Interreflection coefficients for interior lighting calculations based on CIE methods

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The concept and practicability of two useful methods reported for interior lighting calculations in France have been widely introduced and discussed by a few Japanese investigators from various points of view. CIE Publication No. 40: "Calculations for Interior Lighting—Basic Method—" was published in 1978, and the final report on "Applied Method" has now been prepared under the chairman of TC-1.5, A.B. de Graaff.

The authors compare the computation process and its characteristics of RM and MR coefficients obtained by the present studies with that of these coefficients based on the CIE methods approved by TC-1.5, and point out the difference between the data of RM and MR coefficients prepared in the CIE methods and the numerical data calculated by the authors. Lastly, they discuss the effect on the final computation results for lighting designs from the standpoints such as room index, suspension ratio and effective reflectance of the ceiling cavity.

1. Introduction

The concept and practicability of two useful methods reported already for interior lighting calculations in France have been widely introduced and discussed by a few Japanese investigators from various points of view¹⁾. The two recent recommended methods for interior lighting calculations approved by CIE Technical Committee 1.5 intend to retain and combine all the good features of various methods. CIE Publication No. 40: "Calculations for Interior Lighting—Basic Method—" was published in 1978²⁾, and the final report on "Applied Method" has now been prepared under the chairman of TC-1.5, A.B. de Graaff³⁾.

The authors, first of all, review the characteristics and the roles in the CIE methods for computation of mean illuminance or reduced utilisation and flux density of the installed luminaires by the linear expression. They lead up to the numerical computation formulas for obtaining the RM and MR coefficients by using the basic expression of luminous transfer which describes the general interreflection systems in an idealized room.

It is the purpose of this paper to compare the computation process and its characteristics of the RM and MR coefficients obtained by the present studies with those of these coefficients based on the CIE methods approved by TC-1.5, and to point out the difference between the data of the RM and MR

coefficients prepared in the CIE methods and the numerical data calculated by the authors. Lastly, they discuss the effect on the final computation results for lighting designs from the standpoints such as room index, suspension ratio and effective reflectance of the ceiling cavity.

2. Concept of CIE methods

The CIE methods which contain both the "Basic Method" and the "Applied Method" can be used under the following conditions.

- (a) Room is a rectangular parallelepiped,
- (b) Working plane can be assumed to be practical surface in place of floor,
- (c) Room surfaces reflect uniformly and according to Lambert's law,
- (d) Direct flux on working plane does not vary owing to direction of installed luminaires.

Main computation procedures of the CIE methods are as follows.

(1) Cumulative zonal flux

FC1, FC2, FC3 and FC4 correspond to cumulative zonal fluxes for the four zones of total solid angle: $\pi/2$, π , $3\pi/2$, 2π , respectively, and F is the total flux of a luminaire.

(2) Direct flux on the working plane

The direct flux on the working plane emitted by a given luminaire or NM luminaires is calculated from the following expression by using "Geometric

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Multiplier" such as GM1, GM2, GM3 and GM4 prepared in the CIE methods. These GM coefficients depend on the position, mounting height and distribution curve of a luminaire.

$$F_{uj} = FC1 \cdot \sum_{i=1}^4 GM1_i + FC2 \cdot \sum_{i=1}^4 GM2_i + FC3 \cdot \sum_{i=1}^4 GM3_i + FC4 \cdot \sum_{i=1}^4 GM4_i \dots (1)$$

$$F4 = \sum_{j=1}^{NM} F_{uj}$$

where

$$\begin{cases} F_{uj}: & \text{direct flux on working plane emitted by a luminaire} \\ F4: & \text{direct flux on working plane emitted by total luminaires} \end{cases}$$

(3) Flux density of the installed luminaires

Installed luminaire flux per square metre floor area is defined as follows.

- Total flux density of the installed luminaires (NM)F/AB
- Downward flux density of the installed luminaires (NM)FC4/AB
- Flux density emitted directly by the installations to the working plane FA/AB

where

N, M : number of crosswise and lengthwise luminaires
 NM : number of total luminaires
 A, B : width and length of the room (working plane)
 AB : area of working plane

(4) Calculations of mean illuminance

The mean illuminance E_1 on the ceiling, E_3 on the walls and E_4 on the working plane are calculated by means of the linear functions of the flux density of the installed luminaires.

$$E_i = RM_{i1} \cdot (NM)F/AB + RM_{i2} \cdot (NM)FC4/AB + RM_{i3} \cdot F4/AB \dots (2) \quad (i=1, 3, 4)$$

where, RM_{ij} : RM coefficients

RM coefficients are called "Weighting Factors" or "Interreflection Factors", and these values are given in the Tables in the CIE methods.

(5) Calculations of flux density of installed luminaires

By carrying out the inverse transformation of Eq. (2) (NM)F/AB, (NM)FC4/AB and F4/AB are calculated by means of the following linear expression. For example:

$$(NM)F/AB = MR_{11} \cdot E_1 + MR_{13} \cdot E_3 + MR_{14} \cdot E_4 \dots (3)$$

where, MR_{ij} : MR coefficients

MR coefficients are given as well as RM coefficients

in the Tables in the CIE methods. The main characteristics of the CIE methods are to carry out interior lighting calculations by using the RM and MR coefficients. It should be noted that mean illuminance on the frieze: E_2 defined as those parts of vertical surfaces which lie between the ceiling and the plane of the luminaires is approximately equal to mean illuminance on the ceiling: E_1 .

3. Induction procedure of RM and MR coefficients

3.1 RM coefficients for suspension ratio: J=0

Fig. 1 shows the idealized room of a rectangular parallelepiped. The room surfaces contribute to interreflections of the radiation flux of installed luminaires. Total mean illuminance received by the surface: i is equal to the sum of the direct mean illuminance and indirect mean illuminance obtained by interreflections. The basic expression of luminous transfer which describes the general interreflection systems in an idealized room as shown in Fig. 1 is defined as follows.

Fig. 1 Cross section of room.

$$E_i = E_{0i} + \sum_{j=1}^n G_{ji} \cdot \rho_j \cdot E_j / S_i \dots (4)$$

($i=1, 2, 3, \dots, n$)

where, E_i, E_{0i} : total and direct mean illuminance

$G_{ji} = G_{ij}$: exchange coefficient between surface: i and j

ρ_j : reflectance of the surface: j

S_i : area of the surface: i

If the sum of flux on the ceiling and frieze is uniformly distributed over the surface: 1 and 2, and $E_1 \div E_2$ holds good, Eq. (4) is transformed by use of utilance as follows¹⁾ where $H_2=0$.

$$\begin{pmatrix} 1 & -K/2 \cdot (1-\alpha)\rho_3 & -\alpha\rho_4 \\ 1-\rho_1 & 1-\rho_3 & 1-\rho_4 \\ -\alpha\rho_1 & -K/2 \cdot (1-\alpha)\rho_3 & 1 \end{pmatrix} \begin{pmatrix} U_1 \\ U_3 \\ U_4 \end{pmatrix} = \begin{pmatrix} U_{01} \\ 1 \\ U_{04} \end{pmatrix} \dots (5)$$

where, Room index: $K = \frac{A \cdot B}{H_3(A+B)}$

Form factor: $\alpha = F_{1-4}$

Total and direct utilance: $U_i; U_{0i}$

$U_i = S_i \cdot E_i / (NM)F$; $U_{0i} = S_i \cdot E_{0i} / (NM)F$

We can easily solve the simultaneous linear equations of Eq. (5) by means of Cramer's formula. For example, after obtaining the total utilance: U_4 , it is possible to replace U_4 with $S_4 E_4 / (NM)F$, and to replace $U_{01} U_{04}$ with $[(NM)F - (NM)FC_4] / (NM)F$ and $F_4 / (NM)F$, respectively. Mean illuminance on the working plane: E_4 is transformed as the following linear expression which consists of three terms, and three RM coefficients are obtained from Eq. (6).

$$E_4 = \frac{1}{d} [\beta(1+\alpha\rho_1) + \alpha(1-\rho_3)\rho_1 - \beta(1-\rho_1)] \frac{(NM)F}{AB} - \frac{1}{d} [\alpha(1-\rho_3)\rho_1 - \beta(1-\rho_1)] \frac{(NM)FC_4}{AB} + \frac{1}{d} [1-\rho_3 + \beta(1-\rho_1)] \frac{F_4}{AB} \dots (6)$$

where, $\beta = K/2 \cdot (1-\alpha)\rho_3$

d : Determinant of coefficients relating to the left part of Eq. (5); $d \neq 0$

The linear expression for calculating mean illuminance on the ceiling and walls are obtained as well

Table 1 Formulas for computing RM coefficients where suspension ratio: $J=0$

SURFACE	RM _{i,j}	Coefficients for calculation of mean illuminance: E_i
CEILING	RM ₁₁	$-\frac{1}{d} [\beta(1+\alpha\rho_4) + 1 - \rho_3 + \beta(1-\rho_4)]$
	RM ₁₂	$-\frac{1}{d} [1 - \rho_3 + \beta(1-\rho_4)]$
	RM ₁₃	$-\frac{1}{d} [\alpha(1-\rho_3)\rho_4 - \beta(1-\rho_4)]$
WALLS	RM ₃₁	$-\frac{K}{2d} [1 - \alpha^2\rho_1\rho_4 - \alpha\rho_1(1-\rho_4) - (1-\rho_1)]$
	RM ₃₂	$-\frac{K}{2d} [\alpha\rho_1(1-\rho_4) + 1 - \rho_1]$
	RM ₃₃	$-\frac{K}{2d} [\alpha(1-\rho_1)\rho_4 + 1 - \rho_4]$
WORKING PLAN	RM ₄₁	$-\frac{1}{d} [\beta(1+\alpha\rho_1) + \alpha(1-\rho_3)\rho_1 - \beta(1-\rho_1)]$
	RM ₄₂	$-\frac{1}{d} [\alpha(1-\rho_3)\rho_1 - \beta(1-\rho_1)]$
	RM ₄₃	$-\frac{1}{d} [1 - \rho_3 + \beta(1-\rho_1)]$

$$d = (1-\rho_3)(1-\alpha^2\rho_1\rho_4) + \beta[\alpha(\rho_1 + \rho_4 - 2\rho_1\rho_4) + 2 - \rho_1 - \rho_4]$$

$$\alpha = \frac{2}{\pi xy} \left[\log e \sqrt{\frac{(1+x^2)(1+y^2)}{1+x^2+y^2}} + y \sqrt{1+x^2} \tan^{-1} \frac{y}{\sqrt{1+x^2}} + x \sqrt{1+y^2} \tan^{-1} \frac{x}{\sqrt{1+y^2}} - y \tan^{-1} y - x \tan^{-1} x \right], \begin{pmatrix} x = A_i/H_i \\ y = B_i/H_i \end{pmatrix}$$

$$\approx \sqrt{1+K^2} - K^{-1}$$

$$\beta = \frac{K}{2} (1-\alpha)\rho_3, \quad K = \frac{A \cdot B}{H_3(A+B)}$$

as Eq. (6). Table 1 shows the computation formulas for RM coefficients where suspension ratio: $J=0$.

3.2 RM coefficients for suspension ratio: $J \neq 0$

In the general lighting installation as shown in Fig. 1, it is noted that the value of mean illuminance contains error by directly applying the computation formulas for RM coefficients in Table 1. In case of suspension height: $H_2 \neq 0$, it is possible to calculate the effective reflectance of the luminaire plane: ρ_{eff} by applying the concept of ceiling cavity. We can approximately and simply calculate the RM coefficients of suspension ratio: $J \neq 0$ by replacing ceiling reflectance: ρ_1 with the effective reflectance: ρ_{eff} in Table 1.

The computation formulas for the effective reflectance have been already proposed by many investigators, and numerical difference of the effective reflectance is quite small as demonstrated in Fig. 2 regardless of various typical computation

Fig. 2 Effective reflectance for ceiling cavity.

formulas⁵⁾. The detailed computation process and discussion of the effective reflectance are omitted here.

3.3 MR coefficients

As MR coefficients are defined from the inverse transformation of the linear expression of Eq. (2), we can directly calculate these coefficients by using the value of RM coefficients or by applying the computation formulas in Table 1.

3.4 RM and MR coefficients based on CIE methods

The computation formulas based on the CIE methods are different from the method of the authors in terms of computation procedures. The computation methods obtaining the *RM* and *MR* coefficients are introduced in Appendix I of "Calculations for Interior Lighting-Basic Method-", and they are not a type of linear expression but a skillful style of matrix expression. The two cases of suspension ratio: $J=0$ and $J \neq 0$ in the above method may be distinguished. Generality of computation procedures of *MR* and *RM* coefficients are as follows in case of the suspension ratio: $J \neq 0$.

$$MR = \begin{pmatrix} 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \cdot \left(C - \frac{G \cdot R}{AB} \right) \cdot \begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \dots (7)$$

$$RM = MR^{-1} \dots (8)$$

where,

$$C = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2J/(1-J)K & 0 & 0 \\ 0 & 0 & 2/K & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix},$$

$$G = \begin{pmatrix} G_{11} & G_{12} & G_{13} & G_{14} \\ G_{21} & G_{22} & G_{23} & G_{24} \\ G_{31} & G_{32} & G_{33} & G_{34} \\ G_{41} & G_{42} & G_{43} & G_{44} \end{pmatrix}, \quad R = \begin{pmatrix} \rho_1 & 0 & 0 & 0 \\ 0 & \rho_2 & 0 & 0 \\ 0 & 0 & \rho_3 & 0 \\ 0 & 0 & 0 & \rho_4 \end{pmatrix}$$

The calculation of coefficients: G_i , and matrix are quite troublesome unless we can actively use the digital computer in Eq. (7) or Eq. (8). Note that both *MR* and *RM* of Eq. (7) and Eq. (8) are 3×3 matrix, respectively. It is not as simple as it looks in computations.

4. Roles of RM and MR coefficients

It is very popular among the existing methods to calculate the mean illuminance on the working plane by using the utilization factor which is supplied by the luminaire manufacturer. *RM* coefficients are used not only to predict the mean illuminance on the room surface but to calculate the reduced utilance reported by the CIE methods or the utilance on the working plane. Reduced utilance is defined as the ratio of the mean illuminance of surface i to the flux density of installed luminaires, and is obtained from the Eq. (2) by means of the next expression.

$$RU_i = \frac{E_i}{(NM) \cdot F / AB}$$

$$= RM_{i1} + RM_{i2} \cdot \frac{FC4}{F} + RM_{i3} \cdot \frac{F4}{(NM) \cdot F}$$

$$= RM_{i1} + [RM_{i2} + RM_{i3} \cdot DR] \times N4 \dots (9)$$

($i=1, 3, 4$)

where,

$$\text{Direct ratio: } DR = \frac{F4}{(NM) \cdot FC4}$$

$$\text{Lower flux ratio: } N4 = \frac{FC4}{F}$$

Moreover, utilization factors are obtained from the product of light output ratio of the luminaire and reduced utilance on the working plane: RU_4 .

$$UF = \text{Light output ratio} \times RU_4 \dots (10)$$

where

$$\text{Light output ratio: } \eta = \frac{\text{Flux from luminaire}}{\text{lamp flux}}$$

If one side of *MR* or *RM* coefficients is already known, the other side of these coefficients is directly obtained from Eq. (8) by means of inverse matrix.

5. Computation results of RM and MR coefficients

In case of the general lighting as shown in Fig. 1, we can easily calculate nine *RM* coefficients for computation of mean illuminance by directly using the computation formulas of Table 1 for suspension ratio: $J=0$, i.e. suspension height: $H_2=0$. As the computation results of these coefficients agree perfectly with the data of CIE methods or AFNOR

Fig. 3 Nine *RM* coefficients vs. room index.

“S40-001”⁶⁾, we may be sure that the computation procedures and the formulas for RM coefficients which the authors have introduced in above section 3 are correct and useful.

On the other hand, it is necessary to calculate the nine RM coefficients by replacing the ceiling reflectance: ρ_1 with the effective reflectance of ceiling cavity: ρ_{eff} in Table 1 for suspension ratio: $J \approx 0$, i.e. suspension height: $H_2 \approx 0$.

Fig. 3 shows the computation results for nine RM coefficients vs. room index. The data of CIE methods coincide with those of AFNOR “S40-001” except for the significant figure of the last unit. Three RM coefficients for the ceiling obtained by the authors differ from the data of CIE methods or AFNOR “S40-001” for the small room index. This is due to the introduction of concept of ceiling cavity. As RM_{33} and RM_{34} coefficient tend to increase rapidly in proportion to the increase of room index, only part of the curve is demonstrated, and the numerical results are compared with each

other in the lower part of Fig. 3.

Fig. 4 (a), (b), (c) are the computation results for nine RM coefficients vs. suspension ratio by keeping the room index and the surface reflectance constant. The change of surface reflectance more or less has influence on RM_{11} , RM_{31} and RM_{41} coefficients, and all the RM coefficients are proportional to suspension ratio. The computation formulas for RM coefficients consist of the sum of two or three terms as described in Table 1. RM_{11} , RM_{32} and RM_{43} coefficients always take the positive value, and RM_{12} and RM_{33} coefficients always take the negative value, because the determinant of Eq. (6) or delta of Table 1 is always positive.

Table 2 shows the results of comparison of the effective reflectance: ρ_{eff} , DELTA: Δ and RM coefficients by using the various computation formulas for obtaining the ρ_{eff} . Note that difference of ρ_{eff} is of no consequence for practical purposes.

Fig. 5 demonstrates the relation of three MR coefficients vs. room index for the same parameter

Fig. 4 Nine RM coefficients vs. suspension ratio.

Table 2 Comparison ρ_{eff} , DELTA, and RM Coefficients for Suspension Ratio: $J=1/3$

Room Index K		ρ_1	ρ_2	ρ_{eff}^*	ρ_3	ρ_4	DELTA Δ	CEILING			WALLS			WORKING PLANE		
								RM_{11}	RM_{12}	RM_{13}	RM_{31}	RM_{32}	RM_{33}	RM_{41}	RM_{42}	RM_{43}
1	(a)			0.600			0.562	1.199	-0.789	-0.189	0.351	0.511	-0.677	0.442	0.013	0.680
	(b)	0.8	0.7	0.610	0.7	0.3	0.560	1.203	-0.792	-0.189	0.358	0.507	-0.661	0.451	0.007	0.678
	(c)			0.607			0.560	1.202	-0.791	-0.189	0.356	0.508	-0.668	0.449	0.008	0.679
3	(a)			0.721			0.661	1.269	-0.751	-0.198	0.534	1.472	-1.727	0.770	-0.121	0.572
	(b)	0.8	0.7	0.728	0.7	0.3	0.659	1.272	-0.753	-0.198	0.540	1.468	-1.728	0.780	-0.127	0.571
	(c)			0.727			0.660	1.272	-0.753	-0.198	0.539	1.469	-1.728	0.778	-0.126	0.571
5	(a)			0.751			0.691	1.287	-0.740	-0.199	0.586	2.472	-2.754	0.870	-0.160	0.543
	(b)	0.8	0.7	0.755	0.7	0.3	0.690	1.289	-0.742	-0.199	0.591	2.470	-2.755	0.877	-0.164	0.542
	(c)			0.755			0.690	1.289	-0.742	-0.199	0.591	2.470	-2.755	0.877	-0.164	0.542

* Note: See reference (5) for the various computation formulas.

(a) Mastuura or I. E. S. (London), (b) Satone or O'Brien, (c) Spencer

Fig. 5 Three MR coefficients vs. room index.

in Fig. 3. Only MR_{11} , MR_{21} and MR_{31} coefficients differ between the data of authors and that of CIE method because of the introduction of ρ_{eff} as well as Fig. 3. But the other six coefficients agree with each other. Owing to the inverse transformation, values of the three RM coefficients have an effect on the three MR coefficients as shown in Fig. 5.

Fig. 6 demonstrates the RM coefficients for computing the utilisation on the working plane. The two

Fig. 6 Three RM coefficients vs. suspension ratio.

Fig. 7 Three MR coefficients vs. suspension ratio.

RM coefficients are proportional to suspension ratio except for RM_{42} coefficient in which room index is over 1.25.

Fig. 7 demonstrates the MR coefficients for computing the flux density for installed luminaire, and only MR_{14} coefficient is constant regardless of the reflectance, room index and suspension ratio.

6. Application to Practical Lighting Design

Let us consider the practical lighting design in order to explain the use of RM and MR coefficients for CIE methods. Fig. 8 shows the sketch of projected ceiling and across section of the room for general lighting. When the room is lighted by means of the luminaires with two lamps of 2000

Fig. 8 Sketch of general lighting installation.

Proximities: $PL=PC=0.9$ (m)

Spacings: $SL=SC=1.8$ (m)

$H_2=0.56$ (m), $H_3=1.69$ (m)

Numbers of total luminaire: $NM=15$

Suspension ratio: $J=0.25$

Room Index: $K=2$

(lm), and with CIE flux code such as 56, 83, 95, 100 and 64, it is possible to calculate the mean illuminance on each room surface by using the procedures of CIE methods as outlined in section 2. The reflectance of ceiling, frieze, walls and working plane are 0.7, 0.5, 0.5, 0.1, respectively. The total number of luminaire are 15 (unit), and the working plane is taken to be at 0.75 (m) above the floor.

Table 3 shows the results of comparison of mean

Table 3 Comparison of mean illuminance on room surface for general lighting, (See Fig. 8) Numbers of luminaire: $NM=15$; Flux of lamp: 2000×2 (lm) CIE flux code: 56, 83, 95, 100, 64

Method			Result obtained by authors			Result by using CIE data		
Parameter			$E_1(\text{lx})$	$E_3(\text{lx})$	$E_4(\text{lx})$	$E_1(\text{lx})$	$E_3(\text{lx})$	$E_4(\text{lx})$
K	J^*	ρ_i						
1.5	0	$\rho_1=0.7$	105	310	613	105	310	613
		$\rho_3=0.5$						
2	0	$\rho_4=0.1$	100	318	668	100	318	668
2	1/3	$\rho_1=0.7$						
		$\rho_2=0.5$	98	309	655	80	309	655
		$\rho_3=0.5$						
		$\rho_4=0.1$						
2	1/3	$\rho_1=0.8$						
		$\rho_2=0.8$	279	478	988	252	478	987
		$\rho_3=0.7$						
		$\rho_4=0.3$						

* Note: Numerical data of RM coefficients for ceiling differ between the results of authors and that of CIE in suspension ratio: $J=1/3$.

illuminance on each room surface, and the numerical influence of RM coefficients based on data obtained by the authors and data of CIE methods are very few except for mean illuminance on the ceiling. It should be noted that the direct flux on the working plane is calculated by using GM coefficients and Eq. (1), and the mean illuminance on each room surface is calculated by using RM coefficients and Eq. (2).

Table 4 is the comparison of results obtained by the various methods in order to discuss the extent of agreement between the various methods in case of the general lighting of Fig. 8. These data are obtained by using interpolation between the suspension ratio: $J=0$ and $J=1/3$. "Average of Basic

Table 4 Comparison of final results where room index: $K=2$ and suspension ratio: $J=0.25$

Various Methods	Ceiling $E_1(\text{lx})$	Walls $E_3(\text{lx})$	Working Plane $E_4(\text{lx})$
Result by authors	98	311	658
Result by CIE method	85	311	658
Average of Basic and applied method	87	309	661
British method	99	307	662
French method	82	310	658
German method	82	290	664

Note: Results of last four methods are based on Example. 3 of "CIE Applied Method".

and Applied method" corresponds to the value of arithmetic mean for three results: (1) Basic Method, (2) Applied Method (not using classification) and (3) Applied Method (using installation classification).

As the concept and computation procedure of British⁷⁾, French⁸⁾ and German Methods⁹⁾ are omitted here, the lighting engineers who take an interest in these computation methods should refer to the publications listed in the reference section of this paper.

7. Conclusion

The authors have discussed the role and characteristics of RM and MR coefficients by varying the parameters such as room index, suspension ratio and surface reflectance, and have come to the following conclusion by applying the data of these coefficients to practical lighting design.

(1) RM and MR coefficients for the suspension ratio: $J \neq 0$ can be obtained from the basic computation formulas and the concept of effective reflectance.

(2) RM and MR coefficients are generally proportional to the suspension ratio, provided that room index and surface reflectance are fixed.

(3) It is possible to estimate the value of RM or MR coefficients and the final results of mean illuminance or flux density by means of interpolation from the data based on both $J=0$ and $J=1/3$ within the practical lighting condition.

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