THE IMPACT OF C.I.E. 140 ON STREET LIGHTING IN SOUTH AFRICA

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SYNOPSIS

This paper briefly discusses the newly published revisions to SANS 10098-1: 1990:" Public Lighting Part 1: The lighting of public thoroughfares", and ARP035:2002:" Guidelines for the installation and maintenance of street lighting", wherein the street lighting calculation methods in the new C.I.E. 140:" Road lighting calculations" are embraced in favour of the now obsolete C.I.E. 30.2: "Calculation and measurement of luminance and illuminance in road lighting". The paper further takes a deeper look at the differences between C.I.E. 140 and C.I.E. 30.2 and what the practical implications will be on future street lighting installations. The paper also discusses the lighting software that will be required to carry out street lighting calculations in terms of the new calculation methods of C.I.E. 140.

Introduction

The street lighting calculation methods in SANS 10098-1 have all these years been based on the CIE 30.2 document that was published in 1982. This document was published shortly after the luminance concept was accepted as common practice, without much experience in this field during those days.
The calculation methods in CIE 140 bring about several improvements resulting from the experience that has been gained over the past 25 years in street lighting.
The SC 64C technical committee at the SABS have approved the proposed revisions to the SANS 10098-1 and ARP035 documents to incorporate the calculation methods of CIE140, and the amendments were published at the end of September 2007.

Scope of amendments

1) SANS 10098-1

- ✓ All references to CIE 30.2 have been replaced with CIE 140
- ✓ The reference to the computer programs listed in CIE 30.2 have been replaced with a reference to WINDOWS based commercially available computer programs which do calculations according to CIE 140
- ✓ All design methods are to be based on that of CIE 140
- ✓ All design criteria to be based on that of CIE 140
- ✓ The photo goniometer laboratory at the SABS will have to change their method of scanning the photometric distribution of street lights to comply with the recommendations of CIE 140

2) ARP035

- ✓ All references to the SABS 098 road lighting computer program have been replaced by references to WINDOWS based commercially available road lighting programs that can do calculations in terms of CIE 140
- ✓ The encrypted data files that were unique for use in the SABS 098 computer program only, have been replaced with other data files in a suitable format for the WINDWS based commercially available programs. The authenticity of these other data files can be verified by comparison to the source data from the SABS
- ✓ References to encrypted luminaire data files that are to be submitted with tenders, have been replaced with other electronic data files that have to be submitted together with the SABS source data in electronic format
- ✓ References to encrypted data files which are to be created from the intensity tables, have been replaced by other data files that are to be converted by the SABS/ luminaire supplier, from the source intensity tables

Major differences between CIE 140 and CIE 30.2

1.1. Road surfaces.

The laboratory measurement of the reflection properties of the road surfaces, which was fully dealt with in the CIE 30.2., has been omitted in the new CIE 140 document as it will be the subject of a separate publication to come, as will be field measurements.

1.2. Luminous intensity data for luminaires.

The coordinate system used for road lighting is generally the C, γ coordinate system (see Figure 1). Luminous intensity is expressed in candela per kilo lumen (cd/klm) for all the light sources in the luminaire.

Values of luminous intensities are required over the range of angles which are important. In particular, values are required up to the maximum angle of elevation which is relevant for the intended application of the luminaire, with allowance being made for the maximum angle of tilt of luminaire.

Angular intervals stipulated in CIE 140 have been selected to give acceptable levels of interpolation error when the recommended interpolation procedures are used, and to keep the time taken for photometric measurements within practical limits.

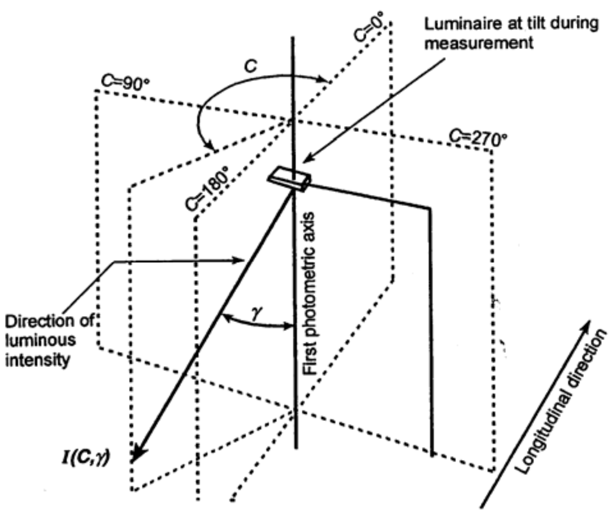

Figure 1 – C,γ coordinate system.

In the (C,γ) system of co-ordinates, luminous intensities will be required at the angular intervals stated below.

For all luminaires the angular intervals in elevation (γ) should at most be 2,5° from 0° to 90° plus the permissible maximum field angle of elevation minus the measurement angle of elevation, for the luminaire. In azimuth the intervals can be varied according to the symmetry of the light distribution from the luminaires as follows:

a) Luminaires with no symmetry about the C = 0°-180° plane : The intervals should at most be 5°, starting at 0°, when the luminaire is in its measurement angle of elevation and ending at 355° ;

b) Luminaires with nominal symmetry about the C = 90° - 270° plane : The intervals should at most be 5°, starting at 270°, when the luminaire is at its tilt during measurement, and ending at 90°

c) Luminaires with nominally the same light distribution in all C *planes: only one representative set of measurements in elevation needed.*

1.3. Interpolation of luminous intensity data.

Up to the present time, I-tables have usually been measured according the angular spacings recommended in the CIE publication 30.2 – 1982. These spacings are wider than those recommended above, and for these I-tables linear interpolation will not be satisfactory. **Quadratic interpolation** or an equivalent mathematical procedure is recommended.

<u>Linear interpolation.</u>

To estimate the intensity I(C,γ) it is necessary to interpolate between the four values of intensity lying closest to the direction (C,γ) as indicated in Fig. 2.

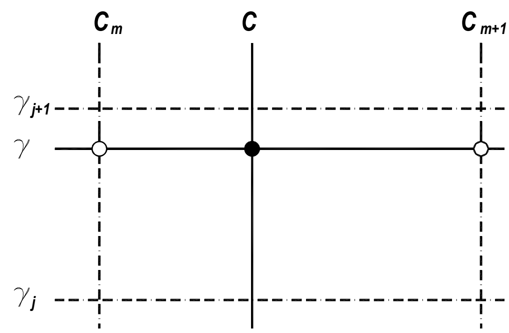

Figure 2 - Angles required for linear interpolation of luminous intensity.

<u>Quadratic interpolation</u>

Quadratic interpolation requires three values in the I-tables for each interpolated value. Figure 3 indicates the procedure.

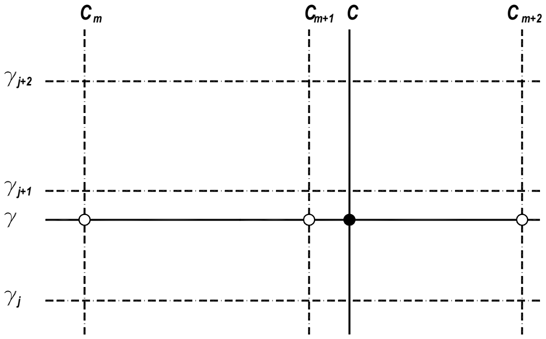

Figure 3 - Values required for quadratic interpolation

If a value of I is required at (C,γ), interpolation is first carried out down three adjacent columns of the I-table enclosing the point. This enables three values of I to be found at γ. Interpolation is then carried out across the table to find the required value at (C,γ). If preferred this procedure may be reversed, that is interpolation can be carried out across and then down the I-table without affecting the result.

1.4. Road surface reflection data.

Road surface reflection data are, conventionally, expressed in term of the reduced luminance coefficient multiplied by 10 000 (for convenience of presentation), at angular intervals and in directions indicated in Table 1.

Table 1 - Example r-table of reduced luminance coefficients (x 10^4 r)

	β (degrees)																			
tan γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0,00	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329
0,25	362	358	371	364	371	369	362	357	351	349	348	340	328	312	299	294	298	288	292	281
0,50	379	368	375	373	367	359	350	340	328	317	306	280	266	249	237	237	231	231	227	235
0,75	380	375	378	365	351	334	315	295	275	256	239	218	198	178	175	176	176	169	175	176
1,00	372	375	372	354	315	277	243	221	205	192	181	152	134	130	125	124	125	129	128	128
1,25	375	373	352	318	265	221	189	166	150	136	125	107	91	93	91	91	88	94	97	97
1,50	354	352	336	271	213	170	140	121	109	97	87	76	67	65	66	66	67	68	71	71
1,75	333	327	302	222	166	129	104	90	75	68	63	53	51	49	49	47	52	51	53	54
2,00	318	310	266	180	121	90	75	62	54	50	48	40	40	38	38	38	41	41	43	45
2,50	268	262	205	119	72	50	41	36	33	29	26	25	23	24	25	24	26	27	29	28
3,00	227	217	147	74	42	29	25	23	21	19	18	16	16	17	18	17	19	21	21	23
3,50	194	168	106	47	30	22	17	14	13	12	12	11	10	11	12	13	15	14	15	14
4,00	168	136	76	34	19	14	13	11	10	10	10	8	8	9	10	9	11	12	11	13
4,50	141	111	54	21	14	11	9	8	8	8	8	7	7	8	8	8	8	10	10	11
5,00	126	90	43	17	10	8	8	7	6	6	7	6	7	6	6	7	8	8	8	9
5,50	107	79	32	12	8	7	7	7	6	5										
6,00	94	65	26	10	7	6	6	6	5											
6,50	86	56	21	8	7	6	5	5												

7,00	78	50	17	7	5	5	5	5
7,50	70	41	14	7	4	3	4	
8,00	63	37	11	5	4	4	4	
8,50	60	37	10	5	4	4	4	
9,00	56	32	9	5	4	3		
9,50	53	28	9	4	4	4		
10,00	52	27	7	5	4	3		
10,50	45	23	7	4	3	3		
11,00	43	22	7	3	3	3		
11,50	44	22	7	3	3			
12,00	42	20	7	4	3			

The plan area covered by the data in the table is indicated in Fig. 4. in terms of the mounting height of the luminaire, and in relation to the position of the luminaire and the direction of the observer.

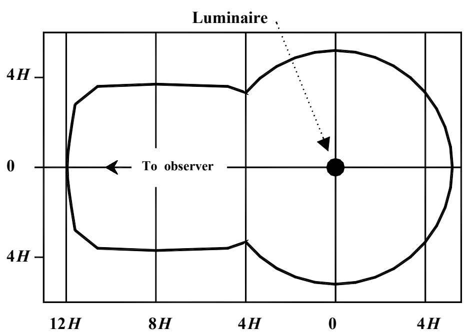

Figure 4 - Plan area covered by r tables

The reduced luminance coefficient varies according the angles indicated on Figure 5 here below:

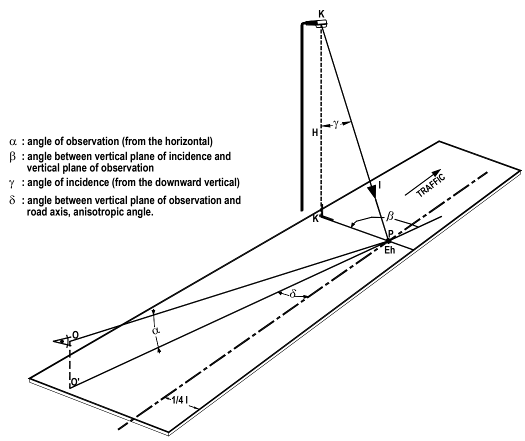

Figure 5 - Angular relationships for luminaire, observer and point of observation.

<u>Interpolation in the r-table.</u>

When a value of r is required for values of tanγ and β lying between those given in the r-table it is necessary to use **quadratic interpolation**, as recommended in CIE 140.

1.5. Calculation of luminance

1.5.1. Luminance at a point

The luminance at a point is determined by applying the following formula or a mathematically equivalent formula.

$$L = \sum \frac{I(C,\gamma)\cdot r \cdot \Phi \cdot MF \cdot 10^{-4}}{H^2}$$

Where :

L is the maintained luminance in cd/m² ;

Σ indicates the summation of the contributions

from all the luminaires

I (*C*,γ) is the luminous intensity in the direction (*C*,γ) , indicated in Figure 1 in cd/klm

r is the reduced luminance coefficient for a light ray incident with angular coordinates (*β*,γ)

Φ is the initial luminous flux in klm of the sources in each luminaire

MF is the product of the flux maintenance factor and the luminaire maintenance factor

H is the mounting height in m of the luminaires above the surface of the road.

I (C,γ) is determined from the luminaire *I*-table after corrections have been made for the orientation, tilt, and rotation of the luminaire and linear or quadratic interpolation, if necessary, applied. Likewise, *r* for the appropriate value of β and tan γ is determined after the use of quadratic interpolation, if necessary.

1.5.2. Field of calculation for luminance

The field of calculation should be typical of the area of the road which is of interest to the driver.

In the longitudinal direction on a straight road, the field of calculation should lie between two luminaires in the same row (Figure 6), the first luminaire being located 60m ahead of the observer.

In the transverse direction, it should cover the whole carriageway width on roads without a central reservation, and the width of one carriageway on roads with a central reservation.

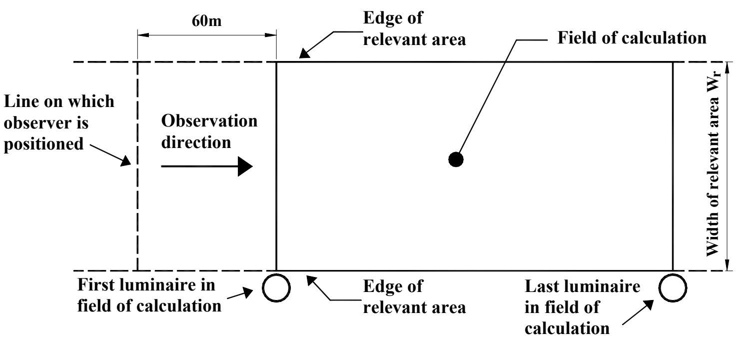

Figure 6 - Field of calculation for carriageway luminance.

1.5.3 Position of calculation points

CIE 30.2 required 5 longitudinal axes of calculation points per lane, whereas CIE 140 only requires three. The longitudinal distance between points in these axes is now less or equal to 3m whereas in CIE 30.2 it was 5m. The first transverse calculation axis was in front of the pole/ luminaire, but has now shifted longitudinally for half of the distance of the spacing between points.
The new calculation points should be evenly spaced in the field of calculation and located as indicated in Figure 7.

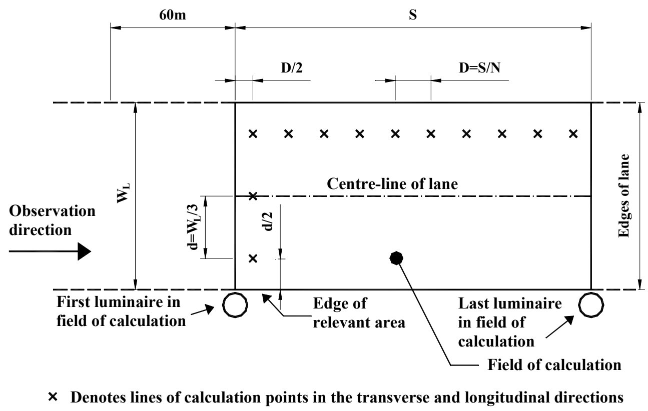

Figure 7 - Position of calculation points in a driving line

(a) In the longitudinal direction

The spacing (*D*) in the longitudinal direction is determined from the equation :

$$D = \frac{S}{N}$$

where :

D is the spacing between points in the longitudinal direction (m) ;
S is the spacing between luminaires in the same row (m) ;
N is the number of calculation points in the longitudinal direction chosen such that :

For $S \leq 30$m, N = 10
For $S > 30$m, N is the smallest integer giving $D \leq 3$ m.

The first transverse row of calculation points is spaced at a distance *D/2* beyond the first luminaire (remote from the observer).

(b) In the transverse direction

The spacing (*d*) in the transverse is determined from the equation :

$$d = \frac{W_L}{3}$$

where :

d is the spacing between points in the transverse direction (m) ;
W_L is the lane width (m).

The outermost calculation points are spaced *d/2* from the edges of the lane.

Where there is a hard shoulder and luminance information is required, the number and spacing of the calculation points should be the same as for a driving lane.

1.5.4. Position of observer

Previously the observer was ¼ of the carriageway width in from the kerb, for luminance, overall uniformity and longitudinal uniformity calculations.

Now the observer is located on the axis of each traffic lane, and for each position of the observer, the luminance is calculated over the whole width of the road. The relevant "operative" values of average luminance, overall uniformity and longitudinal uniformity are the minimum values calculated.
The angle of observation remains fixed at 1° below the horizontal direction.

In the transverse direction the observer is placed in the centre of each lane in turn. Average luminance (L_{av}) and overall uniformity of luminance (U_O) are calculated for the entire carriageway for each position of the observer. Longitudinal uniformity of luminance (U_L) is calculated for each centre-line. The operative value of L_{av}, U_O and U_L are the lowest in each case.

1.5.5. Number of luminaires included in calculation

For each calculation point, all the luminaires which make a significant contribution to the luminance should be included in the calculation. These luminaires lie in the plan area of the *r*-table (Table 1.), which approximates to a rectangle of dimensions 5*H* by 17*H*, and by its symmetry can be used to cover an area 10*H* by 17*H* (Fig. 4). As a consequence it is only necessary to consider luminaires which are situated within five times the mounting height from the calculation point towards the observer, 12 times the mounting height from the calculation point away from the observer, and 5 times the mounting height on either side of the calculation point. Figure 8 shows an example.

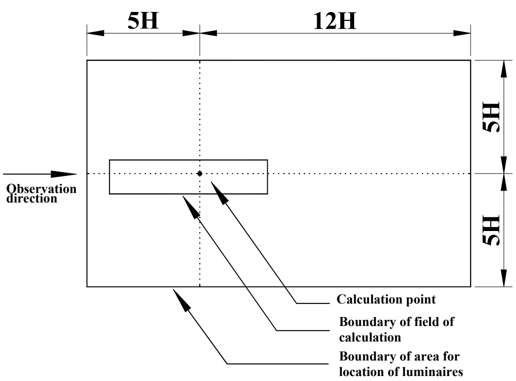

Fig.8 - Luminaires which may contribute to luminance at calculation point.

1.6. Horizontal illuminance

The horizontal illuminance at a point should be calculated from the following formula or a mathematically equivalent formula :

$$E_h = \sum \frac{I(C,\gamma) \cdot \cos^3 \gamma \cdot \Phi \cdot MF}{H^2}$$

where :

E_h is the maintained horizontal illuminance at the point in lux,
Σ indicates summation of the contributions from all the luminaires,
$I\,(C,\gamma)$ is the intensity in the cd/klm in the direction of the point,
γ is the angle of incidence of the light at the point ;
H is the mounting height in m of the luminaire ;
Φ is the initial luminous flux in klm of the lamp or lamps in the luminaire
MF is the product of the lamp flux maintenance factor and the luminaire maintenance factor.

1.6.1. Field of calculation

The field of calculation should be typical of area of the road which is of interest to the driver and pedestrian, and may include the footpaths, cycle tracks and verges. As shown in Figure 9 it should be bounded by the edges of the carriageway and by transverse lines through two consecutive luminaires.

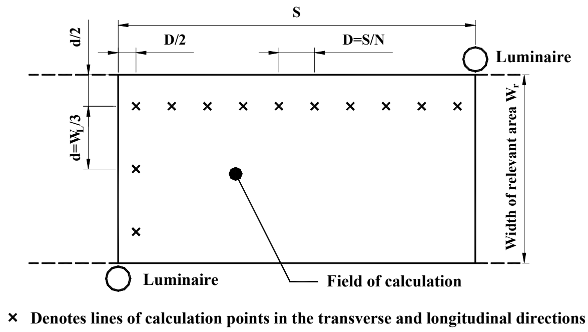

Figure 9 - Calculation points for illuminance

For staggered installations consecutive luminaires will be on opposite sides of the road.

1.6.2. Position of calculation points

The calculation points should be evenly spaced in the field of calculation (Fig.9) and their number should be chosen as follows :

(a) In the longitudinal direction

The spacing in the longitudinal direction should be determined from the equation :

$$D = \frac{S}{N}$$

where :

D is the spacing between points in the longitudinal direction (m) ;
S is the spacing between luminaires (m) ;
N is the number of calculation points in the longitudinal direction with the following values :
for $S \leq 30$ m, $N = 10$
for $S > 30$ m, the smallest integer giving $D \leq 3$ m.
The first row of calculation points is spaced at a distance *D/2* beyond the first luminaire (m).

(b) In the transverse direction

$$d = \frac{W_r}{3}$$

where :
d is the spacing between points in the transverse direction (m) ;
W_r is the width of the carriageway on relevant area (m).

The spacing of points from the edges of the relevant area is D/2 in the longitudinal direction, and d/2 in the transverse direction, as indicated in Figure 9.

1.6.3. Number of luminaires included in calculation

Luminaires which are situated within **five times the mounting height** from the calculation point should be included in calculation.

1.7. Calculation of quality characteristics

1.7.1. Average luminance L_{av}

The average luminance is calculated as the arithmetic mean of luminances obtained at the calculations points.

1.7.2. Overall uniformity U_o

The overall uniformity is calculated as the ratio of the lowest to the average luminance.

1.7.3. Longitudinal uniformity U_L

The longitudinal uniformity is calculated as the ratio of the lowest to the highest luminance in the longitudinal direction along the centre-line of each lane, including the hard shoulder in the case of motorways. The number of points in the longitudinal direction (N) and the spacing between them should be the same as those used for the calculation of average luminance.

The observer's position should be in line with the row of calculation points.

1.7.4. Threshold increment *TI*

CIE 30.2 had a static observer for the TI calculation. CIE 140 requires a mobile observer at a distance equal to the spacing of the luminaires by an increment which is equal to the spacing of the calculation point for luminance.
The threshold increment (*TI*) is calculated for the installation in its initial state, when it will have its highest value. It is calculated from the formula:

$$TI = \frac{k \cdot E_\theta}{L_{av}^{0,80} \cdot \theta^2} (\%)$$

where :
k is a constant which varies according to the age of the observer. It is conventionally taken as 650, which is applicable for an observer of 23 years. Its value for other ages can be derived from the formula :

$$k = 641 \cdot \left[1 + \left(\frac{A}{66,4} \right)^4 \right]$$

A is the age of the observer in years
E_θ is the total illuminance (in lux per 1000 **initial** lamp lumens) produced by **new** luminaires on a plane normal to the line of sight and at the height of the observer's eye. The observer's eye, height 1,5 m above road level, is positioned transversely $W_r/4$ from the carriageway edge and longitudinally at a distance in metres of 2,75 (H – 1.5), where *H* is the mounting height (in m), in front of the field of calculation. The line of sight is 1° below the horizontal and in a vertical plane in the longitudinal direction passing through the observer's eye.
L_{av} is the average **initial** luminance of the road surface;
θ is the angle in degrees of arc between the line of sight and the centre of each luminaire.

This equation is valid for $0,05 < L_{av} < 5$ cd/m² and $1,5° < \theta < 60°$ (CIE 31-1976).

E_θ is summed for the first luminaire in the direction of observation and luminaires beyond, up to a distance of 500 m.

The calculation is commenced with the observer in the initial position stated above and repeated with the observer moved forwards in increments which are the same in number and distance as are used for the longitudinal spacing of luminance points. The maximum value of TI found is the operative value.

1.7.5. Surround ratio *SR*

The obsolete CIE 30.2 did not consider illuminance on the verge of the road, whereas CIE 140 does by means of a "surround ratio".
The surround ratio is the average horizontal illuminance on two longitudinal strips each adjacent to the two edges of the carriageway and lying off the carriageway divided by the average horizontal illuminance on two longitudinal strips each adjacent to the two edges of the carriageway but lying on the carriageway. The width of all four strips shall be equal to 5 m, or half the width of carriageway, or the width of the unobstructed strip lying off the carriageway, whichever is the least. For dual carriageways, both carriageways together are treated as a single carriageway unless they are separated by more than 10 m.
The average illuminance on the strips on and adjacent to the carriageway should be determined by the same procedure, or mathematically equivalent procedure, as used for determining the average illuminance of the footpath.

PRACTICAL IMPLICATIONS

All the changes between CIE 30.2 and CIE 140 have an influence on the various solutions for street lighting installations.
It has been found that the spacing between poles to achieve the required lighting levels, generally have become shorter with the application of CIE 140. End users will now find that the spacing is 5-10% less than what was achieved with the old CIE 30.2 method, with the result that quantity and cost, will generally increase by 5-10% per kilometer of road illuminated.
For the uninformed, their first response may be that the implementation of CIE 140 is going to cost the tax payer more for new street lighting installations. However, we must never forget that the whole purpose of street lighting is to ensure that motorists can negotiate roads safely and comfortably and this can only happen when roads are properly illuminated. The whole purpose of CIE 140 is to utilize the experience gained over all these years so that the correct amount of illumination is applied on the road surface to indeed make it safer for motorists.

STREET LIGHTING SOFTWARE

The SABS in 1991-1992, commissioned a supplier to write a street lighting program which end users such as municipalities, and suppliers of lighting equipment could use to calculate the spacing between poles to achieve the required lighting level. This program, fondly referred to as the "SABS 098 program" is a DOS based program and the CIE standard street lighting program which appears as a FORTRAN computer code listing in the CIE 30.2 document, was used as the source code for this new program.
Although there is no reference to the SABS 098 program in SANS 10098-1, it has been the benchmark of street lighting designs with computer software, as it is referred to in ARP 035. Because of the revisions to ARP 035, this program will no longer be suitable to do street lighting calculations; hence all users will now have to switch to some type of commercial software to do calculations. There is a wide choice of such programs: RELUX, DIALUX, ULYSSE, AGI32, COPHOS, LIGHTING REALITY, to name but a few. The only proviso is that the software must be able to carry out calculations according to the CIE 140 method, and that the results produced by the program must have been tested by an independent authority to confirm that the calculations are accurate.

CONCLUSION

The method of doing calculations as per CIE 30.2 are now obsolete and have been superseded by the methods of CIE 140, which contributes to the assurance that the average luminance as observed by a motorist is correct and that the street lighting installation will promote safety and comfort.
Spacing between poles to achieve certain lighting levels will now generally be shorter with a corresponding increase in the per kilometer cost of street lighting.
The traditional software such as the SABS 098 program that has been used since 1992 to carry out street lighting calculations is now obsolete and will have to be replaced by commercial software which will do calculations as per the method in CIE 140.

REFERENCES

1. SANS 10098-1: *Public Lighting Part 1: The lighting of public thoroughfares*
2. ARP035: *Guidelines for the installation and maintenance of street lighting.*
3. R-TECH (SCHREDER): *Presentations on CIE 140*

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