Study on Energy Efficient Street Lighting System Design

Safaa Alzubaidi, and Prashant Kumar Soori

***Abstract*--Today, energy shortage and carbon emission are the major challenges faced by many countries. There are many ways to save energy in every sector thereby reducing the carbon emission and global warming. Qatar, in the Middle East has shown growing demand for electricity consumption. In Qatar, the energy consumption by 2020 is expected to reach 80,648GWh and the energy consumption for lighting alone is expected to be 15,323GWh. Lighting is used in many applications and it is one of the areas that offer many opportunities for improving the energy efficiency thereby reducing the energy consumption. This paper presents a case study on energy efficient street lighting system design for the roadways in Energy City Qatar. Simulation software DIALux4.9 is used to investigate the efficient street lighting scheme through the use of different types of lamps and highlights how the concepts can be visually compared, its cost effectiveness can be studied during the design phase in order for the decisions to be made prior to its implementation. The study has concluded that forty percent reduction in the energy consumption can be achieved with the proposed street lighting system design.**

***Index Terms*--Energy Efficiency; Light Emitting Diode; Low Pressure Sodium; High Pressure Sodium**

I. Introduction

THE design of street lighting has many objectives and considerations: night-time safety of the community members and the road users, the reduction of crime and fear of crime, minimizing its effect on the environment whilst enhancing the night-time ambience, provide public lighting that is cost effective, taking into account energy conservation and sustainability.

Studies show that a well-designed street lighting shall reduce crime rates by twenty percent in the public places [1] due to the fact that improved street lighting will lead to increase social surveillance and decrease criminal opportunities. Work has been reported by many authors concerning the effect of improved street lighting on crime levels [1-3]. However, their findings focus only on the role of street lighting in the reduction of crime rates through improving visibility and by increasing the number of people on the street in the public area while the energy saving and illumination level is not reviewed. This paper highlights the energy efficient street lighting system design.

There are many ways to save energy. Lighting is one such area that offers many opportunities for improving the energy efficiency. The electricity consumption for lighting alone is estimated to be 19% of the total global electricity consumption. According to United State Energy Information Administration (EIA), the global electricity consumption for lighting in the year 2005 was estimated to be 3418TWh (terawatthours) out of the global total electricity consumption of 17,982TWh. In Qatar, the forecasted energy consumption by 2020 is 80,648GWh of which lighting energy consumption accounts to 15,323GWh [4].

Reducing electricity consumption for lighting by 40% can lead to major reduction in the total electricity consumption for lighting from 19% to 11%. This has many advantages. The energy saving will lead to drop off the need for the establishment of new power plants thereby minimizing carbon emission and hence global warming. Qatar, in the Middle East is mainly depending on natural gas and petroleum products for energy consumption. Due to its rapidly growing economy Qatar has shown a growing demand for electricity consumption and the energy consumption has doubled over the past ten years and forecasted to double over the next ten years also [4]. This study focuses on providing the design methodology and presents a case study for one of the new developmental projects (Energy City) in Qatar to reduce power consumption by designing an efficient street lighting system that can be adopted and considered by local authorities for the development of roadways in other parts of Qatar [5]. The performance of different types of lighting technologies used for street lighting applications and saving in energy consumptions in such applications are discussed.

II. Street Lighting System Design Considerations

Road lighting can be categorized according to the installation area, performance and their use as: Lighting for traffic routes, lighting for subsidiary roads and lighting for urban centers and public amenity areas [6]. Street lighting can be classified according to the type of lamp used such as: Low Pressure Sodium (LPS) which produce monochromatic orange-yellow light, High Intensity Discharge (HID) lamps,

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High Pressure Sodium (SON) lamps that can give golden white light, Metal Halide, Mercury Vapour and Light Emitting Diode (LED) Street lights. Adjustable lamp reflectors and/or holders are usually provided along with the road lighting luminaires in order to optimize the distribution of the light according to road layout. Different types of lamps used in lighting design with their luminous efficiency and lamp service life is given in Table I [6].

TABLE I
LAMP EFFICIENCY AND SERVICE LIFE

Type of Lamp	Lumens per watt	Average lamp life in Hours
Incandescent	8-25	1000-2000
Fluorescent	60-600	10000-24000
High Pressure Sodium (HPS)	45-110	12000-24000
Low Pressure Sodium (SON)	80-180	10000-18000
Metal halide	60-100	10000-15000
LED	28-79	25000-100000

Average road surface luminance (cd/m^2), Overall luminance uniformity (U_O), Longitudinal luminous uniformity (U_l), Threshold Increment (TI) and Surround Ratio are the basic parameters used in street lighting system design [6]. The percentage TI is given by expression (1) [6].

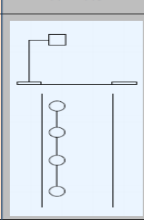
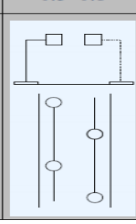
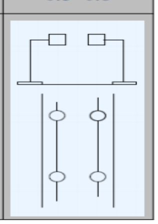
$$TI=65(L_v/L^{0.8}) \qquad (1)$$

L_v is the equivalent veiling luminance (cd/m^2).
L is the road surface luminance (cd/m^2)

As per The Commission Internationale de l'Eclairage (CIE) standard 115:1995, TI should be lower than 10% and never higher than 15%.

There are many arrangements for street lighting. Table II illustrates standard Luminaire arrangement based on lighting class and road type.

TABLE II
LUMINAIRE TYPICAL ARRANGEMENT AND LUMINOUS EFFICIENCY [6]

Lighting Class	Single row	Double row, with offset	Double row, opposing
Road information	W ≤ 6m N ≤2	W ≥ 8m N ≥2	W ≥ 16m N ≥4
Uniformity	0.4~0.5	0.5~0.8	0.5~0.8
Figure			

Road lighting luminaires used for lighting traffic routes are designed to deliver light to the road so that the surface is seen to be of uniform luminance and objects on the road can be seen in silhouette. The light distribution is therefore dependent on the position of the luminaire relative to the road. Most road lighting luminaires are mounted on columns placed at regular intervals at the side of the road or between crash barriers in the median. A recommended lighting criterion for dry road is given in Table III [6].

TABLE III
LIGHTING CLASSES FOR STRATEGIC TRAFFIC ROUTES

Road characteristic	Detailed description	Average Daily Traffic Flow (ADT)	Lighting class	Minimum maintained average road surface luminance (cd/m^2)
Trunk roads and some main roads between primary destinations	Single carriageway	< 15000	ME3a	1.0
		>15000	ME2	1.5
	Dual carriageway	< 15000	ME3a	1.0
		>15000	ME2	1.5

ME2 refers to urban areas lighting class. These roads have 30 miles per hour (m.p.h.) as speed limits and have very high levels of pedestrian activity with some crossing facilities including zebra crossings. On-street parking is generally unrestricted except for safety reasons. ME3a refers to the speed limits which are usually 40 m.p.h. or less, parking is restricted at peak times and there are positive measures for pedestrian safety reasons.

The design requires following information:

- The determination of the street lighting class according to the relevant CIE document [6], lamp power and pole spacing which depend on the street lighting class.
- Data collection such as pole height, type of luminaire, type of lamp, IP rating (Ingress Protection Rating) which indicates the degree to which the device is protected against intrusion of solid objects, dust, accidental contact and water.
- Luminaire maintenance factor [7].
- Carriageway width
- Driving lane width
- Luminaire arrangement and the road surface type (paving material).
- Glare effect is another important factor in the design as the glare produced by the luminaire should be controlled in order to limit the disability glare [8].

III. CASE STUDY

The street lighting system design for Energy City project in Qatar which is located in Lusail city, north of Doha is presented. Energy City Qatar project is one of many cities that Qatar is aiming to develop in the coming years. The total length of the road in this city is 6km. DIALux 4.9 simulation software is used for the case-study. Strategic route is considered for the study and the lighting class ME3a is selected for the lighting level calculation. The other parameters are: The width of the carriageway is 7.3m, number of lanes is two. Three lighting scenarios were applied to know the power consumption of the street lighting. This has been done by designing the road with three types of light fixtures and lamps like Metal halide, High Pressure Sodium (SON) and LED lamps. In the design, the working hours of the lighting is assumed to be 12 hours a day from 6 P.M till 6 A.M, seven days a week. The price of the light pole is considered the same for all three scenarios and it is not included in the calculation. The tariff of energy consumption for public area applications in Qatar is 0.11 United States Dollars ($) per unit of energy (kWh) consumed. The required luminance value for the lighting class ME3a is 1 cd/m^2 and a maintenance factor of 0.8 is assumed [1]. The measurement of required illumination was taken at different locations in the street under consideration and a grid of 14 × 6 points was selected.

A. Scenario-I

The strategic route in Scenario I is illuminated through the use of Philips BGP323 160×GRN-1S/740 DC with LED Lamps. Street lights are arranged in single row placed on one side of the road. Fig. 1 shows the luminaire arrangement. 3-D colour rendering is shown in Fig. 2. Fig. 3 and Fig. 4 show the lighting distribution values.

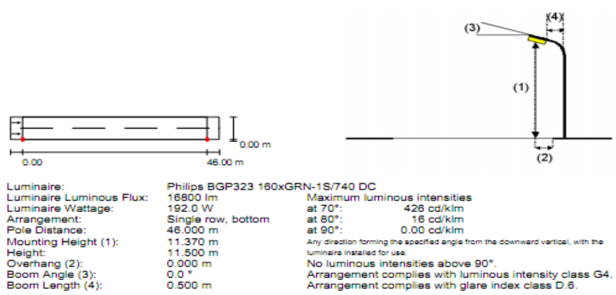


Fig. 1. Luminaire arrangements

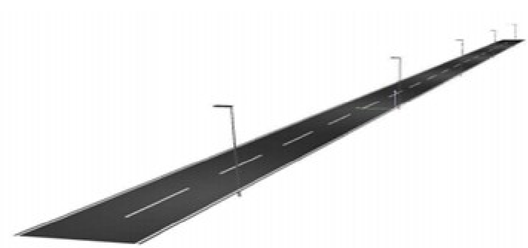


Fig. 2. 3-D renderings

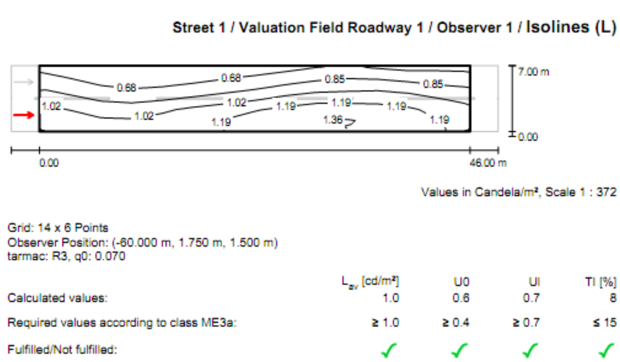


Fig. 3. Lighting distribution values in cd/m^2

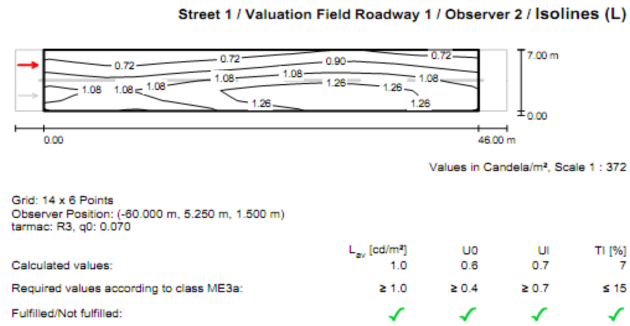


Fig. 4. Lighting distribution values in cd/m^2

B. Scenario-II

The strategic route is illuminated through the use of Philips CGP431 PC 1×CDO-TT250W equipped with Ceramic Metal Halide Outdoor lamp with clear tubular outer bulb. Street lights are arranged in single row placed on one side of the road. Fig. 5 shows the luminaire arrangement. Fig. 6 is the isolines and Fig. 7 shows the lighting distribution values.

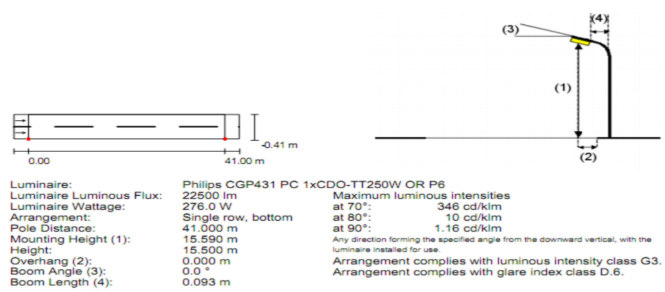


Fig. 5. Luminaire arrangements

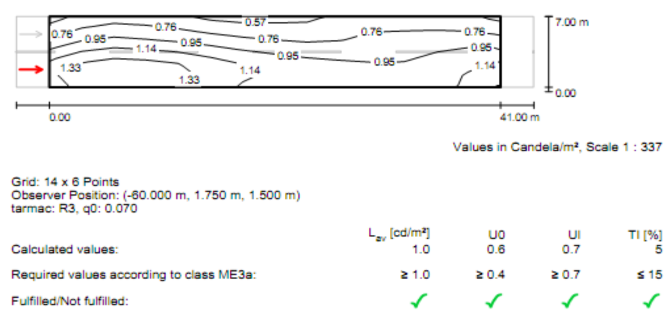


Fig. 6. Lighting distribution values and Isolines in cd/m^2

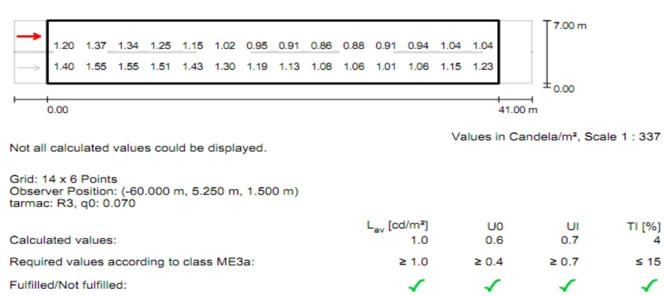


Fig. 7. Lighting distribution values in cd/m^2

C. Scenario-III

The strategic route is illuminated through the use of Philips SGS254 GB 1×SON-TPP250W CP P2 equipped with High Pressure Sodium SON lamp. Fig. 8 shows the luminaire arrangement. Fig. 9 shows the isolines and lighting distribution values are shown in Fig. 10.

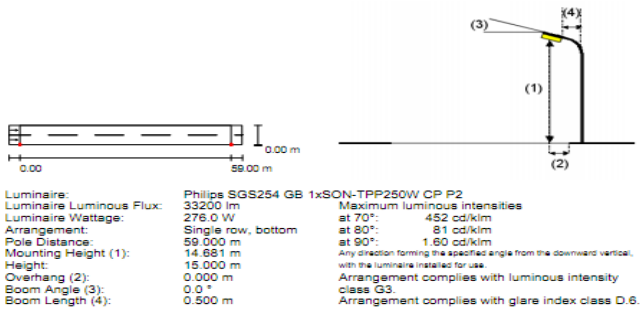


Fig. 8. Luminaire arrangements

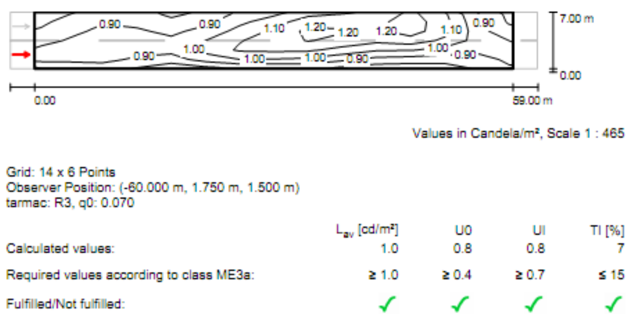


Fig. 9. Lighting distribution values and Isolines in cd/m^2

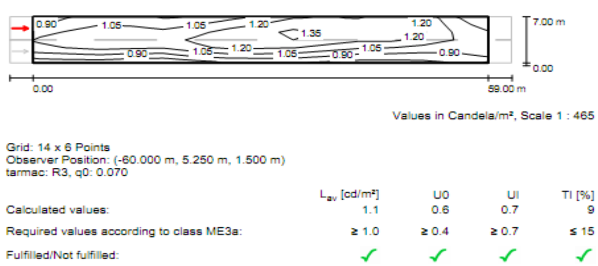


Fig. 10. Lighting distribution values and Isolines in cd/m^2

IV. Results and Conclusions

It is concluded from many studies that lighting play an important role in crime reduction; improved street lighting shows increase in perceived public safety. On the other hand, the energy shortage and carbon emission should be addressed in any developmental projects for the fast growing country like Qatar. Thus, the energy consumption of different type of lighting scenarios in the design of street lighting has been investigated in this paper.

Professional lighting simulation programs presented in this article provide accurate results with option to optimize and visualize the impact of different lighting design scenarios. Manual verification of the results shows that the accuracy of the proposed design is high. The summary of the Simulation results is given in Table IV.

TABLE IV
RESULTS SUMMARY

Type of Lamp	No. of Lamps	Power Consumed (W)	Unit Price in $	Light Fitting Cost (LFC) in $
LED	130	24960	2830	367900
Metal Halide	146	40296	729	106434
High Pressure Sodium (SON)	102	28067	580	59160

In *Scenario-I*, LED lamps are utilized and the design is requiring 130 light fittings to provide illumination of 1 cd/m^2. There is approximately 40% power saving compared to the design with Metal Halide lamps and 9% compared to High Pressure Sodium (SON) lamps. Lighting distribution values illustrate very good illumination level of lighting on different areas in the street; however TI is 8% which is near to the maximum value and glare might be observed.

In *Scenario-II*, Metal Halide lamps are used. Although the power consumption is 40296W, TI is only 4%. Hence minimum glare effect can occur with this design.

In *Scenario-III*, High Pressure Sodium (SON) lamps are introduced and it is observed that there is approximately 31% power saving compared to the design using Metal Halide lamps. TI is 7%. Hence it is well within the maximum limit.

Life-cycle cost analysis is carried out assuming that the only part of the light fittings which requires replacement is the lamps. It is observed that over twenty years of operation, the design using LED lamps will have lesser lamp replacement cost despite its high initial cost. Simple pay-back period (SPBP) calculations have been performed using (2).

$$SPBP = Y/X \qquad (2)$$

Y is the difference in capital cost
X is the expected annual saving in energy cost

It is observed that pay-back period is around thirty five years with the design using LED lamps over Metal Halide lamps and few hundreds of years over High Pressure Sodium (SON) lamps. However, pay-back period is around eight years with the design using SON lamps over Metal Halide lamps. This shows that the design using LED is a bad choice as far as the financial judgment is concerned despite its high energy saving. A High Pressure Sodium (SON) lamp is the best choice due to short return of investment and cost effectiveness.

The design procedure explained in this paper allows the designer to compare different lighting options and select the best possible option with the ultimate goal of achieving energy efficiency without compromising the recommended standards before its implementation in the actual site. This is expected to help the local authorities for proper planning and development of roadways in other parts of the city.

The simulation helped in determining the physically correct numerical values for the proposed system based on CIBSE standards which shall yield better lighting for the road users thereby reducing crime rates. It has been found in many projects that the results obtained from the simulation with the field measurements are close to real data [7]. For these reasons DIALux4.9 based simulation is proposed and used in the proposed design.

V. References

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VI. Biographies

Safaa Alzubaidi obtained Master of Science degree in Energy from Heriot Watt University,Edinburgh, United Kingdom. Currently doing his PhD study with the same university. He is LEED BD&C and LEED AP from United States Green Building Council. PMP from United States Project Management Institute and MCIBSE.
He is a Senior Engineering manager and Sustainability Specialist, Energy City Qatar. He held a number of key positions in the energy and sustainability fields, making his role in different companies an imperative asset. Having been a Senior Researcher, Technical Expert in addition to many years of experience in the field of Energy, Safaa has valuable know-how of the industry.
He has worked on key benchmark projects that aimed to promote sustainability awareness and environmental needs. Specifically, through working at Masdar City Abu Dhabi and Energy City Qatar. Safaa has conducted important researches and studies in the fields of Building Design, Energy Savings and Sustainable Building Design; these researches have been published in international conferences and journals.

Prashant Kumar Soori is a Teaching Fellow in the School of Engineering & Physical Sciences at Heriot Watt University, Edinburgh,UK in their Dubai Campus in Dubai. He was Associate Professor in the Department of Electrical Engineering and the Dean of Mekelle Institute of Technology, a non-profit, accredited higher education institution in Ethiopia. He has served as the Member of the Steering Committee of the Mekelle ICT Business Incubation Center sponsored by the World bank and received Certificate of Appreciation for the Services rendered.
He has an experience of more than 19 years in teaching undergraduate and postgraduate courses in the areas of Energy systems, Power Electronics, Electrical Machines, Electrical Drives and Control. He was the recepient of Oscar's night 2011 Award for Best style of teaching and Best overall academic organized by Heriot Watt University, Dubai. He has guided many Undergraduate and Postgraduate projects in the area of Energy Conservation. He has to his credit many conference and journal papers. He is a life member of Indian Society for Technical Education (ISTE).