

## **ILLUMINANCE MEASUREMENTS OF ROADWAYS**

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**Abstract:** The aim of this paper is to present the first initiatives of the photometric group at Inmetro to analyze and test measurement procedures of lighting performance of roadways. At present, the evaluation for the average illuminance follows the Brazilian standard ABNT-NBR-5101. The illuminance values measured in the field test are compared with calculated values, using the intensity distribution of the luminaires, which have been measured with a goniophotometer. Close agreement is found.

**Keywords:** average illuminance of roads, uniformity factor of illuminance, goniophotometry of luminaires

### **1. INTRODUCTION**

Nowadays, the Brazilian government has been investing in energy saving programs with a special focus in public lighting, with the goal, to turn more efficient about nine millions of lighting points all over the country. Although several cities have already taken steps to save energy of public lighting systems, by changing over from mercury to sodium vapor lamps, the total energy consumption still amounts to 3% of the total electrical energy consumed in the country. Trying to reach the target of 1,5% of more developed countries, cities may have to improve also quality and performance of the luminaires.

*Inmetro* has started close partnership with city administrations in evaluating the performance of lamps and luminaires for public lighting installations, offering goniophotometric testing. Furthermore, a suitable street lighting is of utmost importance for traffic security, pedestrian safety and environmental aspects. Therefore, the present work has the aim to determine and test a convenient method for measurement of illuminance of roadways, by following the

standard ABNT-NBR-5101, "Iluminação Pública" [1], and comparing results with those obtained by other types of grids.

### **2. OBJECTIVES**

The method for measuring the illuminance of roadways follows prescriptions according to the standard NBR-5101, section 7.2, with the aim for periodic checking. Although, being a straight forward procedure with only 9 test points, the method may suffer from the drawback that it doesn't necessarily yield trustworthy results. The NBR-5101 just points out that normally this procedure for determining the average illuminance has an uncertainty of about 10%, in comparison with a more elaborate procedure. In order to verify, whether or not, this is observed in practice, a detailed measurement with 153 test points has been performed. The results are analyzed with regard to evaluate average road illuminance and the factor of illuminance uniformity for a number of different grids, everyone with a decreasing number of test points.

A further aim of this work is, to find out, how close agreement is obtained for the measured illuminance values in the test field and those calculated from the intensity distribution tables of the luminaires, when these are measured with a goniophotometer.

### **3. METHODOLOGY AND RESULTS**

For the measurements a section of a two-lane street was chosen, located within the campus of Inmetro in the town of Duque de Caxias, Rio de Janeiro.

The section of the street chosen was delimited, lengthwise, by two unilateral light posts with a distance of 24,5m between

them and sidewise with 9,0m, as measured from curb to curb across the street. The luminaires were at 7,20 m mounting height, with an overhang of 0,75m to the street side, as measured from the curb to the vertical line passing through the optical center of the luminaire. The luminaires were cleaned and provided with new 250 W HID-Sodium lamps, which had been aged previously for 100 hours [ 2 ]. Both luminaires were fully characterized photometrically on the goniophotometer before reinstallation on the posts.

The test field was marked with points forming a rectangular array with 9 rows and 17 columns. Row spacing was 1,125m, including the points on the curb lines. Column spacing, in the longitudinal direction, was at every 1,531m, as shown in Fig.1. A generic point is identified as  $P_{ij}$ , with  $i = 1,2,3,...9$  and  $j = 1,2,3...17$ . The illuminance measured in the horizontal plane at any generic point, for simplicity, is denoted as  $E (ij)$ .

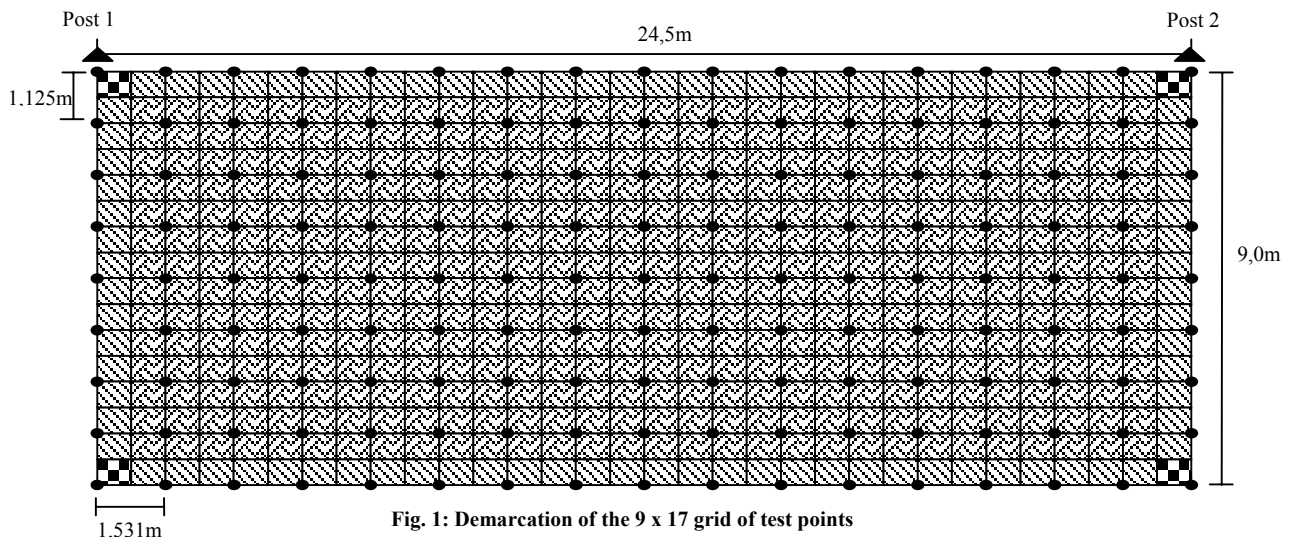


Fig. 1: Demarcation of the 9 x 17 grid of test points

The illuminance values were measured for all 153 points, using a calibrated digital illuminance meter [3]. All neighboring luminaires were switched off. The operating voltage was monitored periodically and found to be 226 V +/- 1 V. Background illuminance was 0,1lux.

Table 1 shows the average of the illuminance values of three successive measurements, already corrected for background subtraction and the readings of the illuminance meter according to its calibration curve. The uncertainty of the illuminance meter was 2% in the range of interest.

Table 1: Average values of illuminance at each point of the grid. Unit: lux (lx)

| $P_{ij}$ | 1     | 2     | 3      | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14     | 15     | 16     | 17     |
|----------|-------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|
| 1        | 44,30 | 48,19 | 42,22  | 60,42 | 27,74 | 30,24 | 20,55 | 27,42 | 25,07 | 23,82 | 25,84 | 20,29 | 33,97 | 41,67  | 40,90  | 52,75  | 58,11  |
| 2        | 57,34 | 62,09 | 63,95  | 80,36 | 57,91 | 31,33 | 28,54 | 37,63 | 30,05 | 30,08 | 32,49 | 23,47 | 35,86 | 66,07  | 58,27  | 73,29  | 75,99  |
| 3        | 81,22 | 83,69 | 87,16  | 86,87 | 89,41 | 35,86 | 46,33 | 46,45 | 41,45 | 36,02 | 43,60 | 33,20 | 53,61 | 102,06 | 94,00  | 121,06 | 114,03 |
| 4        | 99,42 | 95,32 | 102,28 | 88,45 | 91,69 | 48,93 | 50,88 | 49,34 | 47,61 | 48,70 | 54,32 | 48,86 | 76,50 | 119,55 | 117,21 | 141,96 | 128,35 |
| 5        | 92,55 | 85,43 | 88,35  | 81,93 | 89,92 | 60,39 | 42,70 | 47,29 | 48,25 | 56,15 | 58,17 | 52,75 | 86,45 | 108,22 | 98,62  | 113,04 | 95,67  |
| 6        | 67,32 | 63,98 | 68,48  | 61,06 | 71,91 | 59,13 | 36,41 | 42,31 | 40,68 | 51,98 | 51,14 | 44,82 | 77,75 | 84,69  | 68,48  | 70,18  | 54,93  |
| 7        | 40,23 | 40,68 | 46,49  | 42,38 | 50,34 | 45,46 | 30,60 | 31,20 | 31,53 | 39,90 | 39,62 | 36,25 | 59,62 | 59,49  | 41,83  | 39,55  | 30,50  |
| 8        | 24,53 | 26,16 | 29,38  | 32,52 | 35,57 | 37,11 | 25,81 | 22,12 | 26,71 | 27,55 | 25,94 | 25,84 | 39,13 | 38,94  | 26,84  | 22,63  | 18,78  |
| 9        | 18,52 | 19,87 | 22,63  | 25,84 | 24,46 | 28,93 | 19,62 | 16,31 | 21,64 | 17,14 | 15,92 | 19,04 | 26,58 | 27,03  | 19,81  | 16,18  | 14,16  |

The average illuminance,  $E_m$ , for the 9x17 grid is calculated by summing up the illuminance values measured at the observation points,  $P_{ij}$ , weighted by an area factor for which the illuminance at that point is considered constant. Thus, for the 9x17 grid of test points one obtains the following expression:

$$E_m = 1/512 \{ [E(11) + E(117) + E(91) + E(917)] + 2 \cdot [\sum E(i1) + \sum E(i17) + \sum E(1j) + \sum E(9j)] + 4[\sum E(kl)] \} \quad (1)$$

where for the summation signs the indices vary accordingly with  $i=2,3,...8$ ;  $j=2,3,...8$ ;  $k=2,3...8$  and  $l=2,3,4...16$

The number of rows and columns were chosen such that other grids with a reduced number of points can be constructed with points coinciding at the same location as those of the complete

grid. This way a 9x9, 4x8, 3x5, 3x3 and a 2x4 grid can be constructed.

For a 9x9 grid of test points one finds,

$$E_m = 1/256 \cdot \{ E(11)+E(17)+E(91)+E(917)+ 2[ \sum E(i1) + \sum E(i17) + \sum E(1j) + \sum E(9j) ] + 4[\sum E(kl)] \} \quad (2)$$

with  $i=2,3,...8$ ;  $j= 3.5.7...15$ ;  $k=2,3,4...8$  ,  $l=3,5,7...15$

for 4x8 grid of test points,

$$E_m = 1/32 \cdot \sum E(ij) , \text{ with } i = 2,4,6,8 \text{ and } j = 2, 4,.....16 \quad (3)$$

for the 3x5 grid of test points,

$$E_m = 1/32 \{E(11)+E(17)+E(19)+E(917)+2[E(15)+E(19)+E(113)+E(95)+E(51)+E(517)]+4[E(55)+E(59)+E(513)]\} \quad (4)$$

for the 3x4 grid of test points,

$$E_m = 1/16 \{E(13)+E(93)+E(17)+E(97)+E(111)+E(911)+E(115)+E(915)+2.[E(53)+E(57)+E(511)+E(515)]\} \quad (5)$$

for the 3x3 grid of test points,

$$E_m = 1/16 \{ E(11)+E(117)+E(91)+E(917)+2[E(51)+E(517)+E(19)+E(99)]+ 4 \cdot E(59)\} \quad (6)$$

and for the 2x4 grid of test points,

$$E_m = 1/8 \{ \Sigma E(3j) + \Sigma E(7j) \} \text{ with } j = 3, 7, 11, 15 \quad (7)$$

It is noteworthy that in both recommendations, IESNA RP-8-00 [4] and CIE-140 [5], the locations of test points are chosen such that the outermost test points are spaced by one half of their longitudinal and transverse spacing away from the border lines of the test area. This leads, consequently, to the nice feature, that the average illuminance is simply calculated by summing up all  $E(ij)$  and dividing the sum by the number of test points.

Table 2 shows the results of the different test grids.

**Table 2: Results of the different test grids**

| Grids         | $E_m$ lx     | U           |
|---------------|--------------|-------------|
| <b>9 x 17</b> | <b>52,04</b> | <b>0,27</b> |
| 9 x 9         | 53,87        | 0,26        |
| 4 x 8         | 54,88        | 0,40*       |
| 3 x 5         | 54,03        | 0,26*       |
| 3 x 4         | 48,95        | 0,33*       |
| 3 x 3         | 49,99        | 0,28*       |
| 2 x 4         | 53,70        | 0,57*       |

\*No trustworthy results

One should note, that a grid with a reduced number of test points is quite adequate for estimating the average illuminance, however, one cannot get any reliable information about the uniformity of the illuminance. In the present case the point of minimum illuminance, just did happen to be the point P (917) coinciding by accident with all of the grids with odd number of rows and columns, thus, giving accidentally good values for the uniformity factor.

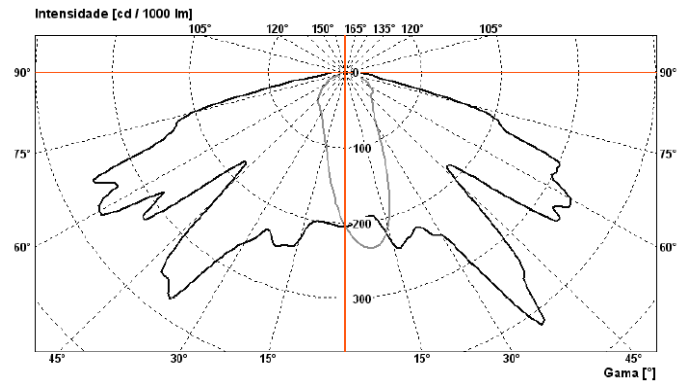
In order to avoid the cumbersome equations, the CIE or IESNA rule to define the test grid with the outermost test points displaced by half point spacing in the transverse and longitudinal directions should be adopted in a future revision of the ABNT standard. Then, even, a 2x4 grid with only 8 test points seems to be adequate for monitoring average illuminance. The factor of uniformity, however, requires always the much more elaborate method.

### 3.1. Intensity Distributions

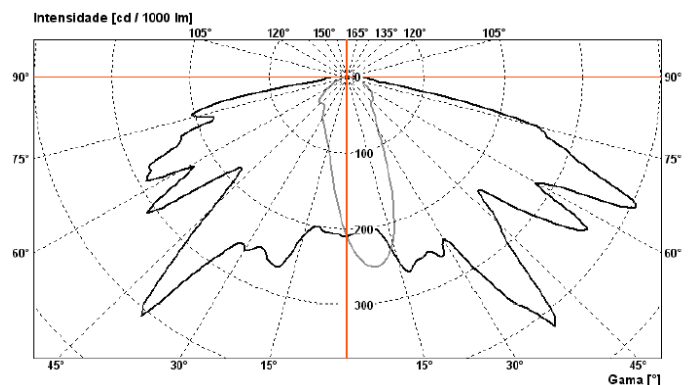
In context with the illuminance measurements, the question arises, how well do these data correlate with calculated values from photometric intensity distribution tables and from the known geometrical parameters of the luminaires in the particular installation of the test field.

For this purpose, both luminaires were characterized with a goniophotometer [6], according to CIE 121 recommendation [2]. The measurements were done in the C- $\gamma$  system of coordinates, with the C angle ranging from 0 to 350 degrees in steps of 10 degree and the  $\gamma$ -angle from 0 to 90 degrees in steps of one degree.

Although both luminaires were of the same kind, their polar intensity diagrams showed significant differences, both in shape and absolute values of intensity. Fig. 2 and 3 above show the polar intensity distributions of luminaires I and II, respectively, for the two principal planes.



**Fig.2: Polar intensity distribution of luminaire I**



**Fig.3: Polar intensity distribution of luminaire II**

The lengthy intensity distribution tables are not reproduced here. The data files can be generated by the software program of the goniophotometer in any of the usual file formats used with commercially available softwares for luminotechnical simulation.

For testing the photometric data the ab-initio method was followed by calculating the illuminances, according to the calculation as detailed in reference [4,5] for several test points, taking into account tilt angle, ( $19^{\circ}$  and  $15^{\circ}$  for luminaire I and II, respectively), mounting height (7.20m), post separation (24,50m) and overhang (0,75m) into the road.

The calculated values show a very good agreement with the measured values in the field. For example the test point P<sub>9, 12</sub> the measured illuminance was 19,04 lx. For Luminaire I and II, the calculated values are 9,25 lx and 8,62 lx, respectively, summing up to 17,87 lx., in close agreement with the field measurements. Other test points show similar agreement with less than 10% percent difference.

#### 4. CONCLUSIONS

The average illuminance of roads can be inferred with a rather restricted number of points. This statement made in the ABNT-NBR 5101, that with a number of nine test points, is confirmed by measurements presented here, the estimation might accurate within 10%. However, the location of the test points should be changed, to the configuration adopted by IESNA or CIE as shown above. Low number of test points, however, cannot give more information, such as the factor of illuminance uniformity, requiring at least 81 test points for a two lane road.

Furthermore, it was found that photometric characterization of a luminaire with a goniophotometer gives detailed information, which provides for reliable predictions through calculations. A future extension of this work presented here will consider the computer simulations with commercially available softwares and compare these with the measured values in the test field.

#### 5. ACKNOWLEDGMENTS

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