A Versatile Method of Calculating

Illumination and Brightness

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OUR SYSTEM OF computing interior illumination is based on three fundamental concepts, the maintenance factor, the room index (or room ratio), and the coefficient of utilization. If the correct value for each of these three variables is used in the calculations, the predicted illumination will match the measured quantity. Probably the largest errors in the predicted illumination are caused by misjudging the maintenance factor. Adequate information is not available for use in evaluating this quantity and a comprehensive study coupled with extensive experimental work is needed. While experimental checks are necessary in studying the other two concepts, the basic work is of a mathematical nature. These two subjects will be discussed in detail.

Room Ratio

Our current room ratio system was established by Harrison and Anderson[1] in the period from 1916 to 1920 and was later improved through the efforts of Crouch and Freyer[2] who assembled data provided by Hisano.[3] These data were unavailable in 1920 and later were given insufficient attention. The early work of Harrison and Anderson treated room shape as a ratio that could be computed from a formula. The ratio, regrettably, was abandoned later in favor of the room index in which all rooms of approximately the same shape were called equal through classification by a room index letter.

Our current room ratio system might be called a "double ratio" system. One room ratio formula is used for direct luminaires, another for luminaires that are predominately indirect. For luminaires that direct more than 40 per cent of their flux below the horizontal the room ratio formula is:

$$\text{Room Ratio} = \frac{\text{width} \times \text{length}}{(\text{width} + \text{length}) \times \text{mounting height above work plane}}$$

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 17-22, 1958, Toronto, Ont. AUTHORS: Smoot-Holman Co., Inglewood, Calif., and Westinghouse Electric Corp., Los Angeles, Calif. This paper accepted by the Papers Committee of I.E.S. as a Transaction of the Illuminating Engineering Society.

For luminaires that direct more than 60 per cent of their flux upward, the room ratio formula is:

$$\text{Room Ratio} = \frac{3 \times \text{width} \times \text{length}}{2 \times (\text{width} + \text{length}) \times \text{ceiling height above work plane}}$$

Setting these formulas equal to each other, it can be seen that the ceiling height above the work plane must equal $^3/_2$ times the luminaire mounting height above the work plane. Therefore, the room ratio can be exact for both the direct and indirect components of suspended luminaires only if the suspension length is one-third the distance from the ceiling to the work plane. Ordinarily, they are mounted nearer the ceiling. Thus, an error is introduced.

Our current tables of coefficients of utilization being based, as they are, on room ratios of 0.6, 0.8, 1.0, 1.25, etc., are not particularly well suited for interpolation in the usual event that one finds a room of ratio of some odd value. An inverse relationship similar to k_r would appear to be better suited to the needs.

Possible Room Classification System

The writers feel that one of the most promising room classification systems would be based on the following principles (see Fig. 1):

1. Divide the room into three basic cavities:
   (a) The cavity above the luminaires,
   (b) The cavity below the work plane,
   (c) The space bounded by the planes of the luminaires on the top, the work plane on the bottom, and the walls of the room.
2. Compute the ratio of the basic room by the formula given in Fig. 1. The cavity ratios for the floor and ceiling cavities can then be found by one slide rule setting, since they are proportional to the heights of the cavities compared to that of the basic room. It may be desirable to use some other symbol than k_r for the ratio of the basic room, to avoid confusion with the present use of the same formula to comprehend the total ceiling height. K_r is being used in this system because it seems to be the best

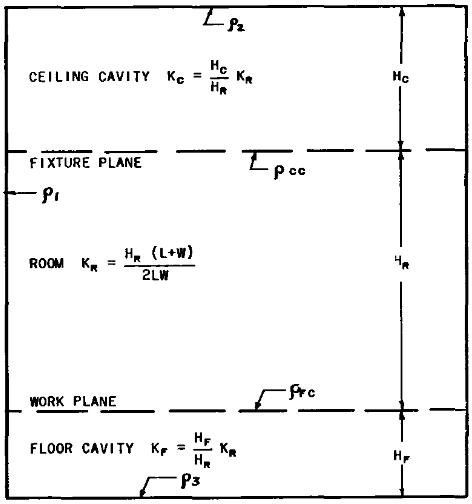

Figure 1. Method of splitting room into three sections. ρ_{cc} = effective reflectance of ceiling cavity; ρ_{fc} = effective reflectance of floor cavity.

currently available system of classifying room shapes, although it represents flux distribution accurately only in a square room.

This treatment of room shape has already been suggested by Caracciolo[4] and others. The principal advantages of this treatment are as follows:

1. It eliminates the "double ratio" system and thus reduces confusion, and adds accuracy.
2. It is well suited to interpolation, thus adds convenience and accuracy.
3. It simplifies the computation of coefficients of utilization. This will be dealt with more thoroughly later.
4. It would permit accuracy in coefficients for rooms in which the walls above the luminaires and below the work plane differ in reflectance from the remainder of the walls (dadoes and so on).
5. It would eliminate the error incurred in instances where the work plane is at some elevation other than 30 inches (or one-fourth the ceiling to floor distance), as is assumed in the systems now current.
6. It yields a method of handling partitions within a room.
7. It focuses attention on the effect of varying mounting height and upper wall reflectance.

The cavity above the luminaires can be treated as a surface at the plane of the luminaires whose reflectance is the effective cavity reflectance. The coefficients of utilization would then be published on the basis of effective cavity reflectance rather than on the basis of ceiling reflectance as is now done. In large rooms having a shallow cavity, the effective cavity reflectance would approach the ceiling reflectance. In small rooms with a deep cavity, the effective cavity reflectance would normally be considerably lower than the ceiling reflectance, particularly if the upper walls were dark. Effective cavity reflectance can be determined from plotted data similar to Fig. 2. This chart and Fig. 3 were computed by a variety of methods all based on the assumption that the flux enters the cavity diffusely. Part was computed by the method used by Spencer[5] and part by the algebraic interflectance method.[6] Caracciolo has also done work on this problem and achieved results which agree with the data in Figs. 2 and 3. In a more comprehensive study of this problem the initial cavity wall bright-

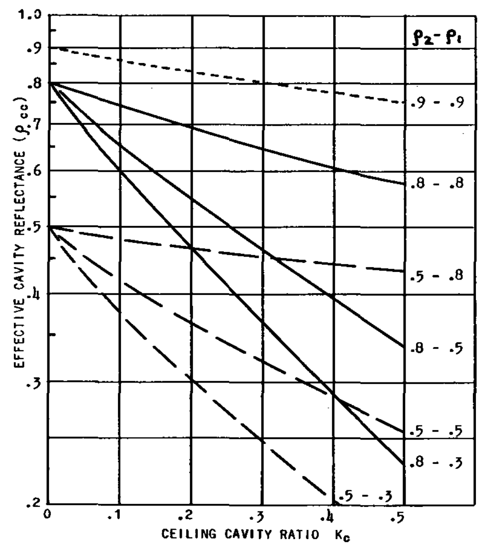

Figure 2. Effective ceiling cavity reflectance as a function of cavity ratio for several combinations of reflectance.

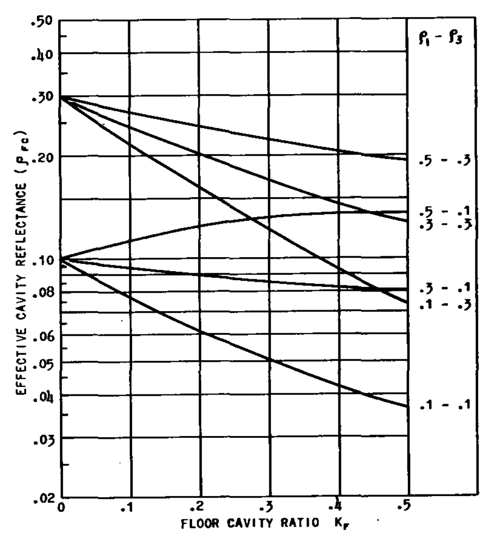

Figure 3. Effective floor cavity reflectance as a function of cavity ratio for several combinations of reflectance.

ness could be varied according to any desired pattern, and studied by means of a computer, and the effect of changing the ceiling ratio studied. Changing the initial brightness pattern affects the effective reflectance somewhat in cavities having relatively high values of K_c or K_f.

Replacing the cavity with a fictitious plane at luminaire height does not impair the accuracy of the coefficients of utilization if the surfaces of the cavity are perfect diffusers and if the brightness of the walls of the cavity is uniform and equal to the ceiling brightness. The currently accepted calculation method makes the same assumptions except that it does not assume the wall and ceiling brightnesses equal. It does, however, assume the flux on the wall of the cavity to be spread out over the entire room wall, inducing an error not present in the proposed system. The assumption of equal brightness for walls and ceiling of cavity is necessary because of the fact that the flux emanating from the cavity is assumed to be diffuse. It is not perfectly diffuse if the walls and ceiling are not equal in brightness. However, the error introduced in the coefficients by a brightness difference appears to be small, of the order of a few per cent in practical cases. It is felt that the benefits stemming from the ability to consider wall reflectances in the cavities that differ from the reflectance of the room walls is ample justification for incurring a possible loss in accuracy caused by a lack of perfect diffusion.

The cavity below the work plane can be replaced by a fictitious plane at the level of the work plane whose reflectance would equal the effective reflectance of the cavity, and otherwise be treated in the same manner as the ceiling cavity.

Thus, the basic room is bounded by surfaces whose reflectances are fairly accurately known. Ordinarily, there is no furniture in this space, and the process of computing coefficients to obtain the illumination on the "floor" of the space is greatly simplified.

Coefficients of Utilization

Our present method of computing coefficients has received more study than that of the room ratio, and has been revised more recently.[7] The present system is based on computing the flux streaming directly from the luminaires to the work plane by the use of zonal multipliers. This has been quite successful, and the zonal multipliers are quite accurate for computing direct flux to the work plane. To the direct flux computed by the zonal multipliers is then added the flux reaching the work plane after reflection about the room. Data provided by Moon and Spencer[8] permitted computation of this flux using interflectance values f_1, f_2, and f_3. Interflectance f_1 is the per cent of flux uniformly incident on the wall surfaces that reaches the work plane. Interflectances f_2 and f_3 are the per cents of ceiling and floor flux, respectively, that reach the work plane.

Several mathematical and experimental studies have been made to ascertain the accuracy of these values. Some studies resulted in reports that indicated a high degree of accuracy; others indicated an error of several per cent under some circumstances. However, it is generally recognized that the published f_2 values are generally accurate except for those for high narrow rooms, especially if the reflectances are low. Other methods are available for computing interflectance values. The algebraic method and a method of Dourgnon[9,10] provide practically identical results. The f_2 values of these two methods are very close to those of Moon and Spencer for all conditions except when the room is high and narrow. However, these values are often *too high* since the final wall brightness is not necessarily uniform as is assumed in the derivation.

Another method for the determination of interflectance values has recently been developed by Professor Philip O'Brien at the University of California, Los Angeles.[11,12] It utilizes a luminous analogue computer that permits determination of the final brightness of the room surfaces to an accuracy of about one per cent, if the room is divided into a large enough number of surfaces. It appears to the writers that a computer to comprehend twelve surfaces is sufficient for most lighting problems. (See Fig. 4.) A twelve-surface computer permits determination of the final average brightness of twelve room surfaces when the initial brightnesses of all twelve surfaces are known. The geometrical disposition of the room surfaces envisioned by the authors is illustrated by Fig. 5, and is based on the assumption the room brightness pattern will exhibit axial symmetry. The assumption of axial symmetry permitted this division of the walls into bands encircling the wall. This necessitated writing the basic flux equations in such form as to permit an exchange of flux between the four sections of the same band. Since it is necessary to know the initial brightness of each room surface (ceiling, work plane and each wall band A, B, C, etc.), a means is necessary for computing or measuring the flux streaming from the luminaires to these surfaces. This suggests the need for additional tables of zonal multipliers or perhaps a new system of photometry that would yield these data directly. For the latter, Losh's[13] approach shows promise.

The initial brightness L_{02} of the fictitious plane

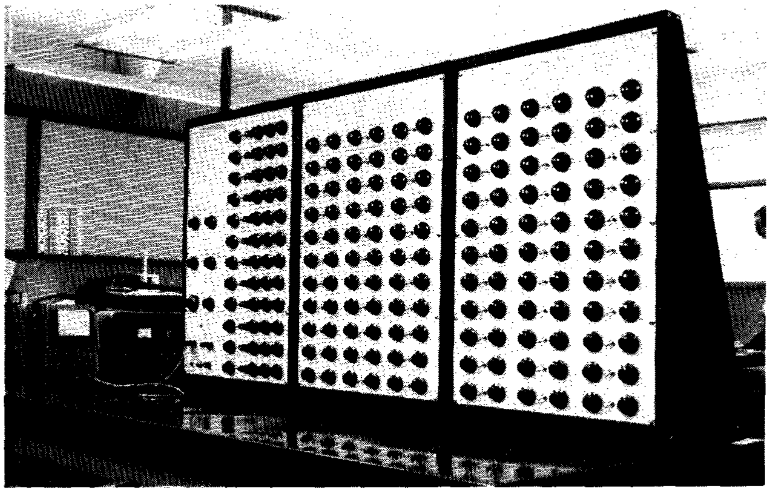

Figure 4. Twelve-surface Luminous Analogue Computer of the type developed by Philip F. O'Brien, UCLA.

at the luminaire level is equal to the product of upward luminaire lumens and effective cavity reflectance, ρ_{cc} divided by A_2, the area of the plane. The effective initial brightness, L_{03} of the work plane, is the product of lumens streaming directly to the work plane (found from the zonal multipliers of Table I) and the effective reflectance, ρ_{fc} of the floor cavity divided by the area of work plane, A_3.

In contrast to dividing the room into many surfaces, as illustrated by Fig. 5, it is possible to consider the walls as a single area of uniform brightness and thus have only three surfaces to consider. This is considered undesirable for two reasons: First, this would not provide a complete knowledge of the brightness pattern of the entire room as is possible if many surfaces are considered. Secondly, it is necessary to divide the wall area into several surfaces in order to minimize errors in the predicted illumination.

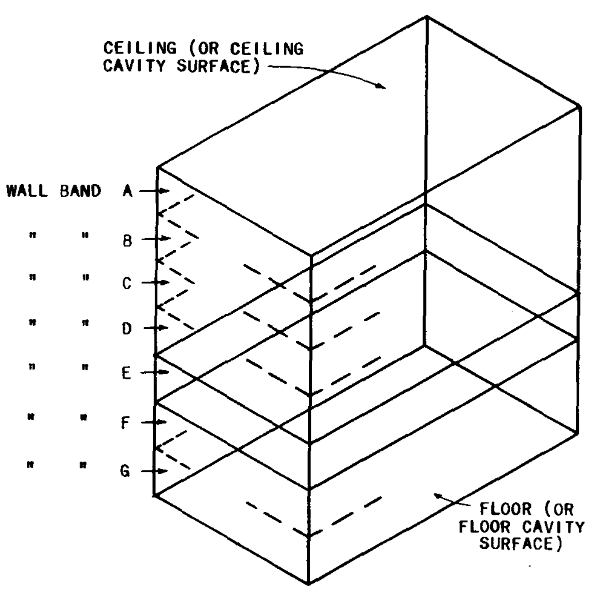

Figure 5. Method of dividing walls into consecutive bands to permit programming of non-uniform brightness distribution on walls. Ceiling cavity surface is plane of luminaires; floor cavity surface is work plane.

In one problem where the walls were considered of uniform brightness, the work plane illumination was 5.1 per cent too high, whereas dividing the walls into ten surfaces yielded an illumination within one-half per cent of the exact solution as computed by Spencer.[14] Since this particular problem had an exact mathematical solution, it was programmed on the computer. The brightnesses of the floor and ceiling, and that of the wall as a function of the distance from the ceiling, were obtained and compared with the exact solution. The wall distributions are compared in Fig. 6, from which it can be seen that the maximum deviation is about 2.5 per cent, and except for the upper two wall sections the deviations are less than one per cent. Table II shows the exact brightness of the floor and ceiling as well as the solution by the Interflectance Method using the approximate kernels[8] and the computer solution. Table III compares the published interflectance values with the computer solution for ceiling brightness and floor brightness as a fraction of the initial ceiling brightness for several common reflectances for a

TABLE I — Zonal Multipliers.

	Room K_r									
Zone	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0-10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10-20	.98	.92	.89	.85	.81	.79	.76	.73	.70	.66
20-30	.94	.89	.84	.78	.73	.68	.64	.59	.53	.48
30-40	.91	.82	.72	.64	.56	.50	.43	.36	.30	.25
40-50	.88	.78	.67	.57	.47	.38	.28	.19	.11	.06
50-60	.83	.67	.53	.39	.28	.16	.09	.04	.01	0
60-70	.77	.53	.35	.21	.05	.01	0	0	0	0
70-80	.60	.22	.05	0	0	0	0	0	0	0
80-90	.14	0	0	0	0	0	0	0	0	0

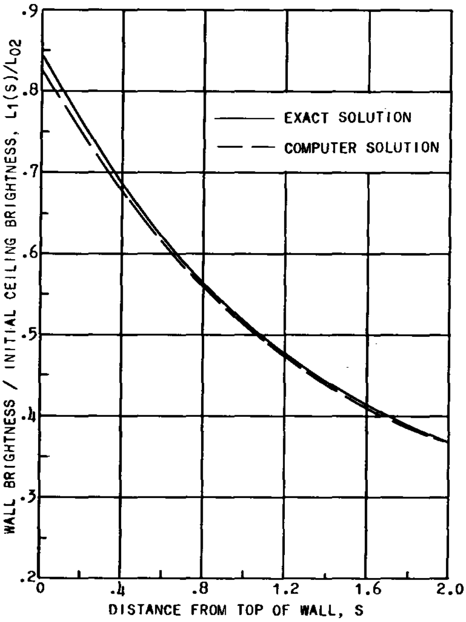

Figure 6. Wall brightness distribution as a function of distance from the top of the wall, referred to initial ceiling brightness. Comparison of exact (mathematical) and computer solutions, using ten wall bands.

cubical room. This procedure could be utilized to provide a set of interflectance tables similar to those presently published, except that the inclusion of tables for each wall band would greatly increase the number of tables required. Therefore, it would be very laborious to use the tables to compute coefficients of utilization. It is felt that a much simpler procedure would be to program the initial brightnesses of the ceiling cavity, floor cavity and wall bands on a computer for solution. This would yield the average brightness of all these surfaces and also provide the utilization factor directly.

Two assumptions are made in this approach which need further verification. Use of the concept of effective reflectance for the floor and ceiling cavities implies that the flux enters and leaves these cavities in a diffuse manner. This is obviously not so in many cases. Examination of the range of ceiling ratios encountered in practice indicates that the error incurred by assuming diffuse flux entry into the cavity would be fairly small. To confirm this assumption, the effective cavity reflectance was determined for a luminaire with extreme deviation from diffuse distribution (a concentric ring luminaire) and compared with that for diffuse entry (see Fig. 7). It will be noted that for ordinary combinations of ceiling and wall reflectance, the error is negligible, while for the extreme case of 80 per cent ceiling, 10 per cent walls and a deep cavity ($K_{rc} = .5$) the error is still less than 10 per cent, and in such a direction as to make the calculated reflectance high. Since ceiling reflectance and utilization of flux striking the ceiling are almost directly proportional, this will incur an error in utilization of approximately the same magnitude.

The error due to assumption of diffuse exit of flux from the cavity was investigated by again assuming an extreme case and calculating the error, knowing it will be less for practical cases. The wall brightnesses and floor utilization factor were calculated for a cubical room with totally indirect luminaires of cosine distribution, suspended at one-half the floor to ceiling distance. Exact calculations were made by programming the

TABLE II — Distribution of Light in a Semi-Infinite Room.

$K_r = 1.0, \quad \rho_1 = \rho_2 = .8, \quad \rho_3 = .5$

	Exact	Inter-flectance	Per Cent Error	Computer	Per Cent Error
L_{1T}/L_{02}	.8449	.8276	−2.05	.826	−2.25
L_{1M}/L_{02}	.5166	.5475	+5.98	.515	− .31
L_2/L_{02}	1.4514	1.4751	+1.63	1.446	− .37
L_3/L_{02}	.3499	.3154	−9.87	.3497	− .06

TABLE III — Distribution of Light in a Cubical Room by Interflectance Method and by Computer.

Reflectances Ceiling/Wall/Floor	L_2/L_{02} Inter-flectance	L_2/L_{02} Computer	L_3/L_{02} Inter-flectance	L_3/L_{02} Computer
80/50/30	1.167	1.158	.087	.1043
50/50/30	1.098	1.096	.0819	.0987
80/50/10	1.154	1.136	.0274	.0333
50/50/10	1.091	1.085	.0262	.0317
50/30/10	1.047	1.048	.0200	.0258

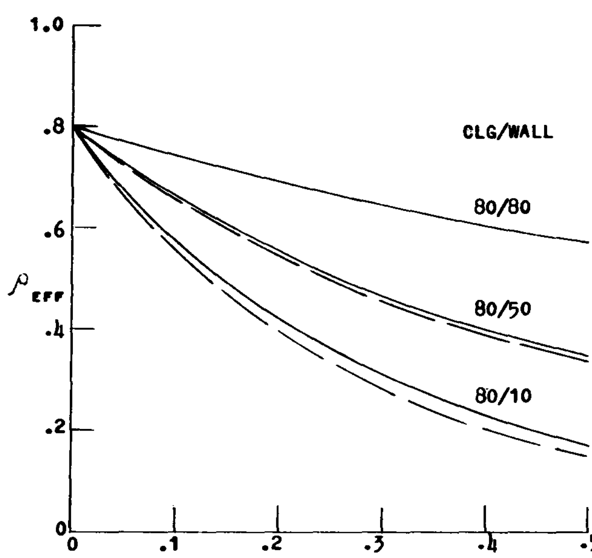

Figure 7. Effect of non-diffuse entry of flux into cavity. Diffuse entry, ceiling ratio = .48 (J Room). Concentric ring luminaire, ceiling ratio = .395 (J).

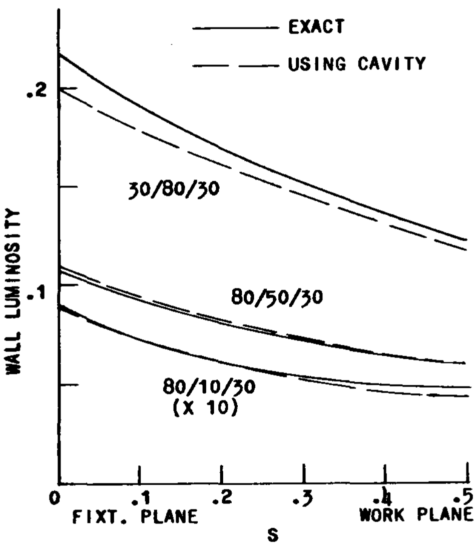

Figure 8. Effect of non-diffuse exit of flux from cavity.

entire room and approximate calculations made by considering the upper part of the room as a cavity whose K_{rc} then equaled .5. Two extreme reflectance combinations and a practical one were chosen. The results appear in Fig. 8 and Table IV. It will be noted that the errors in wall brightness are small, and that only in one of the extreme cases is the error in utilization factor appreciable. This case is for the same wall and ceiling conditions which produced a calculation less than 10 per cent high for non-diffuse entry. Here, it produces an error about 9 per cent low. Therefore, not only are the errors which are incurred by ignoring the non-diffuseness of flux entry and exit from the cavity relatively small, but they are also compensatory. The total error in calculation of surface brightnesses and utilization, therefore, will be quite small for practical cases.

Conclusions

A review of the inadequacies of our present system for making lighting calculations has been made, and a possible system, which overcomes many of the disadvantages of the present system, presented. The major advantage of a system such as this is its ability to comprehend conditions that are outside the limitations of the present system, and to provide a relatively complete picture of the final brightness pattern within an enclosure. A secondary advantage is a substantial gain in accuracy of lighting level calculations.

TABLE IV — Exact and Approximate Utilization Factors.

Reflectances	Utilization Factors Exact	Using Cavity	Per Cent Error
80/10/30	.0839	.0763	−9.06
80/50/30	.205	.202	−1.46
30/80/30	.240	.242	+ .83

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DISCUSSION

D. E. Spencer:* The method of splitting rooms into three sections, suggested in this paper, is an extension of the procedure suggested in my 1956 paper, "The Effect of Furniture on the Coefficient of Utilization."[1] It has a sound basis in the interflection theory. The effective floor cavity reflectance suggested here is correct if there is no furniture. The values given in Fig. 3 are subject to modification if there are any obstructions in the "floor cavity" as is the case whenever it is worthwhile to introduce such a subdivision. However, suitable value of ρ_{FC} can always be obtained by applying Fig. 3 to each open space between furniture and suitably averaging in the reflectance of desk or table tops. Likewise, the ceiling cavity may contain obstructions which should be taken into account in a detailed calculation.

It is gratifying to see the authors formulate the effect of room shape in a rational fashion in terms of domance k_r.** Their use of the luminous analogue computer appears to be in excellent agreement with the interflection method. The only significant discrepancy shown in Table II could be eliminated if the exact expressions for the direct light on the floor, which I recently suggested,[2] were employed. However, even this discrepancy is less than 10 per cent and therefore I feel that it is of scant practical significance.

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**Domance — index of room proportion.

This process of refining the accuracy with which we can predetermine the brightness distribution in any luminous environment can be carried on indefinitely. However, variations of 10 or 20 per cent in the quantity of light and of 100 per cent in the brightness distribution have so little visual significance that I am inclined to be satisfied with simpler, if less accurate, calculation procedures.

The industry with which the authors pursue increased accuracy is admirable. Their procedures are generally sound. I would merely like to inject a word of caution and a plea that practical procedures for applying the interflection method should not be complicated beyond necessity.

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R. T. DORSEY:* These zonal multipliers in Table I are applied to zonal lumens which are derived from average candlepower around each particular zone. In the case of most incandescent downlights, the variation in candlepower around a zone would be relatively small. With fluorescent, luminaires, however, the values vary considerably and so the brightness values calculated for the various wall zones would differ substantially from those which would actually be obtained. In general, with fluorescent luminaires parallel to the wall, the calculated value would be too low, and with the luminaires perpendicular to the wall, the calculated value would be too high.

JEAN DOURGNON:** I found this paper very interesting, primarily because it puts the problem of computations in interior lighting in its true light. For this reason, I am pleased to have the opportunity to comment.

In regard to room ratio, it was not Hisano but Margoulies (in 1928) who first referred to the harmonic mean of the sides of a room, using my own method.

The ratio of height/side of the room for the room ratio has been championed by Phillips in Australia, Cadiergues and myself in France and others. Generally speaking, authors of theoretical works prefer this ratio, while the others prefer the reverse, because they do not want to change the current use, and in a certain way, they are right. Committee W.3.1.1.1 had a resolution in favor of side/height. It could be discussed again, but for my part, I think we must be very careful in this matter.

Regarding possible room classification, at the moment I do not have Caracciolo's paper at hand, but I must say that Caracciolo's idea seems to have been given previously by Zijl. The question is being studied very seriously by Committee W.3.1.1.1.

We have two methods of approach: (1) We assume that the boundary surfaces of the room are at the top, the plane of the luminaires, and at the bottom, the working plane. Both those planes are assumed to have reflection factors equal to the equivalent reflectance of the cavity above or under the plane.

(2) We assume that the room is an ordinary one and has its height "h" between the plane of the luminaires and the working plane equal to the same height "h" of the actual room, but the ceiling and floor are not at their true places, the distances to those planes being constant ratios of *h*.

Both of these methods are wrong in certain cases. If you want to compute p_{u1}, which I call the partial utilization factor for the walls illuminated alone (from floor to ceiling), you will have a certain amount of flux that flows through the plane of the luminaires. With the first method, you must assume that this flux is uniform on the cavity above the luminaire plane, and calculate the utilization factor and the equivalent reflection factor as if it were. No doubt, this is wrong. It is possible to calculate a rather correct value of the equivalent reflection factor for the direct flux (Fig. A), but the true calculation of the utilization factor is not so easy.

On the other hand, assuming that you have indirect lighting with suspended luminaires, method 1 will be quite correct, but with method 2 you will be obliged to separate the flux on the walls between the ceiling and luminaire plane and assume it is uniform on the whole surface of the walls (between the ceiling and the floor) and use factor p_{u1} which is certainly not the right one for this case.

In regard to coefficients of utilization, the "algebraic" method, O'Brien's method and my method, etc., are but the same method. They have the same assumptions, and the formulas fit these assumptions. The results must be the

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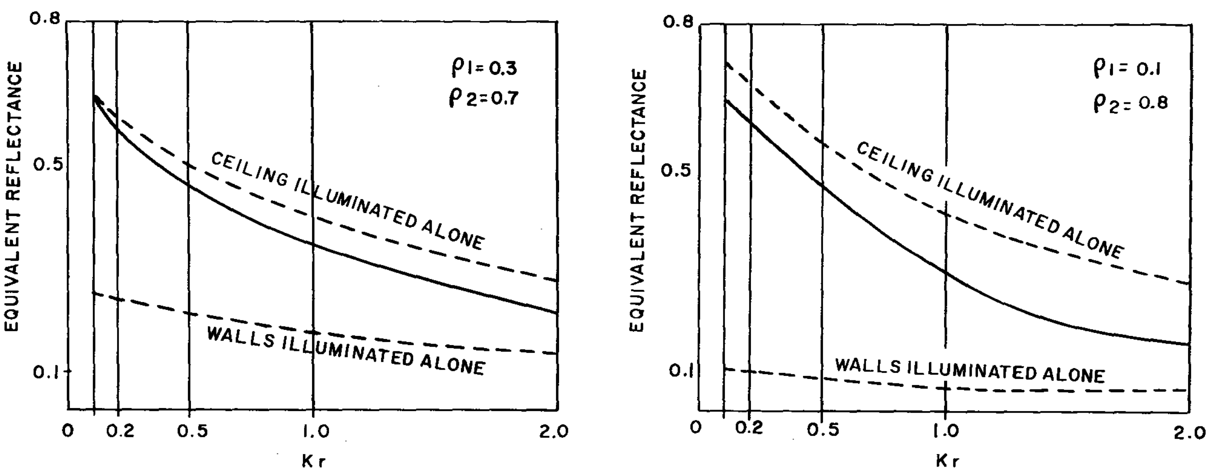

Figure A. Equivalent reflectance of the plane of the luminaires (square room, distance between ceiling and plane of luminaires—0.80 meter)—from Didier Fleury.

same, theoretically, and I am not surprised that they are the same, practically.

In the Bibliography, reference 9 must be wrong. It may be either: Dourgnon, Jean: "Nouvelle methode de predetermination des coefficients d'utilisation," *Revue Generale de l'Electricite*, (Paris), Vol. 23, p. 271 (1928); or Dourgnon, Jean and Cadiergues, R.: "De l'utilisation de l'equation de Fredholm pour la solution des problemes d'eclairage et de chauffage," *Revue Generale de l'Electricite*, (Paris), Vol. 59, p. 299 (1949).

G. W. Clark and M. L. Trostle:* The authors have introduced a rather interesting approach to the further refinement of our coefficient of utilization calculations and to the prediction of the brightnesses of room surfaces. It deserves thorough consideration.

To fully utilize the improvement in coefficients of utilization, it appears that one would have to use the concept of "effective cavity reflectance." We presume this would involve an additional calculation by the user of the coefficient of utilization. This is a deterrent to its use, but not necessarily of sufficient importance to off-set the advantages to be gained. In this respect, it would be similar to the method which we have proposed for predicting the illumination from wall-to-wall translighted ceiling systems where it is so important to adequately consider the influence of the cavity conditions.[1] The data we have published in this manner in our own company literature seem to have been accepted without serious objection.

Fortunately the timing of this paper is such that the extra calculation involved for determining coefficients in the proposed method is not so unreasonable to contemplate as might have been the case a few years ago. Obviously, this is feasible only with the use of computing devices, a trend already underway.

1. Clark, G. W., and Trostle, M. L.: Discussion of Russell, A. H. and Churchill, R. D.: "Measured Utilization Data for Luminous Ceilings," Illuminating Engineering, Vol. LI, No. 4, pp. 316-317 (April 1956).

Philip F. O'Brien:** This excellent paper is concerned with the predetermination of the luminous flux distribution in symmetrical rooms. Twelve finite difference equations which describe an infinitely long hallway are solved using a Luminous Analogue Computer. The evaluation of the coefficients of these finite difference equations requires a knowledge of the shape modulus. Because information regarding the mathematics of the shape modulus and the numerical values of this geometrical parameter is distributed throughout the literature of radiative transfer, lighting engineers may find this lack of unified information a barrier to the utilization of this design tool.

The effective reflectance of certain cavities in a room is suggested as a device to simplify the analytical representation of flux transfer. By this artifice, the complicated network of the cavity is replaced by a single network branch containing the resistance $\rho n c / (1 - n c) A$. Although simplicity is gained, the reduction of network branches makes unavailable information regarding the directional aspects of flux flow within the cavity and between the cavity surfaces and the room. For example, the initial flux streaming from the cavity defined by the luminaire plane should be computed from a detailed network representation of the cavity in order to account for the trapping effect which is sensitive to the directional aspects of the flux streaming upward from the luminaires. Dourgnon[1] has recently treated this problem of flux transfer in the ceiling cavity.

Because contributions to this problem of lighting predetermination are being made at an increasing rate on a world-wide basis, the lighting engineer who wishes to be up-to-date in this area must read many papers with a variety of nomenclatures and notations. For example, the effective ceiling cavity reflectance ρ_{cc} of this paper has been designated by other authors as: effective reflectance ρ_{EFF}, *fattore apparente di reflessione* r_a, equivalent reflectance ρ_{eq}, *le facteur de reflexion equivalent* ρ_e and R_o, equivalent reflectance factor of cavity, and apparent reflectance ρ_2^*. If the rapid growth of this technical area prevents the early use of standard notation, it may not be unreasonable to expect each author to define quantities by a functional relationship with each term identified by typical units or dimensions.

The authors are to be commended for this first report of the application of the network representation of lighting systems in an industrial environment. I look forward to additional reports of the utilization of the Luminous Analogue Computer both for the design of room lighting and for the analysis and synthesis of luminaires.

1. Dourgnon, Jean: "Recherche Preliminaire sur la Diminution du Facteur D'Utilisation Suite de L'Occultation des Appareils D'Eclairage." *Cahiers du Centre Scientifique et Technique du Batiment*, Paris, June 1958.

B. F. Jones and J. R. Jones:* We would like to express our appreciation to the discussers of this paper for their kind comments. There is really little to rebut, and what there is is due mainly to differences in viewpoint.

Rather than using a difference exact expression to obtain light on the floor for each room shape, as suggested by Dr. Spencer, it might be preferable to calculate tables of interflectances by computer, thus removing those inaccuracies occasioned by the approximations of the equations.

The visual significance of 10 or 20 per cent variations in intensity is not at issue in this discussion. We need, for at least three reasons, to perform calculations as accurately as possible. First, by starting from an accurate base, the unavoidable deviations (in lamps, voltage, etc.) moves us less far from the correct value, on the average. Second, specification of footcandle levels is becoming more general, and with the present competitive situation, it is often necessary to calculate quite accurately. Finally, an accurate calculation method raises the stature of the illuminating engineering profession in the eyes of the other professions.

Mr. Dorsey's comments are basically the same as those voiced in discussion of the original zonal method, which was subsequently adopted as the current IES standard. It should be remembered this is an engineering method of calculation, and must be simple enough for rapid and convenient use by the engineer. An extremely accurate calculation of brightness could be made by dividing the areas involved into a sufficient number of elements and programming them on a computer of sufficient size. We feel that the time required for such calculations is justified in only a very few cases. The average brightness of wall surfaces given by this method is a definite advance over those previously available for engineering use.

We particularly thank Mr. Dourgnon for his comments and for giving us the international view on the problems

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involved in a unified calculations system. We should very much like to see more work done on the problem of an accurate system of room classification, since no current system adequately represents all room shapes. We do not look with favor on the adoption of the resolution in favor of side/height.

Mr. Dourgnon did not have the benefit of the additional checks on non-diffuse entry and exit of flux from the cavity when he wrote his discussion. Thus, while his comments relative to the first method of approach (which we used) are quite accurate, the magnitudes of error introduced in practice are quite small.

We bow to Mr. Dourgnon's more intimate knowledge of contributions from outside this country. Unfortunately, we in the United States undoubtedly pay too little attention to the work of our colleagues overseas.

The incorrect bibliography reference pointed out by Mr. Dourgnon has been corrected for publication in ILLUMINATING ENGINEERING.

Effective cavity reflectance, referred to by Messrs. Clark and Trostle, can be obtained from charts similar to Figs. 2 and 3, which would be made available for whatever combinations of reflectance were felt desirable. The only additional calculation is of the cavity K_r which is obtained at the same time as room K_r, as noted in the paper.

Regarding Professor O'Brien's comments, the directional aspects of the flux streaming from the cavity do not seem to have great effect on the illumination and brightnesses within the room, as can be seen from Fig. 8. The effect of luminaire trapping, however, needs a good deal of research. Incidentally, such research would be greatly facilitated by the use of the computer. Obviously, it would affect this system only by modifying the value of the effective cavity reflectance.

We feel it would be quite desirable for a standard notation to be developed at this time, and we believe that the I.E.S. Nomenclature Committee, of which Professor O'Brien is a member, is currently working on this.

Polar Palace Relighted

A 48-foot ceiling height at the center of Polar Palace ice skating rink, Los Angeles, made maintenance a real problem with the previous lighting system of suspended units. In relighting the 21,000-square-foot area, the fixtures were installed along the sides of the building just below the supporting tie rods. Continuous rows of 96-inch four-lamp units with acrylic diffusing panels are mounted at an angle of 30 degrees to the vertical, 28 units on each side. Units are wired for switching from two to four lamps for various levels. Colored PAR-38 reflector lamps are installed on alternate columns to create the desired atmosphere for specialty performances. Walls and woodwork were repainted for higher reflectance. Illumination level is from 8 to 10 footcandles. Photo and data courtesy Department of Water and Power, Los Angeles, Calif.