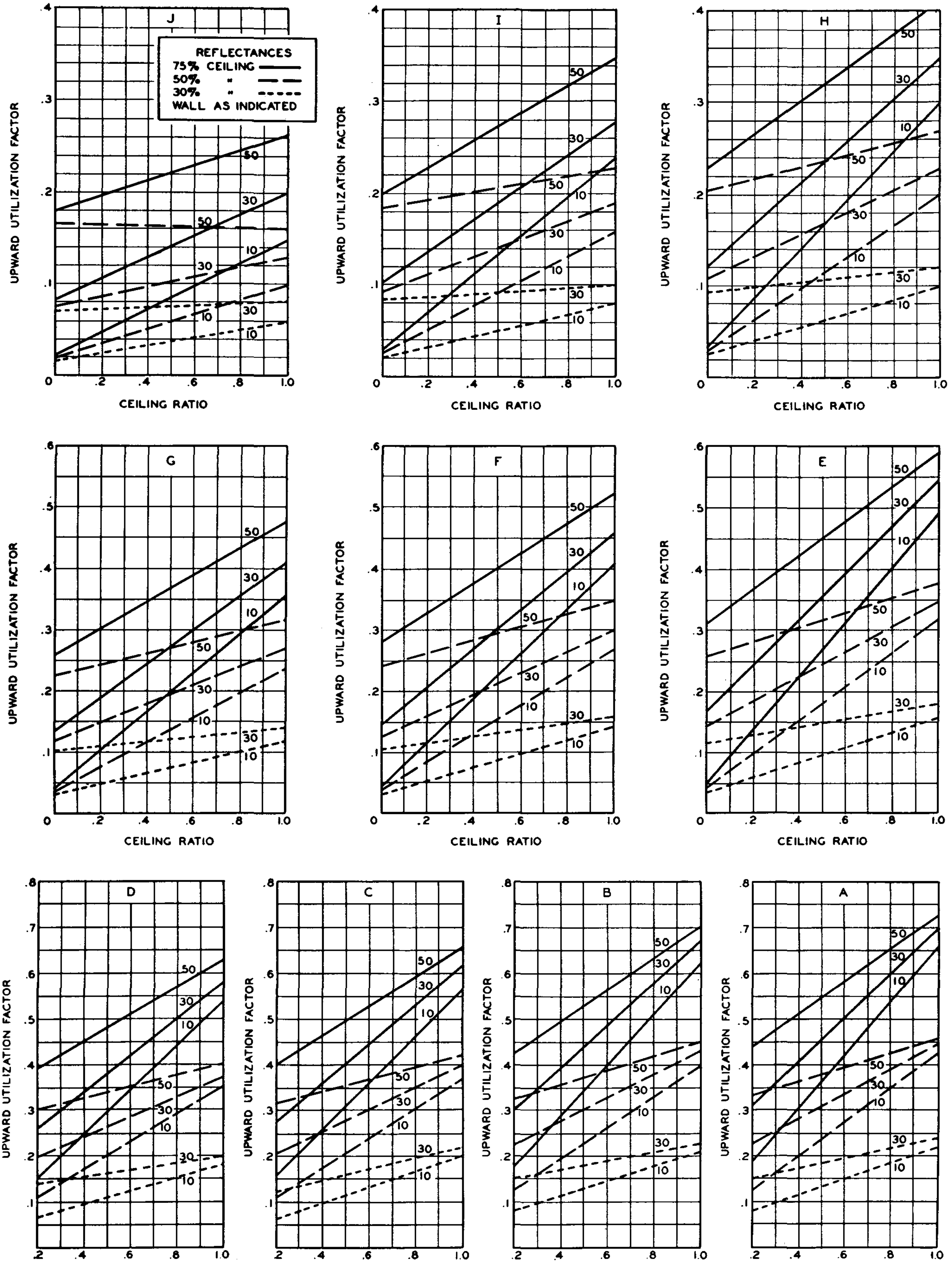

Figure 4. Upward utilization factor plotted against ceiling ratio for each room index.

Appendix

Terms and Symbols:

The following summary of terms and symbols is submitted for convenient reference.

F_D *Downward Flux,* luminaire lumens emitted downward (0° to 90°).

F_U *Upward Flux,* luminaire lumens emitted upward (90° to 180°).

F_L *Lamp Flux,* total lumens generated by the lamp or lamps in a single luminaire.

ZM *Zonal Multiplier,* for each 10° zone.

DR *Direct Ratio,* the per cent (expressed as a decimal) of the luminaire lumens emitted downward (0°-90°) that strike the working plane directly (without being reflected off room surfaces).

DRC *Downward Reflected Component,* the per cent of luminaire lumens emitted downward (0°-90°) that are reflected from the room surfaces to the working plane.

DUF *Downward Utilization Factor,* the sum of *DR* and *DRC.*

DC *Downward Coefficient,* the Downward Utilization Factor multiplied by the ratio of the Downward Flux to the Lamp Flux.

CR *Ceiling Ratio,* the per cent of luminaire lumens emitted upward that strike the ceiling (without reflections).

UUF *Upward Utilization Factor,* the per cent of luminaire lumens emitted upward that are reflected to the working plane.

UC *Upward Coefficient,* the Upward Utilization Factor multiplied by the ratio of Upward Flux to the Lamp Flux.

C.U. *Coefficient of Utilization* = *DC* for totally direct luminaires.
= *UC* for totally indirect luminaires.
= *DC* + *UC* for all others.

Derivation of the Method and Limitations:

The accuracy of this method of calculating coefficients of utilization obviously depends on the accuracy of the zonal multipliers and the reflected component curves of Fig. 2 and Fig. 4.

The zonal multipliers are calculated for specific symmetrical luminaire locations in a square room for each room index. For small high rooms the individual multipliers may be altered appreciably by basing calculations on different luminaire spacing-to-mounting-height ratios. The Direct Ratio is also somewhat dependent on the spacing-to-mounting-height ratio, being slightly lower when the luminaires are mounted closer together. For example, in the installations illustrated in Fig. 2 the actual coefficient of utilization, as calculated by the Point-by-Point Method, is about 5 per cent higher when four luminaires are used than when nine are employed. A spacing-to-mounting-height (above the work plane) ratio of .4 was used in calculating the zonal multipliers listed in Table I, so the Direct Ratios and the coefficients of utilization are always conservative, even for concentrating luminaires.

The zonal multiplier for a single zone for one luminaire may be determined by the method illustrated in Fig. 1. Or for greater accuracy, the term $2\phi/360$ may be ascertained by calculating the lumens that strike the wall and dividing by the zonal lumens as follows:

$$2\phi/360 = \frac{\text{Average Footcandles} \times \text{Area (shaded in Fig. 1)}}{\text{Zonal Lumens}}$$

$$= \frac{(I \operatorname{Cos}^3\theta/H^2) \times \text{length of arc} \times dr}{I \times \text{zonal constant for } \theta_1 \text{ to } \theta_2}$$

$$\text{length of arc} = 2\phi r$$
$$= 2\phi H \tan\theta$$
$$r = H \tan\theta$$
$$dr = H \sec^2\theta d\theta$$

$$2\phi/360 = \int \frac{(I \operatorname{Cos}^3\theta)/H^2 \times 2\phi\, H \tan\theta\ H \sec^2\theta d\theta}{I \times \text{Zonal Constant}}$$

$$= 1/\text{Zonal Const}) \int (\sin\theta \times 2\phi\, d\theta)$$

$$\phi = \text{arc cos } (K \operatorname{Cot}\theta/H)$$
$$\text{let } P = K/H$$
$$y = P \operatorname{Cot}\theta \qquad \text{then}$$

$$2\phi/360 = (1/\text{Zonal Const}) \int_{\theta_1}^{\theta_2} 2 \sin\theta \text{ arc Cos } (P \operatorname{Cot}\theta)\, d\theta$$

$$2\phi/360 = (1/\text{Zonal Const}) \left[2 \operatorname{Cos}\theta \times \text{arc Cos } y + \text{arc sin} \left(\frac{2y^2 + P^2 - 1}{1 + P^2} \right) \right]_{\theta_1}^{\theta_2}$$

The above quantity checks closely with the value for $2\phi/360$ determined by Fig. 1. The solution of this formula for all the zones for each luminaire location and for all room indices is obviously a long and tedious task. Hence, this formula was used only for the relatively high narrow rooms and a few of the others. The zonal multipliers for most of the larger rooms were calculated by the method illustrated in Fig. 1. The authors feel that the resultant errors are negligible because of the large number of sources involved.

If the zonal multipliers in Table I are plotted against room index (the ratio of the room width to two times the mounting height above the work plane), curves will be obtained (Fig. 5) from which it is convenient to select zonal multipliers for calculating the flux that the luminaires direct to the floor. These zonal multipliers for the floor were determined on the basis of the room index formula, but the mounting height above the work plane was changed to mounting height above the floor. These zonal multipliers (for the floor) were then used to calculate the flux directed to the floor (designated F_3 in the Interflection Method data) for certain luminaires. Obviously the remainder of the 0° to 90° flux (F_1) was directed to the walls. Knowing F_1 and F_3 for specific luminaire distributions, it was then possible by using the Interflection Method to calculate the

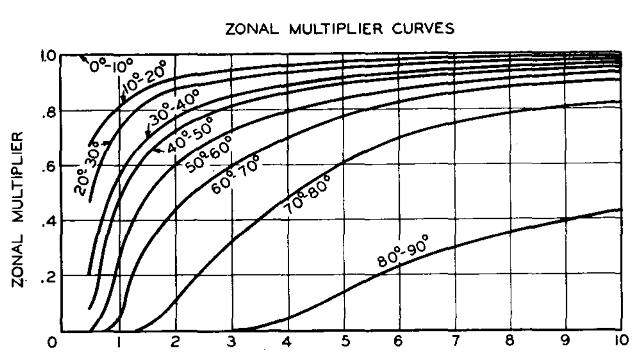

Figure 5. Zonal multipliers plotted against room index.

curves of Fig. 2 where the sums of the wall and floor components are plotted against the Direct Ratio for a wide range of distributions. An assumed floor reflectance of 14 per cent was used in order to correspond with that of the Harrison-Anderson Method.

Fig. 5 was also used to determine the zonal multipliers for calculating the Ceiling Ratio. It is obvious that this is possible if the ceiling is thought of as the work plane and the length of the suspension hanger is thought of as the mounting height of a direct luminaire above the working plane. The "room index" of this space between the luminaire and the ceiling was calculated from the room index formula for direct luminaires. For this calculation the length of the suspension hanger used as "mounting height above the work plane" was such that the same room index (for the entire room) would be obtained from the room index formula for indirect luminaires as would be obtained from the room index formula for direct luminaires. To obtain the same room index from both formulas, the length of the suspension hanger must always be one-half the distance the luminaire is mounted above the work plane. Hence, the "room index" of this upper area is always twice that of the room below as calculated for a direct luminaire. Therefore, the ceiling zonal multipliers for an "I" Room (room index = 1.0), for example, are found in Fig. 5 at room index equal 2.0. The 90° to 100° multiplier is on the curve marked 80°-90°, the multiplier for the 100° to 110° zone is on the curve marked 70°-80°, etc. In actual practice the length of the suspension hanger is usually less than one-half the mounting height above the work plane so the actual ceiling ratios are somewhat higher than those obtained from Table III. This tends to make the upward coefficients slightly conservative. Also, Table III is really based on a spacing-to-mounting-height ratio of 0.8. This too tends to produce results that are slightly conservative. On the other hand, the multipliers for the 150° to 180° zone have been raised to 1.0, making the zonal multipliers somewhat less conservative but more realistic. They are more realistic because almost invariably indirect luminaires are hung near enough to the ceiling for all the lumens in this zone to strike the ceiling directly.

The ceiling zonal multipliers (Table III) and the Interflection Method were used to prepare Fig. 4 just as Table I and the Interflection Method were used to prepare Fig. 2.

The reflected component curves (Fig. 2 and Fig. 4) reflect the accuracy of the interflection data on which they are based and they are subject to the same limitations. Data for the curves representing 30 per cent ceiling reflectances were extrapolated, and the data for the other curves were interpolated. The interflection data are based on the assumption of perfectly diffusing room surfaces that are illuminated uniformly. Actually the maximum wall brightness created by a luminaire is near the ceiling for wide distributions, and approaches the floor as the distribution becomes more concentrating. Also, the room surfaces are never perfectly diffusing, but it is felt that these variables introduce only small errors into the reflected component curves.

The Upward Coefficients are based on the assumption that the luminaires are very small and do not absorb any light that is reflected off the ceiling. Actually all luminaires absorb some light and some fluorescent types that are rather large may absorb a sufficient amount to lower the Upward Coefficient enough to justify changes in Fig. 4. This error is of the same general nature as that caused by the existence of furniture, machinery, or columns in an area. The authors feel that until this source of error is investigated. the Upward Utilization Factor curves of Fig. 4 should probably be lowered about 5 per cent.

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DISCUSSION

NEAL JACOBUS*: This paper suggests a new method of determining coefficients of utilization which will provide more accurate values than the presently used method. The need for more accurate coefficients is generally recognized specially where light interior surfaces and luminaires with strong indirect components are used. The authors are to be congratulated for undertaking this work.

Of particular importance is that the method can be applied to data from candlepower distribution curves commonly available for luminaires. The basic interflection method required photometric data generally not available. Greater emphasis relative to the reflectivity of the floor (14 per cent) would seem desirable. Data for at least one higher value of floor reflectivity would be useful and interesting. A paragraph relative to the basis of determining the "room index" is suggested. This would help correlate Tables I and III and Figure 5 and also remove any question as to on what basis the RI was determined. While the working plane is referred to in several places, it is not unmistakably clear as to just what height above the floor was used. Relative to the method being dependent upon symmetrical luminaire locations, this does not seem to be a serious objection considering the lumen method applies only when the distribution of light on the working plane is reasonably even.

Lighting engineers responsible for calculating and publishing coefficients of utilization for luminaires would do well to study this paper. It is hoped they would determine coefficients for several typical luminaires and compare them with those determined by the conventional method. The authors would certainly welcome comments and reports of field experience.

J. A. LOSH**: The authors of this paper have assumed the difficult task of reconciling the units of the lumen and interflectance methods. The extent of their success can probably be best realized by experiment.

If the authors had investigated the basic interflectance method equations further they would have seen that the two statements, "The Interflection Method itself, however, was not carried to a conclusion so that it could be used directly to calculate coefficients of utilization" and "Also, the Interflection Method assumes that the working plane is located

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one-quarter of the distance from the floor to the ceiling'' are not true.

Interflectance is another name for what is called ''utilization factor.'' That is, the coefficient of utilization is equal to the product of efficiency and interflectance or utilization factor or any other name by which the entity of surface reflectance, room shape and flux distribution is known. The very name of the method implies that it is a means whereby coefficients of utilization can be known.

The Interflectance Method equations can be used to calculate the interflectance on any plane, including the 30″ plane, for any ceiling height. It is the Q&Q committee, not the method, that assumes the one-quarter figure above.

H. L. LOGAN*: This is the kind of material that goes far in filling the voids that exist in the present day lighting art. The method proposed can be expected to attain rapid and widespread use by engineers. The paper satisfies a real need.

Some important limiting conditions should be clearly stated. The coefficients of utilization obtained for certain specific luminaire locations at certain specific spacing-to-mounting height ratios in square rooms will not always hold true in general application. The engineer must consider whether the problem at hand is within the limits of this method—whether the coefficients of utilization will apply to the given interior.

For example, if the luminaire layout is symmetrical but not the standard layout which calls for the end rows of luminaires to be a distance from the walls equal to half the spacing betwen rows (assumed to be the layout used by the authors) or if the luminaire layout is non-symmetrical which is the case in a high percentage of the jobs (industrial) which require luminaires with concentrating distributions, then the zonal multipliers will vary, perhaps considerably, from those arrived at in Table I by the authors. The coefficients of utilization calculated by this method will be most accurate for standard symmetrical luminaire layouts.

In small rooms particular caution should be used in application if the spacing-to-mounting height ratio differs appreciably from the .4 used by the authors in calculating the zonal multipliers.

Finally, the authors' proposal is still frozen to one floor condition, namely 14 per cent reflection factor, just as was the original Harrison-Anderson Flux Method. That this can make an important difference in interiors such as gymnasiums, sports arenas, airplane hangars and similar spaces is indicated by one example where the Jones-Neidhart coefficient of utilization would be 54.6 but the actual coefficient based on a 30 per cent floor, would be 60.6 per cent. It is to be hoped that the authors will add one or more floor reflectances to their tables, in addition to the one they are using of 14 per cent. In fact, 14 per cent has no particular validity. A series of 10, 20, and 30 per cent would be more useful.

W. M. POTTER**: All concerned with the design of lighting installations will appreciate the considerable efforts of the authors to extend the range of over-all utilization data. Such analyses—of a problem whose complexity is evident from their charts for only one floor reflectance and only one spacing ratio—contribute much to needed information. As the authors point out, however, the reflected components for direct lighting and all the results for indirect are based on other calculations involving assumptions that may cause departures in varying degree from the results in actual practice. These need experimental evaluation over a wide range of conditions. I would further comment that the method appears most readily employed for individual small luminaires with candlepower distributions symmetrical about a vertical axis.

Over-all utilization data appears to be most useful if based on a certain degree of uniformity of illumination. In this paper the computations for all downward zones are based on a fixed small spacing-to-mounting height ratio, which, although it yields conservative coefficients, may not equitably reflect the situation for units of wide distribution.

This spacing ratio selected by the authors is 0.4. We have compared (a) actual test results for direct lighting elements at this ratio in room conditions of J and H index with (b) calculations using the Jones and Neidhart zonal factors as applied to the candlepower distributions used in our tests. In the calculations appropriate corrections were made for the differences in room reflectance conditions. Test results were 8 per cent and 4.7 per cent higher than the calculated results.

In the authors' calculations on indirect lighting, a ratio of spacing-to-suspension distances of only 0.8 is used as a basis. This would mean, for example, only 24″ luminaire spacing for a 30″ suspension, or a very long suspension for normal spacing—conditions which are certainly not at all representative. A different ratio would affect the number of luminaires and their relationship to wall and ceiling surfaces, and the distribution of ceiling brightness. At first glance, indirect lighting appears simple. But tests of even limited scope reveal that differences in utilization resulting from changes in luminaire location and suspension distance cannot be ignored.

The usefulness of utilization data by 10-degree or even smaller zones is recognized. However, I feel that a single figure or flux ratio may still be useful for ready description of candlepower curves. It may be different from the one selected by Harrison and Anderson. They selected the ratio of 0-40 degree lumens to 0-90 degree lumens as applying to common types of curves, specifically excluding those with the flux concentrated in very narrow zones.

J. R. JONES and J. J. NEIDHART*: The authors appreciate the comments that Mr. Jacobus, Mr. Losh, Mr. Logan, and Mr. Potter have offered.

Mr. Jacobus and Mr. Logan have both suggested that data be made available for higher reflectance floors. The curves in Figures 2 and 4 are now based on a 14 per cent floor reflectance in order to agree with the presently published coefficients of utilization. The authors agree, however, that additional curves of the same general form as Figures 2 and 4 should be provided for higher reflectance floors. Tables I and III would not be altered since they are used only to determine the per cent of luminaire lumens that strike, directly, the work plane and ceiling respectively. These ratios are not affected by room surface reflectances.

Tables I and III, as Mr. Logan and Mr. Potter point out, assume a 0.4 spacing-to-mounting height ratio. This is a lower ratio than most luminaires require in order to attain uniform illumination on the work plane. Thus, the Direct Ratios and Ceiling Ratios are conservative (particularly in high narrow rooms) for luminaires that are likely to be

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spaced further apart in actual installations. The reader should bear in mind, however, that in order to provide an adequate quantity of illumination, luminaires are frequently spaced closer together than is necessary to provide *uniform* illumination. This practice is particularly prevalent in installations employing one- and two-lamp fluorescent luminaires. Also, in high narrow rooms the coefficient of utilization is low so luminaires must be spaced close together to provide an adequate level of illumination, and being in a high narrow room they would likely be mounted rather high so the spacing-to-mounting height ratio is quite low, particularly for high illumination levels. So the error *tends* to be minimized, but the coefficients are no doubt generally slightly conservative.

The data in Tables I and III are calculated specifically for square rooms, as Mr. Logan points out. However, it is but a simple matter to determine the room index of an equivalent rectangular room by the use of the two standard I.E.S. room index formulas[1] which the authors used, or by the standard room index table. The height of the working plane above the floor was assumed to be 30 inches although this dimension cancels out in these two equations. The data in Table I were calculated using the I.E.S. formula for predominantly direct luminaires, and Table III was calculated using the I.E.S. formula for predominantly indirect luminaires. The standard conversion table was used to convert from Room Ratio to Room Index.[2] The authors feel that basing the data on square rooms introduces no problem and concur with Mr. Jacobus' comment that dependence of the method on a symmetrical luminaire layout does not present any serious objection. Any system of calculating illumination levels that is based on the concept of a coefficient of utilization would necessarily be subject to the same kind of limitations (i.e. uniform illumination, approximately symmetrical spacing, etc.). A coefficient of utilization cannot possibly be exactly correct for all layouts. As Mr. Jacobus points out, the Lumen Method applies only when the distribution of light on the working plane is reasonably uniform.

It is interesting to note that most of Mr. Potter's objections to the authors' Zonal Method are also applicable to the existing method of calculating coefficients. If the simplicity of the Lumen Method of calculating illumination is to be retained, certain assumptions must be made that will not always agree with actual installation conditions. Despite these necessary limitations, it cannot be denied that the proposed Zonal Method is more accurate than the currently used method. The authors admit conservatism and consider Mr. Potter's test results as verifying the accuracy of the method.

Although a 0.8 spacing-to-suspension distance ratio may seem unrealistic for indirect lighting, it would be inconsistent to select any other ratio as a basis for Table III if the 0.4 ratio is selected for Table I. To satisfy both the standard I.E.S. formulas for room index (one for predominantly direct luminaires, the other for predominantly indirect luminaires), it is necessary for the luminaire to be suspended one-half as far below the ceiling as it is above the work plane. Thus, if the spacing-to-mounting height (above work plane) ratio of 0.4 is selected, the ratio of luminaire spacing-to-suspension distance must be 0.8. The authors agree with Mr. Potter that this 0.8 ratio should be nearer 3.0, but if the 3.0 ratio had been used one would obtain a different coefficient of utilization for a totally indirect luminaire than one would obtain from the indirect component of a direct-indirect luminaire. Therefore, the authors feel that until the room index formulas are altered, it is imperative that the 2.0 to 1.0 (0.8 to 0.4) ratio be maintained. Perhaps the room index formulas should be re-examined. Even with the 0.8 ratio, however, the results of a few tests on indirect installations indicate slightly conservative but considerably more accurate coefficients by the zonal method than the current method. In the light of Mr. Potter's objections to the limiting assumptions that the authors had to make to retain simplicity, it seems incongruent to suggest the use of a single figure or flux ratio as being sufficiently descriptive of a luminaire distribution.

Mr. Losh is correct in stating that it is difficult to reconcile completely the Lumen Method and the Interflectance Method. However, aside from the difference in the method of classifying the room shape there is no significant difference between the two methods. In both methods the initial ilumination level is equal to the quotient of the product of lamp lumens, utilization factor (or interflectance) and luminaire efficiency (or logance) divided by room area. So the two methods are not dissimilar.

Mr. Losh has taken exception to two statements that appear in the paper. The authors believe that there is no real disagreement, but actually only a difference in opinion as to what should be the definition of "Interflectance Method." The authors consider that the Reports of the Committee on Standards of Quality and Quantity have described the Interflectance Method.

The authors were aware that the basic equations can be used to calculate interflectance tables for the 30-inch work plane or any work plane. So far, however, tables have been prepared only for a work plane located one-fourth the distance from the floor to the ceiling. It is not convenient for the lighting application engineer, or for anyone, to use the basic equations to calculate interflectances for the 30-inch work plane for typical luminaires. So until tables are prepared for the 30-inch work plane the ordinary use of the Interflectance Method will lead to considerable error in high bay lighting installations.

Mr. Losh also states that the basic equations can be used to calculate coefficients of utilization. For luminaires that have a distribution approximately the cosine curve, or some other simple mathematical function, this is true. But for other luminaires it is necessary to measure or calculate the percentage of luminaire lumens that strike the walls, ceiling, and floor. To calculate these percentages with the basic interflectance equations would be a difficult task. The authors are not aware that anyone has made such calculations for luminaires that are not perfectly diffusing. It is assumed that Mr. Losh is referring to a system[3] wherein the per cent flux striking the walls, ceiling, and floor was determined by measurement in order to obtain these percentages for use in conjunction with the tables published in Report No. 3 of the Committee on Standards of Quality and Quantity.

The authors do not consider the system mentioned above,[3] nor the basic equations used to develop the interflection method, any more a part of that method than the test room of Harrison and Anderson was a part of their method. They were all tools that were used in the development of the two methods.

1. *IES Lighting Handbook*, Second Edition, p. 9-2.
2. *IES Lighting Handbook*, Second Edition, p. 9-5.
3. Coradeschi, R. A., and Innis, L. E.: An Application of the Interflection Theory to Commercial Practice. ILLUMINATING ENGINEERING, Vol. 43, 1948, p. 949.