International Conference on Renewable Energies and Power Quality (ICREPQ'14)
La Coruña (Spain), 25th to 27th March, 2015
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.13, April 2015

Analysis of LED lighting for a service ship

JM. Orbaneja[1], A. Álvarez[1], J. López-Beceiro[2], R. Artiaga[2] and B. Álvarez[3]

[1]Department of Naval and Oceanic Engineering
E.P.S., A Coruña University
Campus of Ferrol – Esteiro, Ferrol (Spain)
Phone/Fax number: + 0034 981 337400, e-mail: chema792000@yahoo.es, aalvarez@udc.es

[2]Department of Industrial Engineering II
E.P.S., A Coruña University
Campus of Ferrol – Esteiro, Ferrol (Spain)
Phone/Fax number: + 0034 981 337400, e-mail: jbeceiro@udc.es, rartiaga@udc.es

[2]Department of Financial Economy and Accounting
Economy and Business Faculty, A Coruña University
Campus of Elviña – 15071 A Coruña (Spain)
Phone/Fax number: + 0034 981 167000, e-mail: balvarez@udc.es

Abstract. The main objective of the study is to assess the cost to replace the traditional illumination by LED and analyze the impact on reduction CO_2 emissions and the fuel consumption.

Key words

LED, Ship, Efficiency energy, Ilumination.

1. Introduction

There is currently a great degree of sensitivity and concern over the reduction on greenhouse gas emissions from ships. Hence, any idea significantly that help to reduce fuel consumption and CO_2 emissions is well received.

By the other hand the recent advance in LED (light-emitting diode) technology (in terms of efficiency, reliability and durability) [1], its price getting cheaper, the crude price and the boom in diesel-electric naval propulsion make interesting to analyse the potential saves given by applying LED technology [2]. It will compare traditional technologies with LED in order to find out how many hours of service will compensate the higher acquisition price of LED technology, because of its superior efficiency and lifecycle. In this case shall be used the onboard power supply (230V/60Hz) and the network cabling sized to bear the higher power consumption of traditional technology lightning, and also luminaries of dual use for the same voltage supply. For this study, we only took in consideration the differentiator elements. We haven´t took in consideration installation cost because is the same in both cases. This consideration also makes possible to mount the spare lights available from any of the analysed technologies, even combined, always being compatibles with the luminaries.

2. Lighting systems characteristics

A. Power and light

Illuminance is a measure of how much luminous flux is spread over a given area. Luminous flux (measured in lumens) is a measure of the total "amount" of visible light present, and the illuminance is a measure of the intensity of illumination on a surface. A given amount of light will illuminate a surface more dimly if it is spread over a larger area, so illuminance (lux) is inversely proportional to area when the luminous flux (lumens) is held constant. One lux is equal to one lumen per square meter given by $1 \text{ lx} = 1 \text{ lm/m}^2 = 1 \text{ cd·sr/m}^2$ (in SI units).

LED is a two-lead semiconductor light source consisting in a p-n junction diode, which emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called LED electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor [3].

Normally LEDs require low voltage DC supply, so there are two basic supply alternatives: using a low voltage DC supply net (24 volts or below) or using directly a regular AC-230V/60Hz net found on board with an inverter, a rectifier and the electronic circuits for filters and control

(this is known as ballast circuit) integrated in each LED lamp [4]. The second one has been chosen because it makes it possible to use traditional technologies in the same luminaries, even combined with LEDs.
Another difference about LEDs is that this ballast circuit is a nonlinear load, this means that LEDs don´t use as active power as incandescent bulbs. However incandescent bulbs don´t consume reactive power as LEDs do [5].

LEDs compared to fluorescents lights of the same lumens consume less power, both active and reactive, but with a different power factor [6]. This power factor is function mainly of the ballast circuits. The most advanced LED lamps includes in their ballast circuit an specific electronic circuit to control the power factor and also to reduce the harmonics produced in the electric current by all the ballast circuit, but this harmonics can´t be totally suppressed [7, 8, 9].

LEDs are also more reliable in service because they´re solid-state devices and are subject to very limited wear and tear, they´re also difficult to damage with external shock, unlike fluorescent and incandescent bulbs, which are fragile.

LEDs are sensitive to voltage sags causing flickering or even back out, depending of sag depth, sag duration events, LED junction voltage and their ballast circuit. They´re less sensitive to sags that fluorescents, but they won´t work with very low voltage like incandescent bulbs (of course, giving much less light) [10, 11].

Typical lifetimes of LEDs quoted are 25000 to 100000 hours, but heat and current settings can extend or shorten this time significantly. The most common symptom of LED failure is the gradual lowering of light output and loss of efficiency. Sudden failures, although rare, can occur as well. With the development of high-power LEDs, new devices are subjected to higher junction temperatures and higher current densities than traditional devices. This causes stress on the material, problems with heat evacuation and may cause early light-output degradation. In order to classify useful lifetime in a standardized manner it has been suggested to use the terms L70 and L50, which is the time taken by a given LED to reach 70% and 50% light output respectively.

LED performance is temperature dependent. Most ratings of LEDs published by manufacturers relate to an operating temperature of 25 °C. LED light output rises at lower temperatures and gets worst at higher ones.

LEDs have the advantage over fluorescent lamps that they do not contain mercury, they may contain other hazardous metals such as lead and arsenic.

LEDs don´t emit infrared light, so they don´t heat the surfaces illuminated by them. This is very interesting in indoor applications like rooms that require ventilation or air conditioning systems (all the habilitation spaces found onboard), comparing with the traditional illumination technologies (especially the incandescent one). LED illumination won´t add calories to be evacuated by ventilation or the air conditioning system, so energy is been saved in two ways. The only heat produced by LEDs is in their ballast circuit, and this heat must be dissipated in order to improve light output and lifetime. Many LED lamp models have their ballast circuits in aluminum housing with a radiator configuration to dissipate this undesirable heat.

The following table shows the differences between traditional illumination and LED technology, comparing power consumption (Watts) for equivalent elements and for the same level of illumination (Lumens).

Table I. - Consumption and light emitted

Source	Lamp Wattage	Lumens
Fluorescent Lamp	46	1890
Incandescent Lamp 1	60	986
Incandescent Lamp 2	25	380
LED 1	18	1890
LED 2	8	986
LED 3	4	380

B. Price

Table II shows the differences between traditional illumination and LED technology and comparing market price for equivalent elements giving the same level of illumination (Lumens). LEDs prices are expected to be reduced upon the years due to the amortization of research expenses and the bigger production series, as this technology gets more market share. This research also gave more powerful, efficient and reliable LED lamps. In the other way, prices of traditional lamps, like incandescent bulbs or fluorescents is expected to be constant, because it´s cost represent only the production cost, there´s no more development on this technologies. For this study, we will consider both values as a constant because this is most disadvantage supposed for LEDs technology application.

Table II. - Price and light emitted

Source	Price (€)	Lumens
Fluorescent Lamp	3	1890
Incandescent Lamp 1	1	986
Incandescent Lamp 2	0,6	380
LED 1	14	1890
LED 2	9	986
LED 3	4	380

C. Comparative per day

Given a defined generation plant, consumption cost is mainly function of marine gasoil cost [12] which in turn is direct function of crude barrel cost. Nowadays

(January 2015) prices are unusually low because of fracking technology and political reasons of production levels, but fracking is not economic below about 75 dollars per barrel and offshore production is also expensive, so marine gasoil prices are expected to raise upon the years. In this study, we will consider marine gasoil price as a constant because this is most disadvantages supposed for LEDs technology application.

Tables III and IV show consumption (Watts) per room and service hours for each technology.

Table III. - Traditional technology consumption per room & service hours

	Fluorescent Lamp (46 W)	Incandescent Lamp 1 (60 W)	Incandescent Lamp 2 (25 W)	Service hours per day	Kwh / day
Cabins (Main)	264	132	500	8	97152
Cabins (Toilet)		132		2	15840
Cabins (Secondary)			500	2	25000
Passages and stair trunks	328			24	362112
Dining Room	88			12	278784
Video Room	22			10	72160
Toilets		4		8	1920
Galley	54			16	19008
Food Storage		6		3	1080
Laundry	20			12	12960
Gymnasium	28			12	15456
				Total	**901,472**
		Daily gasoil consumption (t)			0,21635
		Daily cost estimated (€)			97,79

Table IV. - LED consumption per room & service hours

	LED 1 (18w)	LED 2 (8 w)	LED 3 (4 w)	Service hours per day	Kwh/day
Cabins (Main)	264	132	500	8	38016
Cabins (Toilet)		132		2	2112
Cabins (Secondary)			500	2	4000
Passages and stair trunks	328			24	141696
Dining Room	88			12	278784
Video Room	22			10	72160
Toilets		4		8	256
Galley	54			16	19008
Food Storage		6		3	144
Laundry	20			12	12960
Gymnasium	28			12	6048
				Total	**575,184**
		Daily gasoil consumption (t)			0,13804
		Daily cost estimated (€)			62,40

3. Case of study

The case of study is the accommodation of a service ship with the following main characteristics:

Overall length	89 m
Length between perpendiculars	83 m
Beam	27 m
Depth	7 m
Displacement	13700T
Block coefficient	0,83

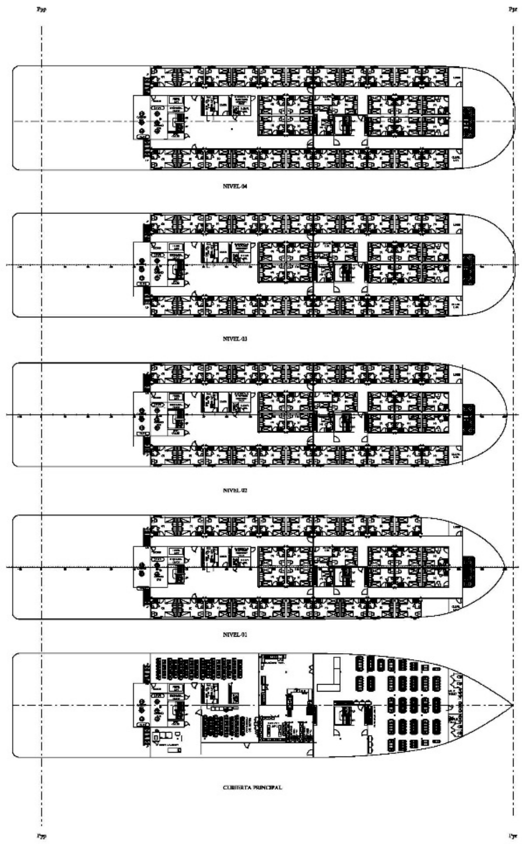

Fig. 1. Accommodation General Arrangement

This vessel is suited to transport people to an offshore working area and that is why it has a dynamic position system that allows it to stay in a specific point. Moreover the ship can be used when it is moored on harbour, in areas with no support accommodation facilities.
The ship is designed to accommodate 324 passengers, 38 service personnel (waiters, cooks, laundrymen, etc…) and 23 crew members, bringing a total of 385 people living on board, men and women (see figure 1). There are five accommodation decks, being the lower one (the Main deck) the one that holds the common services like dining room, laundry, community rooms, etc… The other four upper decks mainly hold cabins with its toilets. Most

of the crew and service personnel are hosted on the first level (the deck just up on the main deck). Passengers/workers are hosted on the three upper decks, working eight hour per day on three innings, so the passages and stairs have to be illuminated 24 hour per day. The galley has to serve three different breakfasts, lunches and dinners and furthermore other community rooms, such as video room for example, have to be operative. The ship is designed to be on the working area indefinitely, while any work is in progress, being supplied by other ships.

All the energy needed onboard (including propulsion and dynamic positioning) is provided by 4 turbocharged medium speed diesel generators, using MGA (marine gasoil) with an specific consumption of 0,24 kg / kWh for this kind of fuel, giving 2700 kW (3375 KVA) at 690 VAC 3Ph each one. Those generators are mounted in two separated machinery rooms, hosting two generators each machinery room. During navigation (that is the situation under more power is needed) three of the generator are operating and the fourth is in standby. Once ship reaches the working area, only two generators are needed, mainly for dynamic positioning and the other needs onboard (including illumination). Once ship is moored on harbour, only one generator is needed to satisfy normal energy requirements. If necessary, all the four generators can work together.

All the energy is distributed by a main distribution panel that feeds the different power networks that can be found on board:

- Main propulsion and manoeuvring power drives distribution transformers; 6600V-60Hz-3ph AC.
- Mainly general machinery onboard; 690V-60Hz-3ph AC and 440V-60Hz-3ph AC.
- Main and emergency systems, illumination, dynamic position control system, domestic apparatus, PC networks; 230V-60Hz-3ph AC.
- Emergency systems, automation systems, electrical tools and portable illumination; 24V-DC.

The economic illumination cost on board can be shown as the sum of two terms, one the acquisition and the other the fuel expense:

$$C_I = C_A + C_G \qquad (1)$$

where C_I = total cost of illumination (€ per day)
C_A = total cost of acquisition (€)
C_G =total cost of gasoil for illumination (€ per day)

The total cost of acquisition C_A and fuel expense C_G include the cost of traditional illumination and LED illumination, $C_A = C_{ATI} + C_{ALI}$ and $C_G = C_{GTI} + C_{GLI}$ respectively.

The total cost of acquisition can be obtained using the following equations

$$C_{ATI} = F_L \times N_{FL} \times I_{L1} \times N_{IL1} \times I_{L2} \times N_{IL2} \qquad (2)$$

where C_{ATI} is the traditional illumination acquisition cost, F_L the fluorescent lamp unitary cost, N_{FL} the total number of fluorescent lamps, I_{L1} the incandescent Lamp 1 unitary cost, N_{IL1} the total number of incandescent Lamp 1, I_{L2} the incandescent Lamp 2 unitary cost and N_{Il2} the total number of incandescent Lamp 2.

$$C_{ALI} = L_1 \times N_{L1} \times L_2 \times N_{L2} \times L_3 \times N_{L3} \qquad (3)$$

where C_{ALI} is the LED illumination acquisition cost, L_1 the LED1 acquisition cost, N_{L1} the LED 1 unitary cost, L_2 the LED 2 acquisition cost, N_{L2} the LED 2 unitary cost, L_3 the LED 3 acquisition cost and N_{L3} the LED 3 unitary cost.
Further, the total cost of gasoil used for illumination can be expressed as

$$C_{GTI} = \left[(h_F \times N_{FL} \times P_{FL}) + (h_{IL1} \times N_{IL1} \times P_{IL1}) + (h_{IL2} \times N_{IL2} \times P_{IL2}) \times S_C \right] \times MGO_P \qquad (4)$$

where C_{GTI} is the traditional daily gasoil cost for illumination, h_F fluorescent lamp service (hours per day), P_{FL} the unitary power consumption of fluorescent lamp, h_{IL1} incandescent Lamp 1 service (hours per day), P_{IL1} the unitary power consumption of Incandescent Lamp 1, h_{IL2} incandescent Lamp 2 service (hours per day), P_{IL2} unitary power consumption of incandescent Lamp 2, S_C specific consumption (kg / kWh) and MGO_P the marine gasoil price (€ per ton).

$$C_{GLI} = \left[(h_{L1} \times N_{L1} \times P_{L1}) + (h_{L2} \times N_{L2} \times P_{L2}) + (h_{L3} \times N_{L3} \times P_{L3}) \times S_C \right] \times MGO_P \qquad (5)$$

where C_{GLI} is the LED daily gasoil cost for illumination, h_{L1} the LED 1service (hours per day), P_{L1} Unitary power consumption of LED 1, h_{L2} the LED 2 service (hours per day), P_{L2} the unitary power consumption of LED 2, h_{L3} the LED 3 service (hours per day) and P_{L3} the unitary power consumption of LED 3.

The table V shows the cost of illumination on board.

Table V. - Total cost of illumination

Cost	Value (€)
C_{ATI}	3054
C_{ALI}	17034
C_{GTI}	97,79
C_{GLI}	62,40
Total	**20248,19**

In addition, it is interesting to evaluate other economic indicators such as CO_2 emissions issued by oil consumption. In this case the cost of CO_2 emissions are calculated taking into account that burning a ton of "conventional" fuel generates three tons of CO_2 according to the Intergovernmental Panel on Climate Change [13]. Therefore, 0.649 CO_2 tonnes will be produce per day with traditional technology and 0,414 CO_2 tonnes will produce per day with LED technology.
Nowadays there is no tax for the emissions from ships to the atmosphere. Nevertheless the rate of CO_2 emissions is

20€/tonne in the case of the air transport. If this rate were applied to the ship there will be an additional cost of 12,98 € per day for traditional illumination and 8,28 € per day for LED, which would imply a potential save of 1715€ per year of operation.

4. Conclusion

The replacement of traditional illumination technologies by LED technologies is very interesting in terms of savings of money and fuel, and reduction of CO_2 emissions. In the case study, LED application was 13980€ more expensive than the traditional one because of the acquisition cost, however LED daily operating cost is 35,40 € less than the traditional one and it allows to save 85,75 tonnes of CO_2 emissions per year. In fact, in one year of operation the LED technology will be amortized and it is possible to save money from the day 395. Savings will be even higher because of the very long lifetime of LED, since repositions are not necessary for at least five years. Nevertheless with traditional illumination it is necessary to spend about 2208€ in order to replace traditional elements that reach their end of useful live at the second year of service. Further potential savings (1715 € per year) will come from future charges for shipping CO_2 emissions for ships.

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