A Flattery Index for Artificial Illuminants

By Deane B. Judd

ARTIFICIAL illuminants are used for a large variety of purposes. Prominent among these are (1) to permit light-dark discrimination of objects (reading, performance of office work, assemblage of non-color-coded parts in manufacture), (2) critical examination of colored objects (as in color matching, inspection of goods being considered for purchase in a salesroom, application of makeup in the home or in a public rest room, or diagnosis of disease by a physician), and (3) appreciative viewing of colored objects (foliage in the home or garden, foods in the dining room or restaurant, or human complexion in the living room, office. or cocktail lounge).

The accepted way to appraise artificial illuminants for the first purpose (light-dark discrimination of objects) is to measure lumen output of the light source, or illuminance of the working plane for a lighting installation.

The recommended way, rapidly becoming accepted, to appraise artificial illuminants for the second purpose (critical examination of colored objects) is by general and special indices of color rendering.[1] These indices of color rendering permit evaluation of the degree to which the artificial illuminant imparts to objects their "true" colors. For illuminants of high color temperature, people regard the color rendered by daylight as the true color of an object; and for illuminants of low-color temperature, people regard the color rendered by incandescent lamp light as the true color. For critical examination of colored objects, the user of the artificial illuminant must choose one giving a sufficient approximation to the truth.

No way has yet been developed to appraise artificial illuminants to be used for appreciative viewing of colored objects. General lighting for the home, office, factory, restaurant, reception room, or ballroom, is not intended for critical appraisal of colored objects. If a lighting installation for these purposes flatters the people viewed there, makes everybody appear to glow with health, it will be preferred to one that is mercilessly revealing of the true state of health. Similarly, a lighting installation for the dining room or restaurant should be such as to make food appear as appetizing as possible. When the food has been placed on the table, the time has already passed for critical examination of the food colors to reveal inferior quality in grocery-store products, or minor errors in preparation. We like to maintain an optimistic viewpoint, even though this involves an element of pretense. We use cosmetics for this purpose, and nobody worries about the element of concealment and subterfuge involved. A lighting installation that promotes an optimistic viewpoint by flattery likewise performs a valuable service, so the purpose of this paper is to devise a way to evaluate the degree to which an artificial illuminant succeeds in flattering people and objects viewed under it.

Basis of the Flattery Index

The Subcommittee on Color Rendering of the IES Light Source Committee, on 29 August 1966, appointed a group to report on Guide Lines for Color Rendition Calculations. At a meeting of this group held at the Shoreham Hotel, Washington, D. C., on 12 October 1966 (Members: C. W. Jerome, Chairman, I. Meister, G. Pracejus, L. Thorington; Guests: C. L. Crouch, D. B. Judd, D. Nickerson, F. Studer) it was pointed out by Pracejus that the color-rendering index of a light source may correlate poorly with public preference of the source for general lighting purposes. He put in a plea for an "Application Index" based on preference studies that might supplement the color-rendering index. I remarked that the color-rendering index penalizes *any* departure from the true colors of objects produced by the light sources being appraised. If a light source of low-color-rendering index was preferred for general lighting to one of higher-color-rendering index, it must be true that some of the distortions were such as to flatter the object, and that these flattering distortions were preferred by the observers to the true

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colors. To test whesther this hypothesis is true, I offered to draw up a flattery index based on the work of Sanders[2] and Newhall[3] on colors preferred or remembered for various natural objects (complexions, foods, foliage). If the values of flattery index of light sources were to be found to correlate well with the results of preference studies of those light sources, the hypothesis would be established. Such a flattery index, like the color-rendering index, would be based solely on the spectral distribution of the source to be tested. It would have an advantage over an "Application Index" based on preference studies of the light sources themselves because values of it could be calculated by an automatic computer for a light source of any known spectral distribution without the need for any lengthy preference study.

The basis of the flattery index is similar to the color-rendering index except that the target colors will not be the true colors computed for the standard reference source, but instead will be the preferred colors of the test samples viewed under the standard reference source. Note that a flattery index based on this principle might have a higher value for a source different from the reference source than for the reference source itself. The lamp manufacturer thus may be able to develop an artificial source superior in flattery to daylight or to any of the conventional incandescent sources, and therefore capable of achieving greater public acceptance for appreciative viewing of selected colored objects.

The IES Group on Guide Lines for Color Rendition Calculations agreed that such a flattery index would be worth developing, and they individually expressed interest in trying it out.

Tentative Definition of Flattery Index

The general color-rendering index R_a, recommended by the CIE,[1] is defined by the formula:

$$R_a = 100 - 4.6\,\overline{\Delta E}_a \qquad (1)$$

where $\overline{\Delta E}_a$ is the arithmetical mean of the eight values $\Delta E_{a,i}$ of chromaticity difference for the eight test samples, to be calculated as follows:

$$\Delta E_{a,i} = 800\{[(u_{o,i} - u_o) - (u_{K,i} - u_K)]^2 + [(v_{o,i} - v_o) - (v_{K,i} - v_K)]^2\}^{1/2} \qquad (2)$$

where:

$u_{K,i}$, $v_{K,i}$ are the UCS-coordinates of any test samples (index i) under the lamp to be tested (index K).

$u_{o,i}$, $v_{o,i}$ are the UCS-coordinates of any test samples under the reference illuminant (index o).

u_K, v_K are the UCS-coordinates of thr lamp to tested (index K).

u_o, v_o are the UCS-coordinates of the reference illuminant (index o).

The UCS chromaticity coordinates[4] are related to chromaticity coordinates (x,y) and tristimulus values (X,Y,Z) in the standard coordinate system for colorimetry[5] as follows:

$$\begin{aligned} u &= 4x/(-2x + 12y + 3) \\ &= 4X/(X + 15Y + 3Z) \\ v &= 6y/(-2x + 12y + 3) \\ &= 6Y/(X + 15Y + 3Z) \end{aligned} \qquad (3)$$

It will be noted that if the test lamp K has the same spectral distribution as the reference illuminant o, then it will have the same chromaticity coordinates ($u_K = u_o$, $v_K = v_o$) and will yield the same chromaticity coordinates for each of the test samples i ($u_{K,i} = u_{o,i}$, $v_{K,i} = v_{o,i}$). Insertion of these values into Equation (2) shows that $\Delta E_{a,i} = 0$ for each test sample; so the average of the chromaticity differences for all eight test samples must likewise be zero ($\overline{\Delta E}_a = 0$). Substitution of this value into Equation (1) shows $R_a = 100$; that is, the general color-rendering index R_a is defined so that the reference illuminant is characterized by $R_a = 100$, and no other source can have a value of color-rendering index higher than 100. In other words, a value of 100 means perfectly true color rendering, and no source can render colors more than 100 per cent true.

It is proposed to define a flattery index R_f such that the reference illuminant is assigned a value of about 90. We can think of a hypothetical source that would render the test samples precisely as observers prefer to see them. Such a hypothetical source should be assigned the value of 100, but it is by no means certain, or even likely, that there exists a spectral distribution which would render all of the test colors precisely as observers prefer to see them. Observers' preferences are likely to be self-contradictory. For example, it is likely that observers would prefer to see the colors of nearly all of the test samples rendered so as to have somewhat higher saturations than those yielded by the reference illuminant, but if the test samples are large in number, not highly selective, and well-distributed in hue, this is not possible.

To assure that the flattery index R_f for the reference illuminant will have the value of 90, and that a test source yielding precisely the colors preferred for each of n test samples will yield a value of 100, the definition of R_f may be written:

$$R_f = 100 - 10(\overline{\Delta E_{f,K}})/(\overline{\Delta E_{f,o}}) \qquad (4)$$

where $\overline{\Delta E}_f$ is the weighted arithmetical mean of the n values $\Delta E_{f,i}$ of the chromaticity difference for the n test samples to be calculated as follows:

$$\Delta E_{f,i} = 800\{[(u_{o,i} + \Delta u_{f,i} - u_o) - (u_{K,i} - u_K)]^2 + [(v_{o,i} + \Delta v_{f,i} - v_o) - (v_{K,i} - v_K)]^2\}^{1/2} \quad (5)$$

where: $\Delta u_{f,i}$, $\Delta v_{f,i}$ are the chromaticity-coördinate increments that have to be added to the UCS-coordinates ($u_{o,i}$ $v_{o,i}$) of any test samples (index i) for the reference illuminant (index o) to produce the UCS-coordinates of the preferred color of the test sample; and the other symbols are as in Equation (2).

The chromaticity difference $\Delta E_{f,i}$ between the color rendered by the reference illuminant for a test sample and the preferred color for that sample is:

$$\Delta E_{f,i} = 800\ [(\Delta u_{f,i})^2 + (\Delta v_{f,i})^2]^{1/2} \quad (6)$$

and Equation (5) yields this expected result if u_K and $u_{K,i}$ are set, respectively, equal to u_o and $u_{o,i}$ and v_K and $v_{K,i}$ are set equal to v_o and $v_{o,i}$, respectively.

It is proposed to use 10 test samples in the computation of flattery index: samples 1 through 8 used in the general color-rendering index supplemented by samples 13 and 14 used for special color rendering indices. The reasons for this choice are to be explained in connection with evalaution of the preferred colors.

Evaluation of Preferred Colors

As stated by Buck and Froelich,[6] "there is one surface, the average human complexion, which presents itself under nearly every lighting installation and which consciously or unconsciously often becomes the criterion by which the job is evaluated." According to Sanders[2] the preferred color of the human complexion differs importantly from the average actual color by being redder and more saturated. Both the (x,y) and (u,v) chromaticity coordinates of the preferred color of the human complexion found by Sanders are given in Table I for CIE source C. Also shown in Table I are the coordinates computed from the curve reported by Buck and Froelich[6] for the average of 78 Caucasians. They also give the average spectral reflectance curves of eight women with and without cosmetics, and Table I also shows the chromaticity coordinates computed from these curves. The values of $\Delta u_{f,i}$ and $\Delta v_{f,i}$, where i refers to a representative of complexion color, indicated by combining Sanders' preferred color with the Buck and Froelich actual average color are +0.028 and +0.018. The values inferred from the Buck-Froelich measurements of eight women with and without cosmetics are +0.013 and +0.004. I have taken the average ($\Delta u_{f,13} = 0.020$, $\Delta v_{f,13} = 0.011$) to apply to sample 13 (Munsell notation 5YR 8/4) to define the preferred color of complexions and propose to give it 35 per cent of the total weight.

Next in importance are food colors. Buck and Froelich[6] state: "In lighting for homes, restaurants, stores, etc., the appearance of merchandise, of food, and of appointments may be equally as important as that of people." Sanders[2] determined preferred colors for tea, butter, and potato chips, but found that of these three only butter showed a significant discrepancy beween actual and preferred color. The chromaticity coordinates shown in Table I for butter indicate values of $\Delta u_{f,i}$ and $\Delta v_{f,i}$ equal to −0.007 and −0.010; that is, Sanders found that the preferred color for butter is less saturated than the ac-

Table I—Chromaticity coordinates (x, y) and (u, v) of actual colors of some natural objects compared to those of the preferred or remembered colors

Natural Object	Chromaticity Coordinates				Differences (Preferred or remembered minus actual)		
	x	y	u	v	Δu	Δv	$[(\Delta u)^2 + (\Delta v)^2]^{1/2}$
Average Caucasian complexion[6]	0.377	0.342	0.237	0.323	+ 0.028	+ 0.018	0.033
Preferred[2]	.441	.379	.265	.341			
Complexion (average of 8 women)							
No cosmetics[6]	.373	.341	.236	.322	+ 0.013	+ 0.004	.014
With cosmetics[6]	.395	.345	.249	.326			
Butter							
Actual[2]	.403	.415	.225	.347	− 0.007	− 0.001	.013
Preferred[2]	.375	.386	.218	.336			
Foliage[7]							
Actual	.325	.369	.192	.327	− 0.037	− 0.006	.037
Remembered	.266	.368	.155	.321			
Green grass							
Actual[7]	.346	.415	.190	.342			
Remembered[7]	.248	.415	.132	.333	− 0.058	− 0.009	.058
Remembered[3]	.305	.438	.160	.344	− 0'030	+ 0.002	.030

tual color but of closely the same hue. I propose to take sample 2 (Munsell notation 5Y 6/4) as representative of the color of butter, but for reasons to be explained later take $\Delta u_{f,2} = \Delta v_{f,2} = 0.000$, and give it 15 per cent of the total weight.

The only other natural object whose preferred color seems to differ from the actual is green foliage or grass. Newhall, Burnham and Clark[3] and Bartleson[7] indicate that the colors of foliage and green grass are remembered as considerably less yellowish and somewhat more saturated than they really are. Table I shows that if we take the remembered color as identical with the preferred color the values of $\Delta u_{f,i}$ and $\Delta v_{f,i}$ for foliage would be -0.037 and -0.006, and for green grass they would be -0.058 and -0.009, according to Bartleson, and -0.030 and $+0.002$ according to Newhall, Burnham and Clark. There is excellent agreement as to direction of the difference between the remembered and the actual colors of foliage and green grass, but it is hard to believe that these huge shifts would be preferred for chlorophyll-colored foods (lettuce, spinach, green peas). With rather less support than was found for the preferred colors of complexions and butter we take somewhat arbitrarily, $\Delta u_{f,14} = -0.020$, and $\Delta v_{f,14} = 0.000$, and apply these values to sample 14 (Munsell notation: 5GY 4/4) with 15 per cent of the total weight.

The remainder of the weight (35 per cent) is parceled out among the seven samples (Nos. 1 and 3 through 8) by assigning five per cent of the total to each. The preferred colors, except for samples 2 and 3, are based on the reports by Newhall, Burnham and Clark[3] and by Bartleson,[7] that memory colors are more saturated than original colors. Newhall et al state (p. 56) that "Significantly more purity . . . . (was) required to complete the color matches by memory than was necessary for the simultaneous matches." Bartleson states (p. 77), "There is evidence of increased saturation in the memory colors." Although no published proof has been found that the preferred colors are likewise more saturated than the originals, this seems to be a reasonable presumption. It is consistent with the proposal by Pracejus at the meeting on 12 October 1966 to evaluate the merit of a light source by the area on the CIE-UCS diagram enclosed by test colors Nos. 1 to 8 rather than by the average color distortion. Rather arbitrarily, therefore, we have introduced centrifugal shifts (maximum absolute value of $\Delta u_{f,i}$ or $\Delta v_{f,i}$ equal to 0.01). Such a shift for sample 1 cancels the centripetal shift indicated by the difference between preferred and actual butter colors, and justifies the values $\Delta u_{f,2} = \Delta v_{f,2} = 0.000$. For sample 3 (Munsell notation: 5GY 6/8), close to some chlorophyll-colored foods, the preferred color is taken not only as more saturated, but also somewhat less yellowish; so we have somewhat arbitrarily taken $\Delta u_{f,3} = -0.010$, and $\Delta v_{,f3} = +0.004$. Table II lists the test samples by number, i, gives the Munsell notations of them, the values of $\Delta u_{f,i}$, $\Delta v_{f,i}$, and $[(\Delta u_{f,i})^2 + (\Delta v_{f,i})^2]^{1/2}$. Fig. 1 shows on the 1960 CIE-UCS diagram, the chromaticity points (base of arrows) for the 10 test samples for CIE source D_{6500} and the adopted chromaticity points (heads of arrows) for the corresponding preferred colors.

The adopted values of $\Delta u_{f,i}$ and $\Delta v_{f,i}$ refer to natural overcast sky light and to artificial illuminants (such as CIE source C) intended to approximate it. To the extent that these adopted values are supported by experiment, they may also be taken for light sources of correlated color temperature greater than 3500°K. Some adjustment of them would probably be required for sources of lower correlated color temperature (such as incandescent lamp light and warm-white fluorescent light), but these adjustments should probably be postponed until the extent of correlation between the present tentative definition

Table II—Identification of the 10 test samples used in the definition of flattery index by Munsell notations, preliminary choice of chromaticity differences (Δu, Δv) and distance on (u, v)-diagram between their preferred and actual colors for D_{6500} as the light source, and weight (percentage of the total) used in taking the average to obtain $\overline{\Delta E_{f\cdot K}}$ for insertion in Eq. 4 defining a preliminary form for R_f', of flattery index (see Eq. 4a)

Test Sample	Munsell Notation	Chromaticity Differences Δu	Δv	$[\Delta u^2 + \Delta v^2]^{1/2}$	Weight Per Cent,
1	7.5R 6/4	+ 0.010	+ 0.004	0.011	5
2	5Y 6/4	0.000	0.000	0.000	15
3	5GY 6/8	— 0.010	+ 0.004	0.011	5
4	2.5G 6/6	— 0.010	+ 0.005	0.011	5
5	10BG 6/4	— 0.010	— 0.002	0.010	5
6	5PB 6/8	— 0.006	— 0.010	0.012	5
7	2.5P 6/8	+ 0.004	— 0.010	0.011	5
8	10P 6/8	+ 0.010	— 0.005	0.011	5
13	5YR 8/4	+ 0.020	+ 0.011	0.023	35
14	5GY 4/4	— 0.020	0.000	0.020	15
			Weighted Average	0.01490	

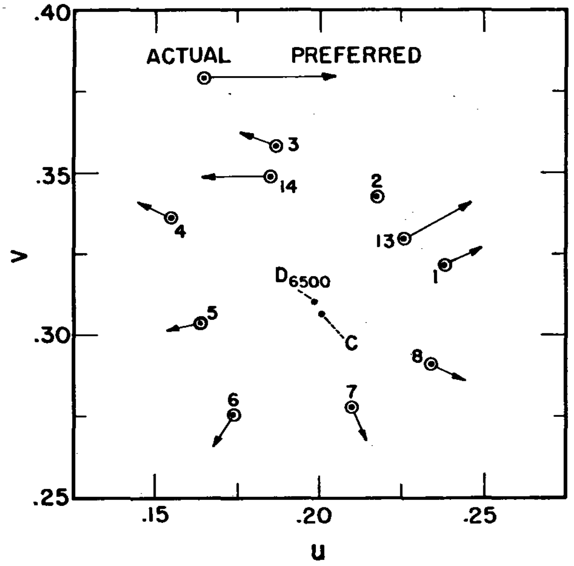

Figure 1. Chromaticities for the ten test samples for reference illuminant D_{6500} shown on the 1960 CIE-UCS diagram (bases of arrows). The chromaticities of these true colors of the test samples for the reference illuminant are compared with those tentatively adopted in Table II as corresponding to the preferred colors of those samples (heads of arrows).

of flattery index and preference studies for light sources above 3500°K has been determined.

Scaling of the Flattery Index

A preliminary definition of flattery index R'_f was based on the chromaticity differences between preferred and actual colors given in Table II from the summary of preferred and remembered colors given in Table I. It will be noted from Table II that the weighted average departure of the preferred colors from the actual colors of the 10 test samples is 0.01490. But, multiplied by 800 this is the value of $\overline{\Delta E_{f,o}}$ appearing in Equation (4) which may now be written simply as:

$$R'_f = 100 - 0.839\ \overline{\Delta E_{f,K}} \qquad (4a)$$

If the reference illuminant is taken as the test source, $\overline{\Delta E_{f,K}}$ would have the value $800 \times 0.01490 = 11.92$, and the value of R'_f becomes $100 - 0.839 \times 11.92 = 100 - 10 = 90$, as intended.

Jerome and Nickerson have criticized this preliminary definition (R'_f) of flattery index on the ground that the scale is compressed compared to that of the general color-rendering index R_a by about a factor of five, thus hindering comparisons between the color-rendering index of a light source and its flattery index. This scale compression can be seen by comparing the constant (4.6) in Equation (1) with that (0.839) in Equation (4a). What we need, they said, is a flattery index that evaluates the departures of the preferred colors in exactly the same way that the general color-rendering index evaluates the departures from the actual colors rendered by the standard. Then the values of the two indices (flattery and color-rendering) will be on the same scale so that direct comparison becomes possible. It is known, they said, that increasing the color-rendering of a standard cool white fluorescent lamp, for example, by preparing a deluxe version of it, also makes objects look better; and so the flattery index should be scaled to rise with the color-rendering index by a comparable amount.

To meet the criticism of Jerome and Nickerson, which seems to have considerable merit, requires that the flattery index R_f be defined with precisely the same constant (4.6) used for color-rendering index; that is, the formula has to be:

$$R_f = 100 - 4.6\ \overline{\Delta E_{f,K}} \qquad (4b)$$

If the flattery index of the standard is to be kept near 90, the values of the chromaticity differences between preferred and actual colors must be decreased by a factor of five. Table III shows these

Table III—Same as Table II except that the chromaticity differences applicable to the redefinition of flattery idnex R_f as in Eq. 4b are substituted for those applicable to the preliminary definition R_f'

Test Sample	Munsell Notation	Chromaticity Differences $u_{f,i}$	$v_{f,i}$	Vector Lengths	Weight
1	8.6R 6/4	0.0020	0.0008	0.0022	5
2	5Y 6/4	.0000	.0000	.0000	15
3	5GY 6/8	−.0020	.0008	.0022	5
4	2.5G 6/6	−.0020	.0010	.0022	5
5	10BG 6/4	−.0020	−.0004	.0020	5
6	5PB 6/8	−.0012	−.0020	.0023	5
7	2.5P 6/8	.0008	−.0020	.0022	5
8	10P 6/8	.0020	−.0010	.0022	5
13	5YR 8/4	.0040	.0022	.0046	35
14	5GY 4/4	−.0040	.0000	.0040	15

Table IV—Color-rendering indices (R_a) and flattery indices (R_f) for some artificial light sources of interest

Identification of source	Standard*	R_a	R_f
Super Examolite, Nickerson No. 26	R7500	90.6	86.9
Super DeLuxe Cool-White Nickerson No' 50	P4400	86.0	82.9
Fluorescent White " " 74	P3600	63.0	62.4
Standard Cool White " " 81	P4500	69.9	66.9
DeLuxe Cool White " " 86	P4200	85.2	82.6
Soft White " " 152	P3800	72.9	73.0
Color-Improved Mercury (Pracejus, 4/21/67)	P4100	49.9	48.1
DeLuxe-White Mercury (Pracejus, 4/21/67)	P3600	47.2	51.1
Multi-Vapor (Pracejus, 4/21/67)	P4800	67.3	70.2

* Correlated color temperature preceded by *R* for reconstituted daylight, or by *P* for Planckian.

revised values. The average vector length found with the same weights is, of course, one-fifth that shown in Table II: 0.01490/5 = 0.00298. For the standard source the value of flattery index by this revised definition would be: $R_f = 100 - 4.6 \times 800 \times 0.00298 = 89$, which is, as intended, near to 90.

Table IV shows color-rendering indices (R_a) and flattery indices (R_f) for some artificial light sources of interest.

Summary

A flattery index for light sources and lighting installations intended for the appreciative viewing of objects (complexions, foods, foliage) has been developed as a tentative measure of the degree to which the lighting installation produces the preferred colors of objects. It is modeled after the general color-rendering index; it uses 10 of the 14 test samples selected for testing color rendition; it uses the same method to determine the reference or standard illuminant; and it uses precisely the same scale. It gives complexion color about one-third of the total weight, food colors about one-third of the total weight, and the remaining weight is distributed equally among six test samples not representing complexion or foods. The differences between the preferred and actual colors on which this redefinition of flattery index is based are, however, only one-fifth of those indicated by the literature on preferred and remembered colors. These arbitrary choices of weights and preferred colors are, of course, subject to change. The selection of test samples is, itself, subject to change. Perhaps it would work just as well to use the same eight test samples by which the general color-rendering index is defined.

It is not expected that this redefinition of flattery index has yielded the most sound or most useful measure, and this redefinition is not recommended, in its present form, for immediate practical use. It is offered as a suggestion for consideration and possible study by those concerned with appraisal of the performance of light sources.

If the idea of a flattery index is found to be attractive to the present Subcommittee on Color Rendering, they might undertake to revise, adjust, and validate the present redefinition. In this way a form of flattery index, worthy of adoption for practical use, might be developed after several years of active work.

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Discussion of this paper, together with the author's reply, will be published in a subsequent issue of ILLUMINATING ENGINEERING.