Performance analysis of Light Emitting Diode, High Sodium Pressure and Metal Halide Lights

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Abstract. Light Emitting Diode (LED) lamps have been widely applied to street lighting in every country, but not a few still using conventional lamps like High Pressure Sodium (HPS) and Metal Halide (MH). This research presents the results of evaluating efficiency and photometric performance from street lighting lamps. The level of illumination and uniformity ratio will be calculated to make a quantitative comparison between LED lights and conventional lamps according to Indonesian National Standards. Research carried out on three different Street Lightings in Bandung with three different lights specification. Conditions in the field will be simulated using DIALux software. The results of this research are obtained that LED lamp is the most effective and efficient type of lamps compared with conventional lamps. This Research will be useful for the Public Works Agency in making decision on the selection of the new lamps technology for street lighting, determining the type of lamp should depends on needs and light quality.

1. Introduction
Street lighting is an important part of the city’s infrastructure, which serves to illuminate city streets at night so that objects can be seen more clearly [1]. Street lighting planning has many considerations one of them as security at night for pedestrians from crime, so it can reduce crime rates at night [2]. Research shows that crime in five cities in the UK has reduced to 38% after street lighting repaired [3]. One of the main challenges now is improving the street lighting system, where street lights must be efficient in energy use and have a good uniformity ratio [4].

Currently the most widely used types of lighting are High Pressure Sodium lamps, Metal Halide lamps, and Light Emitting Diode (LED). By replacing the 250W High Pressure Sodium (HPS) lamp with 110W LED lights can save energy up to 63% [5]. Then the type of lamp used will affect electrical energy requirements [6]. The choice of lamp type must be considered, most of the lighting sources used in public street lighting are High Pressure Sodium lamps, but light emitting diode (LED) lamps are prepared as a more energy efficient alternative [7].

Previous studies on the performance of Street lights serve to analyse and enrich the discussion of research, as well as to differentiate from the research being conducted. As in the journal entitled Field Evaluation of Selected Light Sources for Roadway Lighting which compares the performance of HPS type lights with new technology lamps such as LED lights, induction lamps and plasma lights. The research was conducted in different zones, the factors to be examined were the lighting quality from the
minimum lux to the maximum lux produced and the uniformity of the lighting of these lights with regard to lighting standards [8].

Analysis of the performance of the type of lamp that has been selected for street lighting to find out the advantages and disadvantages of the types of lamps, and will get the most efficient lamps. The parameters used in the study are: street luminance uniformity, Street illuminance level, Street lighting class, Trishold Increment. The results of this study are expected to be useful for the Department of Public Works, in choosing the type of lamp that is appropriate for the light needs, and also useful for the lighting manufacturing industry to improve the design of lighting models according to the needs of the Street Lights.

2. Research methods
Photometric lighting performance and uniformity ratio will be calculated to obtain a quantitative comparison between the types of lamps that are mostly installed in street lighting systems with LED, HPS, and MH lamps.

The first step is to take the road profile of the area to be studied. DIALux software requires road profiles including road width, sidewalk width, bicycle track width, road median width, number of lanes, and road surface, then determines the conditions around the research area such as vehicle speed, determines the main road user, road surface conditions, level crime, and the condition of the streets. The third step is to display the initial information on the lighting class in the research area, the lighting class is set on SNI: 7391: 2008, the regulation can be adjusted.

Analyze performance in a predetermined area with different types of lights. then the data will be analyzed with the research parameters then compared to each type of lamp analyzed, after comparing all types of lights analyzed with regulations that have been determined using DIALux software, the results will be displayed whether the street lights analyzed meet the Indonesian National Standards (SNI): 7391: 2008, the last step is taking data from the performance analysis comparison obtained from the field, this information is needed to report the detailed results of lamp performance analysis to the relevant agencies and consumers, or as a reference for further research. So the research was declared complete.

2.1. Research objects
The research area was in Bandung which was located at coordinates 107 ° East and 6 ° 55 'LS, the road used as the research was Sindang Sirna road, Cipedes Atas road, and Kebon Kawung road and each of these roads used different lights to be studied namely using HPS lights, Metal halide, and LEDs.

![Figure 1. Research area.](image)
Profile of Sindang Sirna, Kebon Kawung, and Cipedes Atas street obtained from the Bandung City Public Works Office and from measurements in the field.

**Table 1. Research profile area.**

| Street Name          | Site 1       | Site 2       | Site 3       |
|----------------------|--------------|--------------|--------------|
| Types of street      | lokal sekunder | kolektor primer | lokal sekunder |
| SNI regulation       | 2 - 5 lux    | 3-7 lux      | 2-5 lux      |
| Length               | 615 meter    | 639 meter    | 920 meter    |
| Width                | 6.1 meter    | 11 meter     | 7.8 meter    |
| Width of right sidewalk | 2.63 meter | 1.95 meter   | 1 meter      |
| Width of left sidewalk | 2.58 meter | 2.07 meter   | 0.8 meter    |
| Traffic system       | two direction| one direction| one direction|
| Traffic lane         | one lane     | three lane   | one lane     |

2.2. Data retrieval techniques

The primary data collection technique in this study is to take data directly in the field on the roads that have been determined with different types of lights, measurements are carried out from 6 pm to completion, at 6 to 9 pm the results of the lux obtained are not constant because there is still a lot of external light from the vehicle lights, the measurement starts effectively at 10 o’clock until it is finished because there are fewer vehicles passing in the research area.

The method used to calculate the illumination value is point by point method. Illumination measurements using lux meters were measured 1 meter above the road surface and carried out in nine points of light. Figure 2 shows the illumination measurement points based on point by point method, while for secondary data obtained from relevant agencies such as the Highways and Irrigation Agency (DBMP), and the lamp manufacturing site under study. Secondary data are road types, road schemes, and types of lights used in the research road area. For more specific types of lights, the data is taken from the manufacturing site of the lamp.

![Figure 2. Point by point method.](image)

After measuring at nine points, the average illumination value will be obtained using equation (1) as follows:

\[
E_{\text{avg}} = \left[ \frac{P1 + P3 + P7 + P9}{4} \right] + \left[ \frac{P2 + P4 + P6 + P9}{3} \right] + \left[ \frac{P5}{2} \right] \text{ (lux)}
\]

Notes:

- \( E_{\text{avg}} \) = Average illumination (lux)
- P1~P9 = point of illumination measurement (lux)
Illumination measurement using Analog Light Meter Lux Meter Sanwa LX3132 and Sanfix digital laser
meter SD 100a, Sanfix digital laser meter SD 100a, the units produced can be meters, inches and feet.
This measuring instrument can not only measure distance, but also can measure the area, volume and
even angle of a triangle, so that it can facilitate researchers to measure the angle of the street lighting
pole.

![Lux meter dan laser distance meter](image)

**Figure 3. Lux meter dan laser distance meter.**

2.3. Data analysis techniques
After the data is obtained with predetermined parameters, data will be putted into DIALux to be
processed and analyzed whether the lighting system that has been installed on the road has met the SNI
standard, lamps data will be compared to obtain a quantitative comparison of the average illumination
level and the most effective and efficient uniformity ratio of the lights.

3. Results and discussion

3.1. Street lighting conditions in the research area
Various road conditions due to the type of road with different functions, the conditions of the street
lighting installed on the road segments are those that have already fulfilled and some are still not
fulfilling SNI: 7391: 2008, which have not met the Indonesian National Standards due to the level of
illumination and uniformity of light still exceeding the prescribed limit.

3.1.1. Street lighting conditions in Sindang Sirna (Site 1). This Site 1 have 10 pole street lights, the type
of lamp used in this site is High Pressure Sodium. Site 1 type of street is a secondary locale with a total
distance of 615 m with a width of 6.1 m, with an average distance between poles of 60.63 m, many poles
are blocked by trees so street lighting is not maximal, and the distance between the poles is still uneven
so that the lighting between 2 pole has a lack of lighting.

3.1.2. Street lighting conditions in Kebon Kawung (Site 2). This Site 2 have 21 pole street lights, the type
of lamp used in this street is Light Emiting Diode. Site type 2 is the primary collector with a total
distance of 639 m with a width of 11 m, with an average distance between 29.99 m, the street lighting
design is in accordance with the standard so the lighting is sufficient well.

3.1.3. Street lighting conditions in Cipedes Atas (Site 3). This Site 3 have 21 pole street lights, the type
of lamp used in this street is Light Emiting Diode. Site type 3 is the primary collector with a total distance
of 920 m with a width of 7.8 m, the distance between the street lighting piles is still irregular with the
closest distance of 26,291 meters and the farthest distance 95,261 meters causes the level of illumination
to be irregular so that the minimum lighting at the point between 2 pole lights, the difference in the
distance of the pole is because there is no street lighting pole but an overhang attached to the low voltage
pole (LV).
3.2. Street lighting analysis in research area

3.2.1. Street lighting analysis in Site 1. Table 2 shows the results of the illumination measurements of all PJU poles on Site 1 with a total of 10 pillars, measuring 9 times and then looking for an average value, while evenness values are the result of minimum illumination with average illumination, the average value the average illumination of the entire PJU is 7.64 Lux with an evenness ratio of 0.13 Lux.

Based on field measurements there are differences in lux that are produced from each lamp, the difference is due to the first pole there is additional light from the outside, that is, there are baligo advertisements, and for lights that produce small lux because the lights are blocked by trees.

Table 2. Measurement of average illumination of HPS lights in Site 1.

| Pole | Lights Measurement Data (lux) | Average (lux) |
|------|------------------------------|---------------|
|      | P1  | P2  | P3  | P4  | P5  | P6  | P7  | P8  | P9  |       |
| 1    | 29  | 14  | 30  | 20  | 15  | 12  | 15  | 11  | 2   | 15.62 |
| 2    | 8   | 14  | 29  | 7   | 20  | 20  | 6   | 2   | 15  | 14     |
| 3    | 2   | 4   | 8   | 2   | 1   | 7   | 3   | 2   | 6   | 3.31   |
| 4    | 5   | 2   | 2   | 6   | 1   | 2   | 2   | 3   | 3   | 2.62   |
| 5    | 13  | 5   | 5   | 7   | 4   | 6   | 12  | 16  | 2   | 7.37   |
| 6    | 9   | 10  | 13  | 6   | 8   | 7   | 15  | 22  | 12  | 10.68  |
| 7    | 3   | 5   | 9   | 2   | 2   | 6   | 6   | 4   | 15  | 4.68   |
| 8    | 6   | 5   | 3   | 9   | 5   | 2   | 8   | 8   | 6   | 5.68   |
| 9    | 2   | 2   | 6   | 1   | 9   | 1   | 2   | 8   |     | 3.68   |
| 10   | 15  | 9   | 2   | 19  | 6   | 6   | 15  | 7   | 1   | 8.68   |

Iluminance average 7.64
Uniformity ratio 0.13

3.2.2. Street lighting analysis in Site 2

Table 3 shows the results of the illumination measurements of all PJU poles in Site 2 with a total of 21 poles, measuring 9 times and then looking for an average value, while evenness values are the result of minimum illumination with average illumination, with a small uniformity ratio below standard.

Based on the measurement results in the evenness of the bright lights at the bottom of the lamp, while at the opposite end of the road, at the measurement points P7, P8 and P9, the resulting illumination is lower so that the evenness level is below the SNI standard.

Table 3. Average LED illumination measurement in Site 2.

| Pole | Lights Measurement Data (lux) | Average (lux) |
|------|------------------------------|---------------|
|      | P1  | P2  | P3  | P4  | P5  | P6  | P7  | P8  | P9  |       |
| 1    | 36  | 15  | 30  | 23  | 19  | 15  | 10  | 7   | 6   | 17.37  |
| 2    | 34  | 17  | 36  | 20  | 14  | 23  | 9   | 6   | 10  | 17.31  |
| 3    | 28  | 20  | 34  | 15  | 13  | 20  | 7   | 3   | 9   | 15.37  |
| 4    | 31  | 25  | 28  | 16  | 15  | 15  | 8   | 5   | 7   | 16     |
| 5    | 25  | 18  | 31  | 14  | 10  | 16  | 10  | 4   | 8   | 13.62  |
| 6    | 32  | 22  | 25  | 21  | 19  | 14  | 12  | 7   | 10  | 17.68  |
| 7    | 30  | 21  | 32  | 20  | 18  | 21  | 10  | 9   | 12  | 18.62  |
| 8    | 28  | 24  | 30  | 19  | 17  | 20  | 8   | 9   | 10  | 18     |
| 9    | 33  | 23  | 28  | 16  | 18  | 19  | 15  | 13  | 8   | 18.62  |
| 10   | 27  | 15  | 33  | 13  | 9   | 16  | 9   | 3   | 15  | 13.37  |
| 11   | 35  | 19  | 27  | 26  | 14  | 13  | 12  | 9   | 9   | 17.06  |
| 12   | 29  | 12  | 35  | 22  | 7   | 26  | 9   | 4   | 12  | 15.06  |
| 13   | 33  | 19  | 29  | 17  | 15  | 22  | 11  | 7   | 9   | 17     |
| 14   | 28  | 19  | 24  | 20  | 12  | 17  | 11  | 3   | 11  | 15     |
### Table 3. Cont.

| Pole | Lights Measurement Data (lux) | Average (lux) |
|------|-------------------------------|---------------|
| 15   | 38 22 28 19 21 20 15 11 11   | 20            |
| 16   | 28 11 38 13 7 19 9 13 15     | 14,37         |
| 17   | 25 21 28 12 17 13 12 11 9    | 16            |
| 18   | 21 17 25 14 15 12 9 8 12     | 14,31         |
| 19   | 23 10 21 9 4 14 6 2 9        | 9,06          |
| 20   | 33 17 23 16 17 9 13 9 6      | 15,31         |
| 21   | 29 13 33 17 11 16 9 5 13     | 14,37         |

| Pole | Lights Measurement Data (lux) | Average (lux) |
|------|-------------------------------|---------------|
| 17   | 25 21 28 12 17 13 12 11 9    | 16            |
| 18   | 21 17 25 14 15 12 9 8 12     | 14,31         |
| 19   | 23 10 21 9 4 14 6 2 9        | 9,06          |
| 20   | 33 17 23 16 17 9 13 9 6      | 15,31         |
| 21   | 29 13 33 17 11 16 9 5 13     | 14,37         |

| Iluminnance average | 15,87 |
|---------------------|-------|
| Uniformity ratio    | 0,12  |

### 3.2.3. Street lighting analysis in Site 3

Table 4 shows the results of the illumination measurements of all PJU poles on Site 3 with a total of 21 poles, measuring 9 times and then looking for an average value, while evenness values are the result of minimum illumination with average illumination, for evenness ratios exceeding predetermined standard limit.

Based on the results of field measurements the level of evenness on the road is good, there are significant differences in lux results caused by additional external light such as lighting ion houses.

### Table 4. Average LED illumination measurement in Site 3.

| Pole | Lights Measurement Data (lux) | Average (lux) |
|------|-------------------------------|---------------|
| 1    | 6 3 7 4 2 7 1 3 4             | 3,75          |
| 2    | 6 2 6 7 2 4 2 2 1             | 3,3125        |
| 3    | 5 1 6 2 1 7 5 3 2             | 3             |
| 4    | 4 3 5 2 4 2 2 4 5             | 3,375         |
| 5    | 2 2 4 2 1 2 1 1 2             | 1,6875        |
| 6    | 7 5 2 3 5 2 6 7 1             | 4,375         |
| 7    | 2 1 7 1 2 3 3 1 6             | 2,375         |
| 8    | 8 12 2 7 8 1 5 11 3           | 7             |
| 9    | 3 1 8 2 4 7 6 2 5             | 3,875         |
| 10   | 2 1 3 2 1 2 3 2 6             | 2             |
| 11   | 6 6 2 3 2 2 3 5 3             | 3,375         |
| 12   | 2 6 6 2 3 3 6 9 3             | 4,3125        |
| 13   | 1 3 2 2 1 2 2 4 6             | 2,3125        |
| 14   | 1 2 1 1 2 2 1 2 2             | 1,6875        |
| 15   | 6 7 1 5 4 1 3 3 1             | 3,6875        |
| 16   | 6 9 6 2 7 5 4 6 3             | 5,6875        |
| 17   | 2 1 6 3 3 2 1 3 4             | 2,6875        |
| 18   | 12 7 2 6 1 3 1 1 1             | 3,375         |
| 19   | 8 17 12 11 19 6 12 19 1       | 13,4375       |
| 20   | 2 1 8 1 2 11 2 1 12           | 3,75          |
| 21   | 1 2 2 1 4 1 2 3 2             | 2,3125        |

| Iluminnance average | 3,87 |
| Uniformity ratio    | 0,12 |
3.3. Simulation of street lighting using DIALux Evo 8.1
The scheme in this study was analyzed using DIALux Evo 8.1. In the study area, the type of lamp used was Philips Spectrum SPP368 1xSON-T150W SGR CP P-A45 with a power of 169 Watt, 11550 lm.

Table 5. Specification of Philips Spectrum SPP368 1xSON-T150W SGR CP P-A45 lamp.

| Manufacture | Philips Spectrum SPP368 1xSON-T150W SGR CP P-A45 |
|-------------|--------------------------------------------------|
| Model       | High Pressure Sodium                             |
| Power       | 169 W                                            |
| Luminance   | 11550 lm                                         |
| Efficacy    | 68 lm/W                                          |
| CRI         | 20                                               |
| CCT         | 2000 K                                           |

![Figure 4. Philips Spectrum SPP368 1xSON-T150W SGR CP P-A45.](image)

![Figure 5. 3D illumination illustration in Site 1.](image)

Table 6. Data simulation PJU Site 1.

| Em [lx] ≥ 2 - 5 | Uo ≥ 0.10 | TI [%]   |
|-----------------|-----------|----------|
| 7.39            | 0.14      | *15      |

The scheme in this study was analyzed using DIALux Evo 8.1. In the study area, the type of lamp used was Philips CitySoul gen2 LED Large BPP531 T35 1 xGRN145 / 740 A DF with power of 106 Watts, 9802 lm.

Table 7. Philips CitySoul gen2 LED Large BPP531 T35 1 xGRN145/740 A DF.

| Manufacture | Philips CitySoul gen2 LED Large BPP531 T35 1 xGRN145/740 A DF |
|-------------|--------------------------------------------------------------|
| Model       | Light Emitting Diode                                         |
| Power       | 106 Watt                                                     |
| Luminance   | 9802 lm                                                      |
| Efficacy    | 92.5 lm/W                                                    |
| CRI         | 99                                                            |
| CCT         | 3000 K                                                       |
Figure 6. Philips CitySoulLED Large BPP531 T35 1 xGRN145/740.

Figure 7. 3D illumination illustration in Site 2.

Table 8. Data simulation PJU Site 2.

| Em [lx] | Uo | TI [%] |
|---------|----|--------|
| ≥ 5 - 7 | ≥ 0.14 | 13.97 |

*6

The scheme in this study was analyzed using DIALux Evo 8.1. In the study area, the type of lamp used was the Metal Halide type with the brand SLC 7422Q/3-70QP.GL with a total power of 83 Watts, 4958 lm.

Table 9. SLC 7422Q/3-70QP.GL lamp specifications.

| Manufacture | SLC Saudi Lighting |
|-------------|-------------------|
| Model       | 7422Q/3-70QP.GL   |
| Type of Lamp| Metal Halide      |
| Power       | 83 W              |
| Luminance   | 4958 lm           |
| Efficacy    | 60 lm/W           |
| Color Rendering Index (CRI) | 87 |
| Correlated Color Temperature (CCT) | 2900 K |

Figure 8. SLC 7422Q/3-70QP.GL Lamp.

Figure 9. 3D illumination illustration Site 3.

Table 10. Data simulation PJU Site 3.

| Em [lx] | Uo | TI [%] |
|---------|----|--------|
| ≥ 2 - 5 | ≥ 0.14 | 3.89 |

*10

3.4. Suitability analysis of street lighting in the research area with SNI standards

Figure 10 Shows that the lux average in Sindang Sirna road is 7.63 and for 7391: 2008 SNI for lux standard lighting on local roads is the illumination level of 2-5 lux. Thus the level of illumination in the research area exceeds the maximum limit of SNI. Figure 11 Showing the lux reliability ratio in Site 1 is 0.13 and for SNI the Uniformity ratio lux lighting standard on local roads is the illumination level of 0.1
lux. Thus the Uniformity ratio in the area of research is still on the scale of the Indonesian National Standard.

![Figure 10. Illumination average in Site 1.](image1)

![Figure 11. Uniformity ratio Site 1.](image2)

Figure 10 shows that the average lux in Site 2 is 15.87 and for SNI the standard illumination of average lux on the collector's path is the illumination level of 3-7 lux. Thus the level of illumination in the research area exceeds the maximum limit of SNI. Figure 11 shows the lux reliability ratio in Site 2 is 0.12 and for SNI the Uniformity ratio lux lighting standard on the collector road is the illumination level of 0.14 lux. Thus the Uniformity ratio in the area of research is slightly below the Indonesian National Standard.

![Figure 12. Illumination average in Site 2.](image3)

![Figure 13. Uniformity ratio Site 2.](image4)

Figure 12 shows that the average lux on the Site 2 road is 3.87 and for SNI the average lux lighting standard on a local road is the illumination level of 2-5 lux. Thus the level of illumination in the research area is in accordance with the Indonesian National Standards. Figure 13 shows the luxity ratio in Site 3 is 0.25 and for SNI the Uniformity ratio lux lighting standard on the collector's road is the illumination level of 0.1 lux. Thus the Uniformity ratio in the area of research is above the Indonesian National Standard.

![Figure 14. Illumination average in Site 3.](image5)

![Figure 15. Uniformity ratio Site 3.](image6)
3.5. Comparative analysis of performance of LED, HPS and MH Lights

Figure 16 shows the results of lux measurements in three different study areas, for HPS lamps on Sindang Sirna street the average lux produced 7.63 lux where the results are above metal halide lights and under LED lights for metal halide lamps alone the average lux results the result is 3.87 and 15.80 LED lights. Figure 17 Shows the results of the Uniformity ratio lux in three different study areas, for HPS lights on Sindang Sirna road the average lux produced is 0.13 lux where the results are above LED lights and under metal halide lamps, for metal halide lamps alone the average results lux produced is 0.25, and LED lights are 0.12.

4. Conclusion

Based on the measurement results in the PJU Site 1 field, it has an average of 7.64 lux over SNI: 7391: 2008 for secondary local roads which are 2-5 lux, while PJU Site 2 has an average of 15.87 lux and exceeds SNI for collector roads primary ie 3-7 lux. PJU Site 3 has an average lux of 3.87 lux according to SNI for secondary local roads, namely 2-5 lux. The uniformity ratio of the three lights is almost all in accordance with the SNI standard except the LED light is slightly below the SNI standard, for the HPS Uniformity light ratio 0.13 where the minimum SNI standard for local roads is 0.1, Uniformity ratio Metal Halide lights are 0.25 where SNI minimum standard for local roads is 0.1, Uniformity ratio of LED lights is 0.12 where the minimum standard of SNI for collector roads is 0.14. Based on the results of field measurements and the existing DIALux Evo 8.1 PJU simulation there was no significant difference, for the DIALux Evo 8.1 simulation calculation the Philips 150W HPS lamp had an average illumination of 7.39 lux and a Uniformity ratio of 0.14, MH SLC 83W lamps had flat illumination - Lux lux 3.89 lux and Uniformity ratio 0.21, Philips 106W LED lights have a lux average of 13.97 lux and a Uniformity ratio of 0.14. Thresold Increment or glare produced by the three lights namely 6% LED light, 10% metal halide lamp, and 15% HPS lamp, the three lights do not exceed the maximum limit of SNI Standard glare which is 20%.
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