JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, Vol. 2, No. 4, July 1973, p. 372.
4. Moys, B. A., "Behaviour of incandescent tungsten filaments during life," *GEC Journal of Science and Technology,* Vol. 40, No. 1, 1973, p. 17.
5. Comenetz, G., Johansen, H. A. and Salatka, J. W., "Hot spots caused by necks in a straight incandescent tungsten filament in gas," JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, Vol. 2, No. 4, July 1973, p. 366.
6. Dawson, C. W., Nelson, J. L., Radzelovage, W. F. and Sell, H. G., "Hot spots and their effect on the lives of incandescent lamp filaments," JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, Vol. 2, No. 4, July 1973, p. 381.
7. Harvey, F. J., "Failure of incandescent tungsten filaments by hot spot growth," JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, Vol. 3, No. 4, July 1974, p. 295.
8. Rabenau, A., "Chemistry of the incandescent lamp," *Angew. Chem. Intern.,* Vol. 6, No. 1, 1967, p. 68.
9. Schob, O., deBie, J. R. and Klomp, W. G. A., "The use of television equipment in research on incandescent lamps," *Lighting Research and Technology,* Vol. 5, No. 1, 1973, p. 29.
10. Hörster, H., *et al,* "A concept for the burning out mechanism . . . ." Discussion by Dawson, C. W. and Sell, H. G., p. 316.
11. Koo, R. C., Parascandola, L. J. and Shurgan, J., "Pressure effects of the fill gas on the filament life of an incandescent lamp," JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, Vol. 3, No. 4, July 1974, p. 317.
12. Harvey, F. J., "High temperature oxidation of tungsten wires in O_2-Ar Mixtures," *Met. Trans. of the AIME,* Vol. 4, June 1973, p. 1513.
13. Harvey, F. J., "High temperature oxidation of tungsten wires in CO_2-Ar mixtures," *Met. Trans. of the AIME,* Vol. 5, January 1974, p. 35.
14. Harvey, F. J., "High temperature oxidation of tungsten wires in water vapor mixtures," *Met. Trans. of the AIME,* Vol. 5, May 1974, p. 1189.
15. Fonda, G. R., "Evaporation characteristics of tungsten," *Phys. Rev.,* Vol. 21, 1923, p. 343.
16. Smithells, C. J., "Effect of impurities on recrystallization and grain growth," *J. Inst. Metals,* Vol. 27, 1922, p. 7.

IES TRANSACTION

A field evaluation of pavement luminance and glaremark

Merle E. Keck, FIES and Herbert A. Odle, FIES

In many parts of the world, particularly in Europe, street lighting performance is evaluated in terms of pavement luminance, and uniformity of pavement luminance. The authors report on the research being conducted to determine the accuracy and suitability of the latest techniques being used in Europe.

The evaluation of disability glare requires that an adaptation level be determined which is usually considered to be the pavement luminance. At its next triennial meeting, the *Commission Internationale de L'Éclairage* (CIE) will consider a method of evaluating discomfort glare, designated "Glaremark." For these reasons, the Research Subcommittee of the IES Roadway Lighting Committee initiated a project to determine the accuracy and suitability of the latest techniques being used in Europe to predict by calculation the following: average pavement luminance; pavement luminance at a point; disability veiling brightness; and discomfort glare (glaremark). Accuracy to be determined by taking physical measurements at the test installation, and in the case of discomfort glare to determine if a number of luminaire systems at the test installation ranked in the same order by the "glaremark" rating as they would be ranked by members of the Roadway Lighting Committee viewing them.

A paper presented at the Annual IES Conference, July 13–17, 1975, San Francisco, California. AUTHORS: Respectively, Westinghouse Electric Corporation, Cleveland, Ohio; Holophane, Division of Johns-Manville, Newark, Ohio.

Test installation

The installation used was in Philadelphia, Pennsylvania on Seventh Street between Packer and Pattison Avenues. At this location, a variable

Table I—System arrangement for calculations and/or field evaluations

System designation	Spacing (meters)	Pole arrangement	Lamp wattage	Lamp type	Calculated data	Field measurement	Observer rated
A	33.9	Opposite	400	H33 Phosphor	Yes	Yes	Yes
B	33.9	Opposite	1000	H33 Phosphor	Yes	No*	Yes
C	33.9	Opposite	250	H33 Phosphor	Yes	No*	Yes
D	67.8	Opposite	400	H33 Phosphor	Yes	Yes	Yes
E	33.9	Opposite	400	H33 Clear	Yes	No	Yes
F	33.9	Staggered	400	H33 Clear	Yes	No	Yes
G	33.9	Staggered	400	H33 Phosphor	Yes	Yes	No

* These can be calculated since the values will be directly proportional to lamp output. The same 400-watt lamps were operated in the same luminaires at 250, 400 and 1000 watts.

output installation has been installed for use by the Franklin Institute, and was placed at the committee's disposal by the Institute and the City of Philadelphia. The geometry of the test street is shown in Fig. 1. Each pole supports two luminaires, one of which is operated at a fixed wattage of 400 watts, and the other, a luminaire with a 400-watt mercury vapor lamp that may be operated at various wattages up to 1000 watts. There are certain switching limitations, and the systems that were selected for evaluation are shown in Table I.

Calculation procedure

The calculation of all parameters was done using a computer program supplied by Dr. Werner Adrian[1] of the University of Karlsruhe. The program is very flexible, and required the following inputs:

(1) Geometry of installation including number of traffic lanes.

(2) Observer location from left curb.

(3) Choice of road surface category or specific gonio-reflectance values for the roadway surface at designated angles.

(4) Luminaire distribution in candelas. Data may be values taken at the center of ten-degree squares, or modified to accept a lesser or greater number of data points.

(5) Choice of field, and the grid points thereon, for calculation or evaluation. The grid chosen is that recommended by Dr. Adrian (see Fig. 2).

(6) Projected area of luminaires at 76 degrees vertical.

The program then calculated the following:

(1) Pavement luminance at each grid point in candelas per square meter (cd/m^2).

(2) Summary of maximum, minimum, and average luminance over the entire grid and for each lane.

(3) Discomfort glare in both the G_{AS} and G_{AE} method as a glaremark rating.

(4) Luminous intensity at 80 and 88 degrees, and the ratio I_{80}/I_{88}.

(5) Disability veiling brightness (L_{seq}) for each luminaire, and the total for all luminaires within 15 degrees of the line of sight in cd/m^2.

(6) Threshold increment (SWE) in per cent. This is the percentage increase in luminance difference between the task and its background, needed to render it as visible with the veiling luminance present, as it would have been if no veiling luminance existed. The task is an eight-minute object (gap in a Landolt Ring), located 100 meters ahead of observer, and seen in silhouette.

(7) Horizontal illumination at each grid point in lux.

(8)Summary of maximum, minimum, and average horizontal illumination over the entire field.

So that data may be as accurate as possible, one luminaire of each type was removed from the installation, and photometered with the type of lamp to be used in the field tests. The fixed watt-

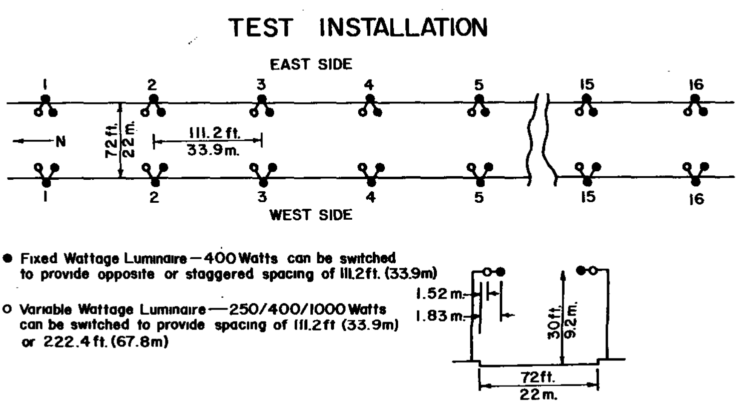


Figure 1. The Philadelphia Seventh Street test installation: a long viewing distance, flexible arrangement, and variable wattage from one luminaire are provided.

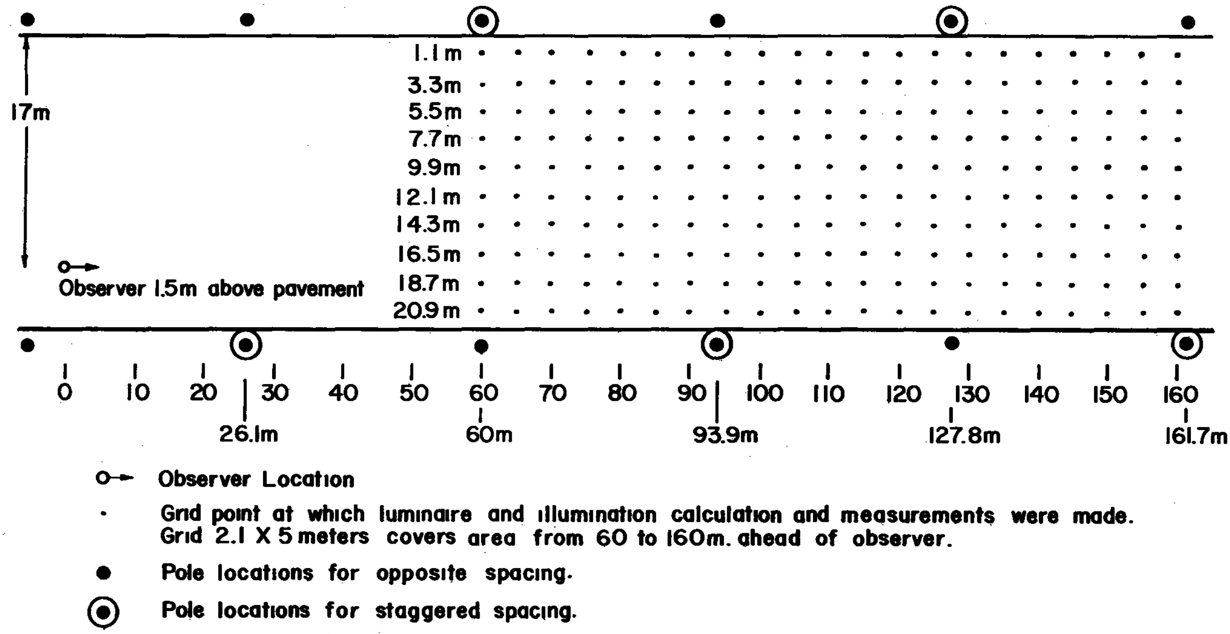


Figure 2. The field and grid under consideration by CIE for luminance evaluation and comfort evaluation. Observer location, field size, and grid points used for both calculation and measurement are shown.

age luminaire was photometered with both clear and phosphor coated lamps. Two pavement cores were removed from the pavement, shipped to the Philips' Laboratories at Eindhoven, and the pavement classification and reflection factor at the required angles were measured. Pavement classification[1,2] was k_p (mirror factor) = .4 and q_o (total reflectance) = .072.

Field measurement procedure

A team of three engineers spent two nights at the test site in September 1974 and recorded data for three of the systems (Systems A, D and G) (see Table I). At that time, all luminaires were equipped with phosphor coated mercury lamps (H33-GL/W). The data taken was:

(1) Pavement luminance at each grid point measured from the observer's location using a Pritchard telephotometer with six-minute aperature.

(2) System Disability Veiling Brightness (DVB) from the observer's location using a Pritchard photometer equipped with a Fry glare lens attachment.

(3) Horizontal illumination at each grid point.

The IES Roadway Lighting Committee visited the test site on the night of October 28 with no knowledge of the calculated results, and evaluated the comfort of each of six systems listed in Table I (Systems A through F), using a numerical scale similar to the glaremark ratings. This observation and rating was organized and directed by A. J. Birkhoff. Twenty eight members of the committee attended and rated the installation.

During the period between September 1974 and October 28, 1974, the lamps in the fixed wattage luminaire had been replaced with clear mercury lamps. Weather was clear, and the pavement was dry for all field measurements and evaluations. All meters and telephotometers were calibrated just prior to taking the measurements.

Calculated vs measured values

Horizontal illumination comparison. The relative accuracy to predict the horizontal illumination (lux) provides a good base line by which to judge the prediction of other values. The calculated and measured values for the three installations (A, D, and G) are shown in Table II. The average lux was predicted with an accuracy of between 9 and 13 per cent, and that of a single point with an accuracy of from 2 to 21 per cent. These accuracies seem consistent with prior experience in comparing calculated to measured values of horizontal illumination.

System DVB comparisons. The system DVB, referred to in the computer prediction program as L_{seq}, as calculated and measured is shown in Table III. The difference between calculated and measured values is from 9 to 22 per cent. It should be pointed out that the formula used in the program for calculation is:

$$L_{seq} = \frac{KE(\text{lux})}{\theta^2}$$

where $K = 9.2$, while the lens used for measurement is based on the formula:

$$DVB = \frac{10\,\pi\, E_{\cos}\theta}{\theta(1.5 + \theta)}$$

Table II—Horizontal illumination comparison

	Average lux			Minimum point lux			Maximum point lux		
System	Calculated	Measured	Difference (per cent)	Calculated	Measured	Difference (per cent)	Calculated	Measured	Difference (per cent)
A	16.8	18.7	10	8.8	7.3	17	28.1	35.8	21
D	8.7	9.6	9	1.4	1.2	14	26.5	30.6	13
G	7.8	9.0	13	2.2	2.1	2	23.7	25.6	7

where E = footcandles[3]. If the constant K of 9.2, used in the computer program were changed to 9.93, it would then be equivalent to the constant of 10 π used in the design of the measuring instrument lens. The difference between θ^2 and $\theta(1.5 + \theta)$ is very slight for large angles, but may be significant for small angles of distant luminaires. Another factor is that the computer program moves the observer until the first luminaire is 15 degrees from the line of sight, while the observations were made from a point (see Fig. 2) which places the first luminaire about 17 degrees from the line of sight.

Pavement luminance comparison. The calculated and measured values of pavement luminance for the average, minimum, and maximum luminance are shown in Table IV. The difference in average luminance is between 40 and 53 per cent, and the difference for a single point on the grid is between 12 and 62 per cent. Here, the program is:

Table III—Disability Veiling Brightness Comparison

	Disability veiling brightness (cd/m²)		
System	Calculated	Measured	Difference (per cent)
A	.309	.339	9
D	.222	.280	21
G	.159	.203	22

(1) used with standard reflectance tables; (2) for the pavement classified as $k_p = .4$, and with q_o of .072; and (3) with gonio-reflectance values contained in the computer program (L_c). The pavement luminance was recalculated using the exact values of reflectance (L_e) as measured by the laboratory in Eindhoven, and a substantially lower value of pavement luminance was found that increased the difference between calculated and measured values.

Figure 3. Plots of pavement luminance along the 1.1-meter transverse line, and the 14.3-meter line of Fig. 2 for System A.

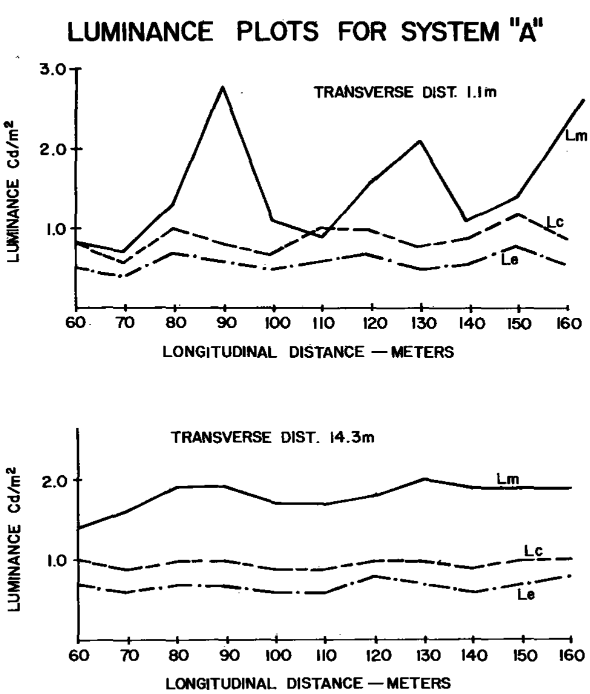
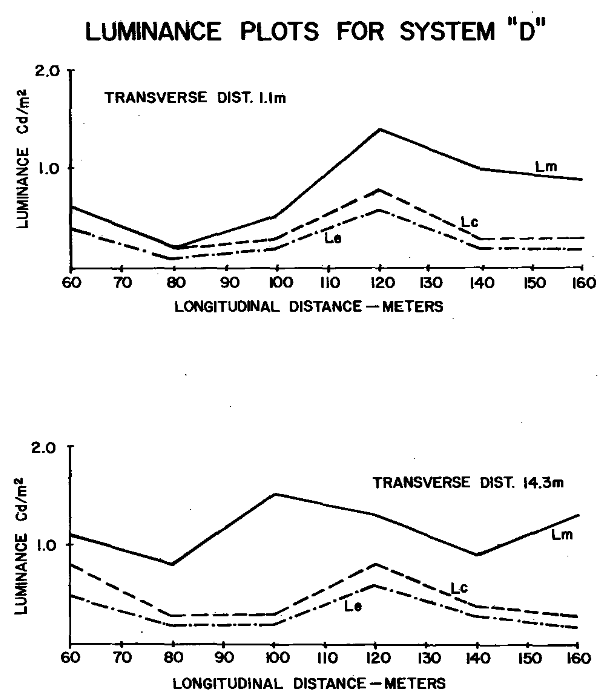


Figure 4. Plots of pavement luminance along the 1.1-meter transverse line and the 14.3-meter line of Fig. 2 for System D.



In Figs. 3, 4 and 5 curves of L_c, L_e, and measured luminance, L_m, are shown for two different transverse distances (longitudinal roadway lines) to illustrate that the difference is greatest on the longitudinal roadway line near the opposite curb. While no precise reasons for differences can be determined at this time, we wish to point out that the use of a six-minute aperature (the smallest available on the Pritchaad telephotometer used) results in the inclusion of a rather large area of pavement (and some nonpavement area) at some points on the grid. A plot of the elliptical area covered by a six-minute aperature for three points is shown in Fig. 6.

Discomfort glare evaluation comparison. Discomfort glare is a psychological factor that must be subjectively rated by each individual, and, by definition, does not affect visual acuity; hence, cannot be measured by visual discrimination techniques. The glaremark[1] system was developed in Europe to predict the subjective comfort rating of a representative group of people. The technique used was to have a large number of observers view a variety of street lighting installations, some in model form, others full scale, and derive an empirical formula using physical factors that will rate the systems in the same way that they were rated by the observers. This work has been underway for a number of years, and initially two somewhat different formulae were developed: one called G_{AE} as proposed by Adrian and Eberbach, and one called G_{AS} as proposed by Adrian and Schreuder. The computer program calculates both G_{AS} and G_{AE} and assigns a numerical value to the system with alternate numbers defined as to the meaning by an observer, as follows:

1—Unbearable
2—
3—Disturbing
4—
5—Just admissable
6—
7—Satisfactory
8—
9—Unnoticeable

The formulae are lengthy,[1] but the physical factors that can be measured or calculated are:

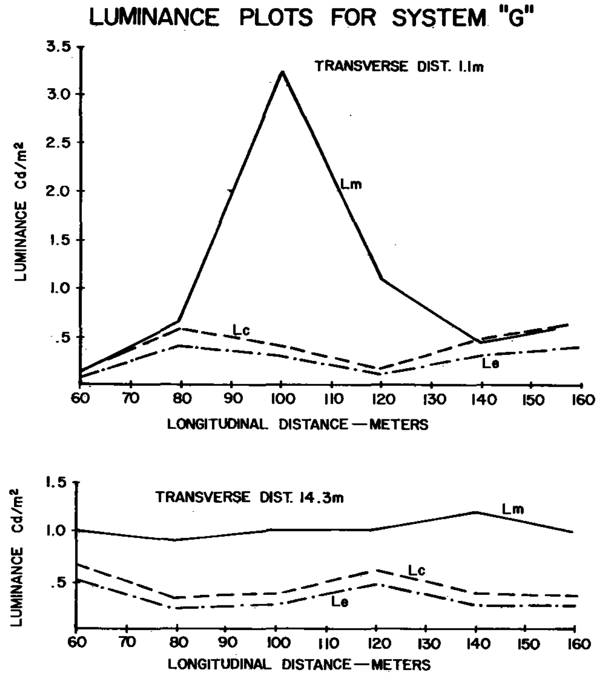


Figure 5. Plots of pavement luminance along the 1.1-meter transverse line and the 14.3-meter line of Fig. 2 for System G.

(1) Ratio of luminaire candlepower at 80 and 88 degrees vertical.
(2) Projected luminous area of the luminaires at an angle of 76 degrees.
(3) Average pavement luminance.
(4) Luminaire height above the observer.
(5) Number of luminaires per unit distance.
(6) Candlepower of luminaires at 80 degrees vertical.
(7) Constant for different light sources.
(8) Disability veiling brightness (DVB) produced by first 12 or 24 luminaires.

It is expected that the G_{AS} formula with elimination of the constant for different light sources, and possibly other minor differences from the formula used in the computer program, will be pre-

Table IV—Pavement luminance comparison

	Average luminance			Minimum point luminance			Maximum point luminance		
System	Calculated	Measured	Difference (per cent)	Calculated	Measured	Difference (per cent)	Calculated	Measured	Difference (per cent)
A–L_c	1.20	2.10	43	.63	.71	12	1.85	4.59	60
A–L_e	.83		60	.42		41	1.27		72
D–L_c	.61	1.22	50	.16	.24	34	1.39	3.20	57
D–L_e	.42		66	.11		53	.96		70
G–L_c	.54	1.15	53	.15	.17	14	1.22	3.23	62
G–L_e	.37		68	.10		40	.83		74

L_c values are calculated using the pavement category classification method.
L_e values are calculated using specific reflectance values as measured in the Eindhoven laboratory.

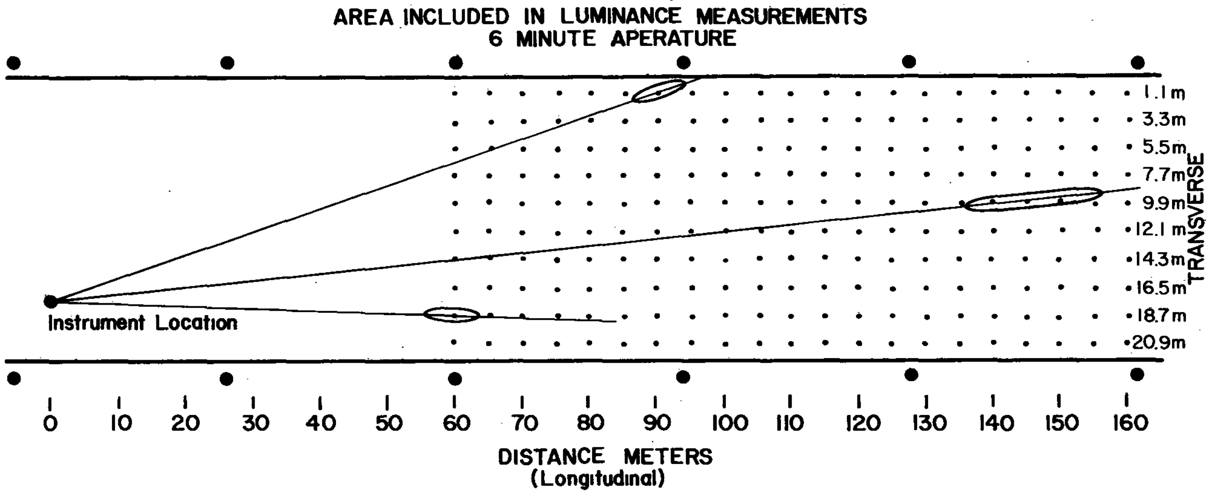


Figure 6. The area included in field luminance measurements using a telephotometer with a six minute aperature. The area is shown with the aperature centered on three typical points.

Table V—Discomfort glare evaluation comparison

Description	System Ranking Order		
	Observers	Calculation G_{AS}	Calculation G_{AE}
Most Comfortable	C	C (4.41)	F (6.09)
	A	F (4.17)	E (5.0)
	D	E (4.03)	D (4.31)
	F	D (3.95)	C (4.30)
	B	A (3.64)	A (3.80)
Least Comfortable	E	B (2.87)	B (3.21)

Numbers indicate the calculated rating on the glaremark 1 to 10 scale.

sented to the CIE for consideration.

The 28 members of the committee who observed and rated the six systems do not represent a typical cross section of our driving population, and all are very knowledgeable of street lighting. For these reasons, we do not believe it proper to disclose the numerical glaremark ratings that they gave to the systems. Mr. Birkhoff, who conducted this portion of the field evaluation, is continuing this work with one or more groups of naive observers. He will, undoubtedly, wish to report on this in greater detail in a separate paper; however, we feel that it is relevant to list and compare the ranking of the installations by the two calculation methods and by the observers. The observer ranking is a simple average of raw scores with no weighting procedure. The rankings are given in Table V.

From the comparison in Table V, there is both a difference in preference between the two calculation systems, and between the observers and either calculation system. The largest difference appears to be in the placement of the two clear mercury lamp systems, E and F, which were ranked near the top (most comfortable) by the calculation systems, and near the bottom by the observers.

We are not able to propose any definite cause for the difference in system ranking, but call attention to the considerable differences in luminaire light distributions that exist between the most commonly used luminaires in North America and the most commonly used luminaire light distributions in Europe. We can find no evidence that luminaire light distributions of the North American type were included in the observations used in developing the glaremark system.

It is not the purpose of this paper to reach any conclusions or recommendations as to the desirability of adopting any of the procedures discussed as part of the Roadway Lighting Practice. Our purpose is to report, as factually as possible, the work of the committee members who selected the most highly recommended calculation procedures available, and compared those calculated results with measured values using high quality commercially available instruments. However, we do feel that the following points should be expressed:

(1) The calculation and measurement of horizontal illumination agree much more closely than the calculation and measurement of pavement luminance.

(2) The results of using two methods of calculation of pavement luminance can be compared with each other, but there is no certain knowledge as to the more correct one.

(3) This is the first data, of which we are aware, that permits comparison of calculated vs measured DVB in a street lighting installation.

(4) Table VI summarizes the calculated data for all installations for ease of comparison between systems, and includes calculated data for the threshold increment. This is defined as the percentage increase in luminance difference between the task and its background, needed to render it as visible with the veiling luminance present, as it would have been if no veiling luminance existed. The formula used in the computer program can, under certain input situations, produce a negative

Table VI—Summary data for all systems evaluated as calculated by two methods

System	Luminaire description	Calc. method	L_{Avg}	L_{Max}	L_{Min}	G_{AS}	G_{AE}	L_{Seq}	Thres. incr.	E_{Avg}	E_{Max}	E_{Min}	Filed data	Observer rated
A 33.9 m Opposite	400-W phosphor mercury	Pave. catagory	1.20	1.85	.63	3.80	3.83	.309	17.3%	16.8	28.1	8.8	Yes	Yes
		Pave. values	.83	1.27	.42	3.64	3.61	.309	**					
B 33.9 m Opposite	1000-W phosphor mercury	Pave. catagory	2.99	4.62	1.57	2.87	3.21	.770	25.5%	41.9	70.2	22.0	No*	Yes
		Pave. values	2.06	3.17	1.05	2.71	2.98	.770	**					
C 33.9 m Opposite	250-W phosphor mercury	Pave. catagory	.66	1.01	.35	4.41	4.30	.169	14.7%	9.17	15.4	4.8	No*	Yes
		Pave. values	.45	.69	.23	4.25	4.08	.169	29.1%					
D 67.8 m Opposite	400-W phosphor mercury	Pave. catagory	.61	1.39	.16	3.95	4.31	.222	37.9%	8.71	26.5	1.37	Yes	Yes
		Pave. values	.42	.96	.11	3.79	4.08	.222	**					
E 33.9 m Opposite	400-W clear mercury	Pave. catagory	1.22	2.38	.46	4.03	5.00	.089	4.9%	18.6	38.2	6.3	No	Yes
		Pave. values	Data not run with actual pavement reflectances.											
F 33.9 m Staggered	400-W clear mercury	Pave. catagory	.61	1.57	.116	4.17	6.09	.042	4.1%	9.31	31.7	1.7	No	Yes
		Pave. values	Data not run with actual pavement reflectances.											
G 33.9 m Staggered	400-W phosphor mercury	Pave. catagory	.54	1.22	.15	4.35	4.53	.159	17.1%	7.81	23.7	2.2	Yes	No
		Pave. values	.37	.83	.10	4.20	4.31	.159	**					

L = Pavement luminance in candela per square meter.
L_{Seq} = Disability veiling brightness in candela per square meter.
Thres. incr. = Increase in contrast needed to render an eight minute test object equally visible.
E = Horizontal illumination in lux.
* Field data not taken but is proportional to System A data per lamp output difference.
** Data calculated by the computer not meaningful.

number which is meaningless.

(5) The results raise as many questions as they answer, particularly in regard to the reversal of rankings between the glaremark comfort rating system and the ratings of the observers.

References

1. Adrian, W. and Enzmann, J., *Calculation of Luminance and Glare in Roadway Lighting with the Aid of Electronic Computers,* University of Karlsrhue, Second Edition, 1971.
2. Verbeck, T. and Vermeulen, J., "Laboratory method for measuring luminaire factors of road surfaces," *Light and Lighting,* Illuminating Engineering Society of Great Britain, April/May, 1971.
3. Fry, G. A., Pritchard, B. S. and Blackwell, H. R., "Design and calibration of a disability glare lens," ILLUMINATING ENGINEERING, Vol. 58, No. 3, March 1963, p. 120.

DISCUSSION

A. KETVERTIS:* The perception of objects in night driving depends on several factors, and they are all important when the overall visual environment quality is assessed. These factors are: contrast, uniformity of pavement, control of stray light, time of exposure, and object size. Assuming that the object size would cause disturbances in the driving process (over six inches), and the exposure time is of the order of 0.2 seconds, the next most important factor in visual perception is the differences in luminous intensity between the object under observation and its background. Interference of direct light flux (glare) and the pavement uniformity are also important partners. Both of these factors are related to the state of eye adaptation and

* Director of Visual Environment, Foundation of Canada Engineering Corporation, Limited, Toronto, Canada.

the later also to contrast. At the present time, the method of lighting system calculations used on this continent does not include the assessment of pavement luminance or luminance uniformity. Glare is often superficially considered.

In the present method, the main attention is paid to the incident light density and the uniformity of distribution. Unfortunately, the incident light does not offer an approximate assessment of background luminance. This is vital in contrast calculation. In short, the photometric units calculated by the North American method are irrelevant to the seeing process. In view of the present energy situation, the IES has a special duty that can be summarized as follows: save energy without losing the effectiveness of visibility on our streets and highways. This objective can be fulfilled by applying two principles: (1) use of more efficient light sources; and (2) improvement in the methods of light application.

If the methods of calculation can be closely related to the visual process, tangible savings can be expected. For example, if we can effectively control disability glare and uniformity of pavement, an overall reduction of luminous intensity may be lowered without losing the effectiveness of visibility, and at the same time a reduction in energy requirements would be achieved. The authors presented a fine paper. The comparison of method discussed at this Conference should result in a better understanding of the problem and eventual improvements in our lighting design practices.

D. M. FINCH:* There seems to be a slight bias in the summary statements implying that the calculated values are not as reliable as the observed or measured data. In particular, the calculated or measured values of roadway luminance are reported to be at variance by 12 to 62 per cent. It is surprising that the point-by-point comparisons are within this range: detailed directional reflectance values of the pavements were not used; the light distributions were typical, but not the actual values of the luminaires used; the voltage at each light was not known, so the output was not adjusted for power input or temperature; and the photometer aperture was too large for the sight distances involved. With so many variables acting simultaneously, it would be expected that substantial differences would be found between measured and calculated values. This should not, however, deter further studies that are directed toward the use of luminance values in the field of view. Ultimately, the luminance concept will have to be used for the analysis and evaluation of visual scenes.

Like the authors, this discusser has no specific recommendations regarding the glaremark calculation procedure. The basic parameters in the algorithm used for the computer program are necessary and sufficient; however, the selection of values and the formulation of the relationships are open to question. It is obvious that the glaremark program needs more refinement. It does not begin to agree with the subjective evaluations obtained in Philadelphia, nor does it rank-order the systems in the same way, using the two different glaremark procedures for G_{AS} or G_{AE}.

J. M. VAN BOMMEL:† This paper is welcome because most of the comparisons between calculations and field measurements are published for North American luminaire distributions for the first time; however, the data should also be carefully judged. In this respect, it is worthwhile mentioning the results of similar tests carried out in Europe. They show much better relationship between measurements and calculations. Some of these tests were dynamic and the others were static. The dynamic tests were carried out on existing installations in different parts of Europe, using a mobile road lighting laboratory that was specially prepared for this purpose. The transverse distance of 1.1 meters should not be used in the comparisons as, especially at this distance, some nonpavement is included in the measurements because of the six-minute slide of the luminance meter. The conclusion from the remaining 14.3-meter transverse distance is that the calculated and measured luminance distributions all more-or-less follow the same course. As for the remaining approximately constant deviation, details of the luminaire light distribution measurements used in the computer calculations would be interesting, especially the intervals at which the values were taken, and an indication of the part of the road where the pavement core was taken.

Regarding the glaremark ratings, this discusser would like to know if the same projected areas of the luminaires were used before and after the replacement of the diffuse lamps by the clear lamps (system E and F). Here, the reversal of ranking order can be explained if, in the calculations, a projected area was too large for the clear lamp versions. In general, the value of the given data would be greater if the statistical deviations were also given.

G. A. ROMA and R. HELMS:‡ The European method for calculating roadway luminance is based upon the reflectance characteristics of the surface derived at an angle of observation of one degree. The use of a single viewing angle may be questioned. Inspection of data reported[1] reveals that in many cases the reflectance behavior of pavement surfaces may differ widely as the viewing angle changes. The work of Roma[2] shows the possibility of a roadway classification system more accurate than the European; however, this may not be enough reason to account for the large differences between calculated and actually measured luminance reported.

Another possible source of error may be due to the use of a single core sample in deriving the reflectance properties of the roadway inspected. Local differences in roadway surface reflectance are found very frequently; therefore, a statistically significant number of measurements, at different places of the surface inspected, should be made in order to obtain a representative set of reflectance values. The use of a single sample may be misleading.

Additionally, the computer program of Adrian and Enzmann provides two outputs for average luminance: one is based upon equal solid angle areas, and the other is the arithmetical mean of the grid. Which one of these results were used for comparison purposes? The six-minute aperture of the telephotometer seems to be too large for the point by point average. On the other hand, when the equal solid angle criterion is used, a trapezoidal aperture of the photometer, including in a single view the whole area inspected, appears to be the adequate procedure.

References

1. King, L. E., "Measurements of Directional Reflectance of Pavement Surfaces and Development of Computer Technique for Calculating Luminance" IERI project 87, Final Report, 1973, to be published.
2. Roma, G. A., "A Luminance Approach Toward a Roadway Surface Classification System," Master's Thesis, University of Colorado, Boulder, Colorado, 1975.

AUTHORS: We would like to thank Mr. Ketvirtis for his discussion on the importance of specifying roadway lighting by the luminance method, and on the fact that system glare should be considered carefully.

Concerning Professor Finch's comments, we sent actual core samples of the street to the Philips Eindhoven Laboratory. Table IV shows calculations based not only on the broad grouping R-table 3 as classified by the Eindhoven Laboratory, but also on the actual gonio-reflectance values as supplied to us by the laboratory from the actual core samples. Oddly enough the calculated values of luminance using R–table 3 come closer to the measured values than do the luminance values using the actual gonio–reflectance values.

Concerning the possible variables, we equipped each luminaire with a new reflector and sent one luminaire of each variety to a laboratory for photometric testing, but there could be minor variations from one luminaire to the next, angular mounting variations, and voltage variations from one luminaire to the next. Finally, we agree wholeheartedly that more investigative effort should be devoted to this project. Concerning Mr. van Bommel's comments, the European tests that show closer correlation is the kind of information the research committee needs, and we would appreciate any further information he can give us. We agree that the readings in lanes (1.1 meters in from

* Professor Emeritus, University of California, Berkeley, California.
† N. V. Philips' Gloeilampenfabrieken, Eindhoven, The Netherlands.
‡ University of Colorado, Boulder, Colorado.

either curb) should not have been considered because of the meter "seeing" curb or other things extraneous to the roadway surface. But even with these lanes discarded, there are still major variations in luminance values between calculated and measured. Concerning the projected area of the luminaire, since the enclosing globes were prismatic refractors, we assumed the same projected area whether the lamp was clear or coated; however, we consider this question very critical and one for further study as to whether it affects the ranking correlation by the observers.

Concerning Messrs. Helms and Roma's comments, it is certainly possible to question the one-degree angle; however, both the measurements and data for the calculations were taken at a one-degree observer angle. The program furnished by Dr. Adrian calculates average luminance for the Adrian and Enzmann equation by the arithmetic mean of the grid method.

A new metal halide ultraviolet curing source

P. J. Gardner, J. C. Morris

W. R. Watson, H. G. Silver and J. A. Scholz

Initial tests of a metal halide mercury lamp have been made on ultraviolet curable materials. The authors discuss the development of a simple model, and relate the iron partial pressure and the axis temperature of the discharge to the maintenance of the ultraviolet output of the lamp.

The use of ultraviolet light to photopolymerize organic coatings is now being utilized in a wide variety of applications. Applications range from coatings for particle boards used in furniture to locating of metal used for beverage cans.[1–3] Some of the major considerations in changing from a thermally polymerized coating to a photopolymerized coating are reduced operating costs for fuel for the drying process, and a reduction in the use of volatile organic solvents derived from oil. Thus, the change to ultraviolet cured coatings is economically attractive, and there are less environmental problems.

In certain ultraviolet curing applications, the problem of providing the required ultraviolet radiation in the space allocated can become critical. One solution is to consider a mercury lamp with a higher input power per unit length than the typical lamp at 200 watts per inch—possibly with loadings of 300 to 400 watts per inch. The problem of exhausting the heat generated by the lamp at these higher power levels becomes a problem. The efficiency of a medium pressure mercury ultraviolet source (that is, watts of ultraviolet power radiated per watt of input electrical power) can be increased by up to 20 per cent by altering the operating pressure, but at the expense of lamp life. In general, a medium pressure mercury lamp operating at 400 watts per inch will increase the ultraviolet output by a factor of 2.0 to 2.5 when compared to a 200-watt per inch lamp.

In the past, mercury lamps have been doped with metal halides to enhance specific and narrow regions in the ultraviolet and blue regions of the spectrum.[4,5] The typical additive would enhance a specific, rather narrow spectral region with a single strong line or several lines, but there was not a large number of spectral lines in the region of interest. One of the primary spectral regions for ultraviolet (UV) curing is near the 365- to 366-nanometer mercury line. The emphasis for our work has been centered on this spectral region.

Iron iodide UV curing lamp

The addition of iron iodide to a mercury discharge leads to a substantial increase in the ultraviolet output in the 350- to 400-nanometer region. This is obtained uniformly along the length of the lamp. One of the primary advantages of the use of iron iodide is that it has a much higher vapor pressure than the metal iodides commonly used in metal halide lamps. As a result, any nonuniformity that a lamp might have at turn-on is easily equilibrated along its length at the vapor pressures of iron iodide obtained in this lamp. Tests for the ul-

A paper presented at the Annual IES Conference, July 13–17, 1975, San Francisco, California. AUTHORS: GTE Sylvania, Inc., General Engineering Laboratories, Danvers, Massachusetts.