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# Road Lighting Energy Reduction: From HPS to LEDs - A Case Study of Uganda Street, Addis Ababa, Ethiopia

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***Abstract*— Modern technology advancements, coupled with aggressive research, has enabled the development and manufacture of superior LED luminaires. The 21st century has seen significant transition from HPS to LEDs in road lighting as a measure to reduce the installed load and the amounts paid by municipal authorities to cover energy consumption costs. This paper investigated the energy saving possibilities of replacing HPS with LED luminaires - Uganda Street, a 1.35km road in Addis Ababa, was used as the case study. *Dialux evo* was used to determine the lighting performance, under HPS and LED lighting, with reference to the requirements of CEN13201-1 and EN13201-2. Vehicular traffic data was used to recommend a part-dimming schedule. Annual energy savings of 51.31 % and 79.75 % were realized by replacing the HPS with LED lamps and by further dimming the LEDs respectively. The study findings provide confidence for city authorities to transit from HPS to LED street lighting as a measure to reduce the overall lighting peak load and achieve huge reductions in their annual energy consumptions.**

***Keywords*— *HPS, LED, Energy Reduction, Dimming and Lighting Performance.***

## I. INTRODUCTION

Installation of functional street lighting systems is nowadays part of the infrastructure demanded by city residents globally. Street lighting enhance road visibility at night, allow business and social activities to proceed beyond the fall of darkness, create ease in the identification of people and traffic for law enforcement purposes and act to deter criminal and violence tendencies, especially in crime hot spots, related to darkness [1].

Lighting accounts for half of the overall energy consumption in cities [2] with street lighting being a key contributor. By 2015, 304 million streetlights had already been installed [3] and the number was poised to rise to 352 million by 2025. The enormous number of installed streetlights inflict significant costs to city authorities in the form of maintenance costs and energy consumption costs. Inefficient street lighting systems are still prevalent worldwide [3] leading to high installed electrical loads, greater pressure on power generations and high green house gas (GHG) emissions. In 2011, for instance, street lighting accounted for 30-60 % [4] of the GHG emissions in Australian local authorities.

Uganda Street is one of the boundary roads serving Merkato, the busiest market centre in Addis Ababa. It is estimated that 200,000 people visit Merkato everyday leading to a contribution of 20-25% revenue to Addis Ababa City [5]. The high number of business people, residents, buyers and tourists visiting this market demand that adequate street lighting be in place to support night time business and social interactions. Currently, high pressure sodium (HPS) lamps are mounted on dedicated galvanized steel lighting poles. Addis Ababa City Roads Authority (AACRA) is responsible for the management of all street lighting infrastructure in Addis Ababa and foots the costs associated with the street lighting system.

The most recent street lighting standards provide a wider classification of lighting levels allowing road lighting designers to better match the designed lighting with the requirements of the road [6]. CEN13201-1 acknowledges the use of adaptive lighting techniques, such as part night dimming, as an energy consumption reduction measure [7].

The other sections of this paper covers the energy reductions achieved in previous studies, execution of this study including scope and methodology, results, conclusion, acknowledgement and references.

## II. ENERGY REDUCTION POSSIBILITIES

The European E-street project identified 36 TWh (63.7%) in annual energy savings achievable through transition from old lighting installations to newer and adaptive ones [8] – high consumption mercury vapor lamps to HPS lamps. Between 2006 and 2008, 20,000 adaptive HPS streetlights had been installed in 12 different European countries.

The Australian authorities projected 27.1% energy savings through transition from inefficient technologies (largely mercury vapor) to modern HPS lamps. With 2.28 million streetlights installed by 2011, 250 W and 400 W mercury vapor lamps had been replaced by lower wattage 150 W and 250 W HPS lamps respectively over the past decade [4].

The US Department of Energy estimated, in 2012, that by 2030, 300 TWh of energy savings would be achieved due to an accelerated transition into LED lighting technologies [9]. It was estimated that 26 million inefficient streetlights existed [10] which contributed to the dire need to move into more efficient technologies which would offer energy savings.

The city of Pittsburgh in 2011 intended to replace 40,000 HPS and HID streetlights with LED streetlights - based on proof-of-concept studies, undertaken by a consultant before

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commencing the project, the City estimated that 70% savings in energy and maintenance costs would be achieved; annual reductions would be to the tune of 1.7 million dollars in energy and maintenance cost and 6,818 metric tonnes of carbon dioxide [11].

In 2014, mercury and HPS lamps were prevalent in Nairobi City with only 4% of installed street lights being LED [12]. HPS lamps accounted for the greatest installation share, 82.3%, and consisted of 150 W, 250 W and 400 W luminaires. If the 250W HPS lamps would be replaced with 120 W LED lamps, 14.52 GWh would be saved annually. The lamp distribution in 2014 was summarised in Table 1.

Table 1: Nairobi City Street Lighting Lamps Summary [12].

| Type of lamp | Number | Frequency |
|---|---|---|
| High Pressure Mercury Vapour | 3,250 | 10.5 % |
| Metal Halide | 450 | 1.5 % |
| High Pressure Sodium (HPS) | 25,500 | 82.3 % |
| Low Pressure Sodium Vapour | - | - |
| Low Pressure Mercury Tubes | 425 | 1.4 % |
| Energy Efficient Tubes | 125 | 0.4 % |
| LEDs | 1,250 | 4 % |

The City of Kigali, in a baseline survey, estimated that replacement of HPS with LED luminaire would lead to 60% in energy consumption [13].

The studies previously conducted [11] [12] did not elaborate the basis for the choice of the given LED luminaire wattage, and lumen output, as being suitable to replace the existing HPS luminaire. For instance replacing the 250 W HPS with 120W LED, in Nairobi City [12], did not ascertain that the original lighting performance (lighting level as defined under EN13201-2) would not be compromised.

## III. STUDY EXECUTION

### A. Project Area

Four primary arterial streets circle the Merkato market area and connect it to the rest of Addis Ababa City. Uganda Street is a 1.35km dual road to the South of the market area as shown on Figure 1.

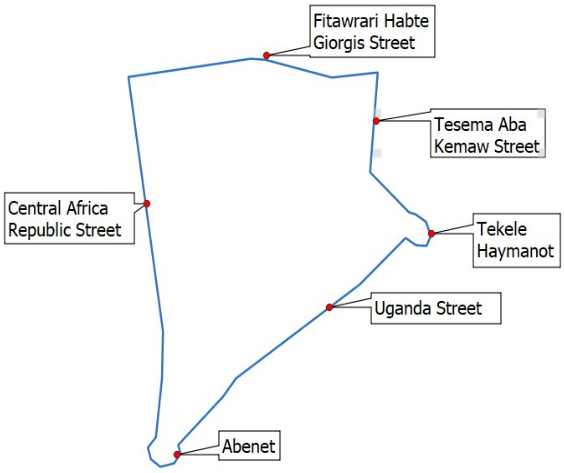

**Figure 1: Study Area – Uganda Street in Merkato.**

The Uganda street cross-section from right to left is typically as follows: right hand side (RHS) walkway, RHS drive lanes, median / green space, left hand side (LHS) drive lanes and LHS walkway. The existing lighting poles are erected on, each side of, the walkway. The outermost lane is in some sections designated a freight or bus-stop area, allowing the movement of people to and from the market area.

### B. Drive Lanes' Lighting Classification

Drive lanes belong to class M lighting according to CEN13201-1. Six categories exist under class M namely M1 to M6 where M1 has the highest requirements. The lighting category of a road is determined by weighting nine factors detailed under CEN13201-1. This was carried out for Uganda Street as shown under Table 2.

Table 2: Drive lanes' lighting class selection.

| Parameter | Option (selected) | Description | Weighting Value |
|---|---|---|---|
| Design Speed | Moderate | $40<v\leq70$ km/h | -1 |
| Traffic volume | High | >65 % maximum capacity (multilane routes) | 1 |
| Traffic composition | Mixed | | 1 |
| Separation of carriageway | Yes | | 0 |
| Junction density | Moderate | ≤3 intersection/km | 0 |
| Parked vehicles | Present | | 1 |
| Ambient luminosity | Moderate | Normal situation | 0 |
| Navigational task | Easy | | 0 |
| Sum of weighting value, VWS | | | 2 |
| Lighting class = 6 - VWS | | | 4 |

The pedestrian walkway similarly belongs to class P and the lighting category was evaluated as P3 according to CEN13201-1 as shown on Table 3.

Table 3: Walkways' lighting selection.

| Parameter | Option (selected) | Description | Weighting Value |
|---|---|---|---|
| Travel Speed | Low | $v\leq40$ km/h | 1 |
| Use intensity | Busy | | 1 |
| Traffic composition | Pedestrians and cyclists | | 1 |
| Parked vehicles | Not present | | 0 |
| Ambient luminosity | Moderate | Normal situation | 0 |
| Sum of weighting value, VWS | | | 3 |
| Lighting class = 6 - VWS | | | 3 |

### C. Methodology

The entire road was divided into seven sections (Section 1 to 7) with distinct cross sections – the cross-section variations were however minor, majorly observed with the median and walkway widths. Dialux evo was used to simulate the existing street lighting case and the recommended LED lighting case(s). EN13201-2 was used to determine the lighting performance in both cases. Determination of a suitable LED luminaire as a replacement to the HPS lamp is an iterative process – the luminaire wattage and lumen output were adjusted until the required level of lighting was achieved (to M4 and P3 for drive lanes and walkways respectively). Traffic data was also tabulated to form the basis of recommending a suitable night dimming schedule.

## IV. RESULTS

EN13201-2 requires the evaluation of the following areas for the main drive lanes; the average luminance, Lm, the Overall Uniformity, Uo, the Longitudinal Uniformity, Ui, the Threshold Increment, Ti, and the Edge Illumination Ratio, EIR.

### *A. Section 1 (0+000 – 0+200), LHS*

The road lighting performance was carried out for the existing case, HPS, and for two LED cases – the selected luminaire flux levels were 17,500, 12,000 and 10,000 lumens, respectively. The lighting performance for section 1 was summarised on Table 4.

Table 4: Drive lanes' lighting performance, section 1.

| | Lm (Cd/m2) | Uo | Ui | Ti (%) | EIR |
|---|---|---|---|---|---|
| M4 | ≥ 0.75 | ≥ 0.40 | ≥ 0.60 | ≤ 15 | ≥ 0.30 |
| HPS, 150 W | 1.16 | 0.63 | 0.75 | 12 | 0.70 |
| LED, 87 W | 1.21 | 0.63 | 0.68 | 9 | 0.70 |
| LED, 73 W | 1.01 | 0.63 | 0.68 | 9 | 0.70 |

The simulation analysis, summarised in Table 4, indicated that an 87W LED luminaire satisfied class M4 lighting requirement providing a level and quality of lighting comparably equivalent to that of the HPS lamps – the average luminance under the lower wattage LED was however higher. It was also noted that an even lower LED luminaire, 73W would still satisfy class M4 lighting for this road – the average luminance would however fall short of the HPS level.

### *B. Sections 2 &3 (0+200 – 0+600), RHS*

These sections differ from Section 1 in that the median and walkways are narrower. The simulation results, summarised on Table 5, however, pointed to a conclusion similar to Section 1 – 87 W LED would achieve the current HPS lighting; 73W LED would also meet M4 lighting but at reduced average luminance.

The 73 W LED luminaire would achieve the greatest load reduction and is recommended – despite the lower initial average luminance level (compared to the HPS lamp), the LED luminaire offers higher operational life than HPS lamps. The overall effect is that the lighting achieved through HPS lamps deteriorates faster, in quality and quantity, compared to the lighting from LED lamps. At the end of life, which is faster for HPS lamps, the average luminance due to HPS lighting would be lower than that of LED lighting.

Table 5: Drive lanes' lighting performance, section 2 & 3.

| | Lm (Cd/m2) | Uo | Ui | Ti (%) | EIR |
|---|---|---|---|---|---|
| M4 | ≥ 0.75 | ≥ 0.40 | ≥ 0.60 | ≤ 15 | ≥ 0.30 |
| HPS, 150 W | 1.17 | 0.64 | 0.75 | 12 | 0.70 |
| LED, 87 W | 1.22 | 0.63 | 0.68 | 9 | 0.70 |
| LED, 73 W | 1.02 | 0.63 | 0.68 | 9 | 0.70 |

### *C. Energy Savings Under LED*

A total of 86 HPS lamps are currently installed on Uganda Street. The achieved energy savings were computed as summarized under Table 6.

Table 6: HPS to LED energy savings.

| | HPS, 150 W | LED, 87 W | LED, 73 W |
|---|---|---|---|
| Number | 86 | 86 | 86 |
| Operation, hrs | 4,380 | 4,380 | 4,380 |
| Load, kW | 14.53 | 7.48 | 6.28 |
| Energy, MWh | 63.66 | 32.76 | 27.51 |
| | 30.90 | | |
| | 36.15 | | |

The energy consumption is based on 12 hours per night, 365 days an year. Due to the HPS lamps' poor efficiency, the input wattage is 169 W and has been applied in Table 6.

### *D. Traffic Data and Dimming Schedule*

24-hour vehicular traffic data was obtained and used to construct an understanding of the nighttime road use trend. The data was obtained for a weekday and for a weekend in September and June 2019, respectively. The weekday vehicular traffic trend was presented under Figure 2.

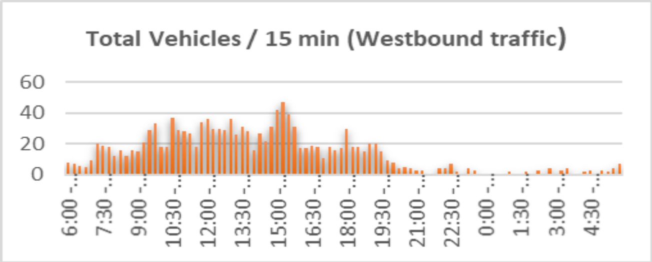

Figure 2: Westbound traffic, weekday.

The weekend eastbound traffic trend was presented as shown under Figure 3.

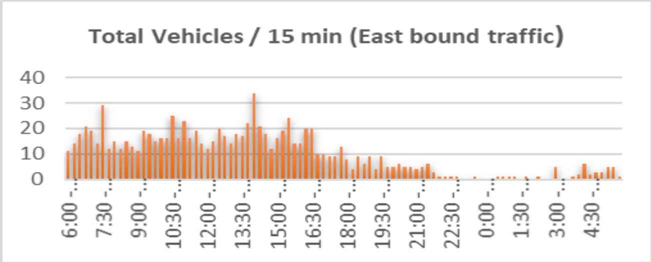

Figure 3: Eastbound traffic, weekend.

The average night-time traffic for both westbound and eastbound traffic calculated for every two hours was summarized under Table 7.

Table 7: Average night traffic.

| | Weekday | | Weekend | | |
|---|---|---|---|---|---|
| | West | East | West | East | |
| Time (hrs) | % of highest | | | | % Average |
| 1800-2000 | 100 | 77 | 100 | 100 | 94 |
| 2000-2200 | 17 | 38 | 28 | 67 | 38 |
| 2200-0000 | 23 | 23 | 14 | 11 | 17 |
| 0000-0200 | 7 | 23 | 10 | 11 | 13 |
| 0200-0400 | 13 | 38 | 10 | 56 | 29 |
| 0400-0600 | 23 | 100 | 17 | 56 | 49 |

The nighttime traffic reduction proregression was presented as shown under Figure 4.

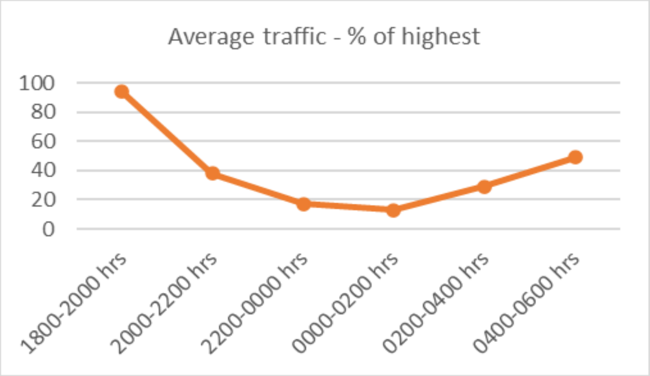

Figure 4: Nighttime traffic progression trend.

From the traffic data analyzed, traffic dipped to less than half between 2000 hrs and 0400 hrs and then recovers to half for the morning hours. From this trend it is recommended that all the luminaire, on Uganda Street, be dimmed as shown on Table 8.

Table 8: Recommended dimming schedule.

| Time (hrs) | Average traffic | Recommended lighting level |
|---|---|---|
| 1800-2000 | 94 % | 100 % |
| 2000-2200 | 38 % | 40 % |
| 2200-0000 | 17 % | 30 % |
| 0000-0200 | 13 % | 30 % |
| 0200-0400 | 29 % | 30 % |
| 0400-0600 | 49 % | 50 % |

### *E. Dimmed-LED Energy Savings*

The energy consumption based on the night-time dimming schedule recommended under Table 8 was calculated by Equation 1.

Energy = Installed load x dimmed level x operating hours
Equation 1

The energy consumption was computed for each of the distinct dimming periods and then aggregated to obtain the total consumption for one night as summarized under Table 9.

Table 9: Dimmed-LED Energy Savings.

| Time (hrs) | Load, kW | Dimmed level | Energy, kWh |
|---|---|---|---|
| 1800-2000 | 7.48 | 100 % | 14.96 |
| 2000-2200 | 7.48 | 40 % | 5.98 |
| 2200-0000 | 7.48 | 30 % | 4.49 |
| 0000-0200 | 7.48 | 30 % | 4.49 |
| 0200-0400 | 7.48 | 30 % | 4.49 |
| 0400-0600 | 7.48 | 50 % | 7.48 |
| Total daily | | | 41.89 |

Given 365 days in an year, the resulting annual consumption is 15.29 MWh (41.89 kWh x 365). If a 73 W is used, the consumption was computed as 12.89 MWh.
The nighttime dimmed load/energy profile was plotted as shown under Figure 5.

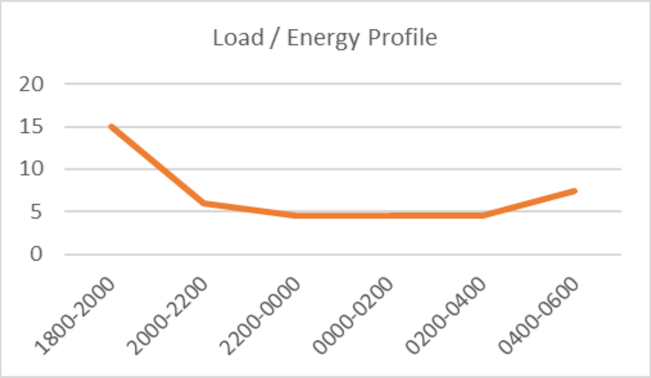

Figure 5: Dimmed load/energy profile.

### *F. Savings Summary*

The savings achieved through transition from HPS to LED street lighting were summarized under Table 10.

Table 10: Energy savings summary.

| | HPS, 150 W | LED, 87 W | | LED, 73 W | |
|---|---|---|---|---|---|
| | | 100 % | Dimmed | 100 % | Dimmed |
| Annual Energy, MWh | 63.66 | 32.76 | 15.29 | 27.51 | 12.89 |
| Savings, MWh, % | 30.90 MWh, 42.02 % | | | | |
| | 48.37 MWh, 75.98 % | | | | |
| | 36.15 MWh, 51.31 % | | | | |
| | 50.77 MWh, 79.75 % | | | | |

Through immediate transition from the current HPS lamps to 87 W LEDs, 30.90 MWh of annual energy savings would be realized for the 1.35km of road. The potential energy savings, for the entire city of Addis Ababa, would be to the scale of TWh given the thousands of principal arterial and secondary arterial streets which are currently served by HPS lighting.

The graphical presentation of the consumptions under each case appeared as shown under Figure 6.

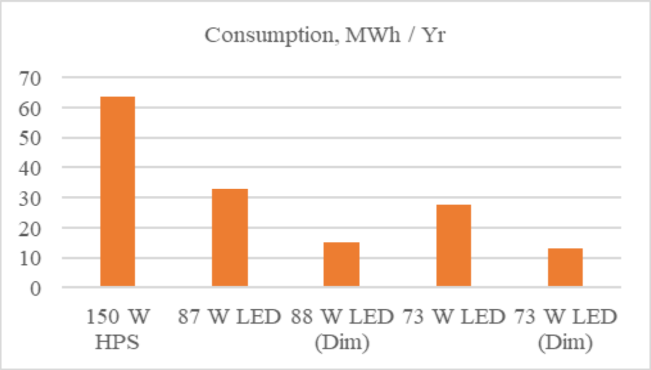

Figure 6: Energy Consumption - HPS & LED Cases.

## V. CONCLUSION

The transition from 150W HPS to 73W LEDs led to the reduction of the peak load from 14.53kW to 6.28kW for Uganda street and 51.31% reduction in annual energy consumptions. Dimming of the LEDs would achieve even greater savings (79.75%).

Replacement of high wattage HPS lamps with lower wattage LED luminaires provide a strong case for city authorities to reduce their annual energy consumption burdens. The choice of the LED luminaire must however be verified based on photometric computations to ensure that the road lighting levels are not reduced or compromised in relation to the EN13201 standard.

Dimming of the LED streetlights would further provide extra savings but must be based on traffic volume checks. Since the traffic volumes vary from time to time, it is recommended that frequent studies be made to inform the dimming pattern accordingly.

The adopted dimming pattern should not lead to lighting levels lower than the lowest class under EN13201, namely M6 and P6 for the drive lanes and walkways respectively – the average luminance and the horizontal illuminance, for instance, should not be lower than 0.3 $Cd/m^2$ and 2 lux respectively.

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