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Optimizing Generator Power Usage Through LED Lighting Distribution on Tugboats: A Case Study of a 26.80-Meter Vessel

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LED Technology
Energy Efficiency
Zonal Cavity Method

ABSTRACT – The 26.80 meter long tugboat plays a critical role in Indonesia's maritime operations, particularly in towing and maneuvering vessels between Semayang Port and open sea areas. As part of its operational infrastructure, the vessel relies on fluorescent lighting systems, which are known to be less energy efficient and less durable than modern lighting technologies. This presents a significant operational challenge, particularly in light of rising fuel costs and the global shift toward more sustainable maritime practices. This study addresses the issue of inefficient energy use in onboard lighting systems by evaluating the performance of conventional fluorescent lamps compared to Light Emitting Diode (LED) lighting on tugboats. The objective is to assess and compare both lighting types in terms of energy consumption, lighting uniformity, and compliance with international lighting standards set by classification societies. The research adopts the Zonal Cavity Method (ZCM), which involves dividing the interior of the tugboat into three lighting analysis zones: the High-Ceiling Cavity (HCC), High-Rise Cavity (HRC), and High-Floor Cavity (HFC). Each zone was analyzed to determine the required illumination levels based on standardized guidelines, enabling a systematic comparison of lighting performance between the two technologies. Results indicate that LED lighting systems outperform fluorescent lighting in all evaluated aspects. LEDs provided significantly higher energy efficiency and more uniform lighting distribution across all zones of the tugboat. Additionally, LED systems demonstrated better compliance with minimum illumination levels as outlined in international maritime lighting standards. The study concludes that implementing LED lighting can lead to substantial improvements in shipboard energy efficiency, reduced generator load, lower operational costs, and improved environmental sustainability. These findings suggest that maritime operators should consider transitioning to LED systems as a long-term solution for enhancing energy performance. Future research is recommended to explore the integration of LED systems with renewable power sources such as solar energy, and to evaluate the long-term economic and maintenance benefits across different vessel types and operational profiles.

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INTRODUCTION

The maritime industry is an essential pillar of the global economy, playing a central role in the movement of goods and people across international waters. As global trade continues to expand, the maritime sector has become increasingly vital in sustaining economic growth and ensuring the seamless flow of commodities between countries. In this context, the operational reliability and efficiency of maritime vessels have emerged as critical concerns for ship operators, policymakers, and researchers alike. Indonesia, recognized as the world's largest archipelagic state, relies heavily on maritime transport as the primary mode of inter-island logistics and connectivity. The country's geographical composition, consisting of more than 17,000 islands, necessitates a robust and efficient maritime infrastructure to support domestic and international trade routes. Among the various types of vessels operating in Indonesian waters, tugboats hold a particularly significant position. These vessels provide essential services such as towing large ships, facilitating port maneuvers, assisting with cargo transfers, and ensuring navigational safety in restricted or congested port areas [1][2]. Given their continuous and often high-intensity usage, improving the energy efficiency of tugboats has become a key target for operational and environmental optimization [3].

One of the most critical components affecting the operational efficiency of tugboats is their onboard lighting system. Lighting serves not only as a functional necessity for crew visibility and safety but also as a substantial contributor to the vessel's overall electrical load. Inefficient lighting systems can lead to excessive energy consumption, increased generator loads, and ultimately, higher fuel consumption. As the maritime industry grapples with tightening regulations on emissions and fuel efficiency, there is a growing need to identify and implement energy-saving technologies that can contribute to both cost reduction and environmental sustainability [4]. Traditionally, tugboats and other vessels have employed fluorescent lamps for general lighting. However, numerous studies have demonstrated that these systems are relatively inefficient when compared to modern lighting alternatives such as Light Emitting Diode (LED) technology [5][6]. LED lamps are widely recognized for their high energy conversion efficiency, extended operational lifespan, and superior lighting quality. They require significantly less power to produce the same or greater levels of illumination, thereby reducing the load on the vessel's generators and contributing to lower fuel consumption [7][8]. These benefits are particularly valuable for vessels like tugboats that operate under varying conditions and often for prolonged durations.

In practical terms, lighting systems represent a non-negligible component of a tugboat’s auxiliary power consumption. Because most lighting systems are powered through onboard generators that run on diesel fuel, any reduction in lighting load can directly translate to measurable savings in fuel usage. This is especially pertinent in today’s context of rising global fuel prices, where ship operators are under increasing financial pressure to minimize operating costs without compromising vessel performance or crew safety [9][10][11]. The transition to more energy-efficient lighting systems, such as those based on LED technology, is not only a cost-saving measure but also aligns with broader global efforts to decarbonize the maritime sector. Reducing auxiliary energy demands can contribute to lower greenhouse gas (GHG) emissions and support compliance with international maritime environmental standards. Moreover, the adoption of LED lighting systems can improve working conditions onboard, as these systems offer more stable, flicker-free, and high-lumen illumination, thereby enhancing crew comfort and safety during operations in low-visibility environments [12].

To ensure the practical feasibility and safety of new lighting systems onboard tugboats, it is essential to evaluate their performance against international standards. Organizations such as the American Bureau of Shipping (ABS) have established guidelines for minimum illumination levels in different operational areas of ships. Compliance with these standards is necessary not only for operational approval but also for ensuring that the upgraded lighting system does not compromise navigational safety or regulatory certification [13][14]. This study seeks to perform a comparative analysis between conventional fluorescent lighting systems and LED-based alternatives on tugboats operating in Indonesian waters. The research focuses on quantifying differences in energy consumption, fuel usage, and lighting quality, while also assessing adherence to applicable maritime lighting standards. By providing empirical evidence of the advantages of LED lighting in a real-world maritime setting, this study aims to support the transition toward more sustainable technologies within Indonesia’s maritime industry. Ultimately, the outcomes are expected to provide actionable insights for ship operators, regulators, and maritime engineers aiming to enhance energy efficiency and reduce the environmental footprint of maritime operations [16].

MATERIALS

Ship Description

This vessel is classified as a tugboat, specifically designed to perform essential maritime functions such as towing, maneuvering, and berthing assistance for other ships. The tugboat’s electrical system is powered by a three-phase generator driven by a Perkins 6TG2AM marine auxiliary engine, which delivers a rated power output of 64 kW [9]. This auxiliary power system supplies electricity for the vessel’s lighting, communication, and other auxiliary systems critical to onboard operations. The tugboat was constructed in 2014 at the PT. Dumas Tanjung Perak Shipyard, located in Surabaya, Indonesia one of the prominent shipbuilding facilities in the country known for producing commercial and specialized vessels. Designed to support coastal and port operations, the tugboat is equipped to accommodate a crew of up to 12 personnel, with onboard systems tailored to ensure safe and efficient operation in confined or congested maritime environments.

The vessel’s design adheres to regulatory requirements for stability, maneuverability, and energy distribution, making it a suitable case study for evaluating the integration of energy-efficient technologies such as LED lighting systems. A summary of the vessel’s principal specifications, including dimensions, engine configuration, and crew capacity, is presented in Table 1.

Table 1. Lighting Load on LED Lamps

Tugboat Specification	Unit
Length Over All (LOA)	26.80 meters
Molded Breadth (BMLD)	7.32 meters
Designed Draft (TMLD)	2.30 meters
Molded Depth (HMLD)	3.7 meters
Speed Service (Vs)	10 knots
FO Capacity	135 tons
FW Capacity	25 tons
BM Capacity	50 tons
Main Engine Generator	Cummins KTA 19-M3, 640 HP 1800RPM x 2 units 30 KW x 2 Units

Figure 1. Tug Boat Length 26.80 m [11]

Electrical Installation

Similar to land-based infrastructure, ships require a continuous and reliable power supply to support essential systems such as navigation, communication, and lighting [2]. On this tugboat, electrical power is generated by two main generators, each rated at 110 kW, serving as the primary source during operations. Additionally, a 12 kW harbor generator is used when the vessel is docked to reduce fuel consumption, while a 24 kW emergency generator ensures power availability during critical failures. These generators distribute electricity to various zones onboard, including the engine room (JL 1), vehicle deck (JL 2), intermediate deck (JL 3), passenger deck, and navigation deck—each with specific lighting needs based on their function. The ship's electrical system is designed according to a structured wiring diagram, which governs the distribution of power and supports the integration of efficient lighting systems, as illustrated in the figure below.

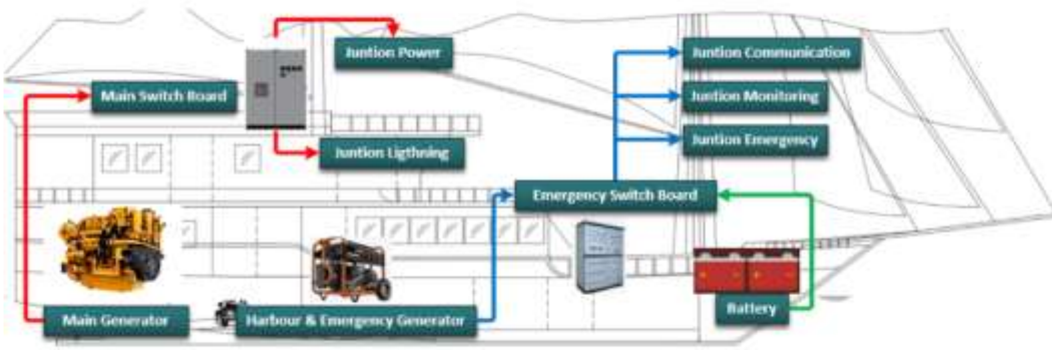

Figure 2. Example of Electric Power Distribution on the Pinisi Tourist Ship [6].

Room Illumination Standards on Ships

Illumination is defined as the intensity of light flux received by a surface area of an area, expressed in lux units [13]. This concept is very important in designing effective lighting systems for various needs, both on land and on board ships. Illumination is closely related to the level of light, where an extreme example is bright sunlight in summer, producing the highest level of illumination that can be experienced by humans [14]. Adequate illumination levels are essential to creating a safe, comfortable, and productive environment, especially in work or accommodation spaces. On board ships, illumination standards for each room are designed to suit specific operational and activity needs, such as accommodation spaces, engine rooms, navigation rooms, and other public areas. This standard aims to ensure that every activity can be carried out properly, reduce the risk of accidents, and improve crew work efficiency

Table 2. Standardized Lighting Criteria for Crew Habitability Areas [15]

Space	Illuminance Level	Space	Illuminance Level
Cabins and Sanitary Spaces			
For the reading room in general	150 Lux		
Reading and Writing		Sanitary Spaces	
Desk	500 Lux	Lavatory/Toilet room	200 Lux
Bunk Light	200 Lux	Bath/shower area	150 Lux
Changing Room	200 Lux	Light During Sleep Period	<30 Lux
Dining Room			
Mess Room and Cafeteria	300 Lux	Snack or Coffee Area	150 Lux
Recreation Space			
Lounges	200 Lux	Gym Room	300 Lux
Library			
General Lighting	150 Lux	Bulletin Board	150 Lux
Reading Area	500 Lux		
Computer Room	300 Lux	Game Rooms	200 Lux
Movie room/Movie Theater	150 Lux	Reception Areas	300 Lux

METHOD

The Zonal Cavity Method, also referred to as the Lumen Method, is a widely adopted approach for calculating and determining indoor lighting levels. This method is particularly popular in applications involving enclosed environments such as buildings, industrial facilities, and ships, due to its ability to yield accurate and reliable estimations. Its strength lies in the consideration of inter-surface reflectancean important factor that significantly influences the overall illumination within a space [17]. The method conceptualizes the interior as consisting of specific zones or "cavities" that affect how light is distributed. These zones include the ceiling cavity, room (or middle) cavity, and floor cavity, each contributing to the light reflection and absorption characteristics of the space. As illustrated in Figure 3, this zonal division enables a systematic analysis of light interactions within a room, allowing for more precise lighting design and evaluation.

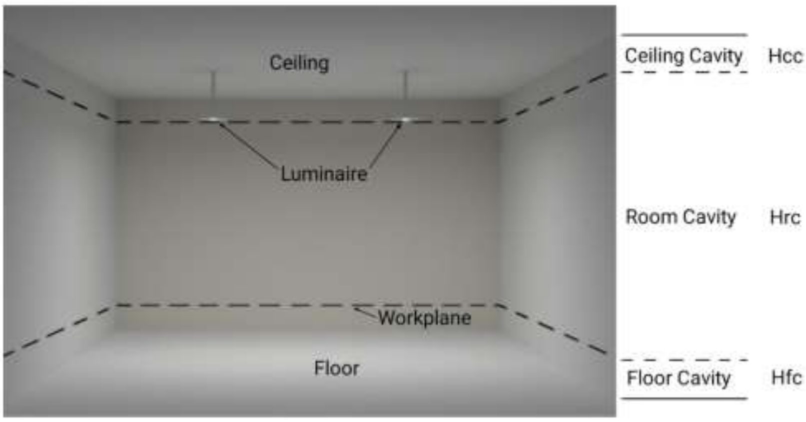

Figure 3. Cavity dimensions of the room

The calculation stages in finding the lighting level are the first to determine the Cavity Ratio, then determine the reflectance factor, then determine the coefficient of utilization and finally, compute the average illuminance level.

To get the value of the Room Cavity Ratio (RCR) ratio, you can use the following formula: Room Cavity

Ratio (RCR) = 5 hrc (L + W) / (L x W) (1)

Where :

hrc = distance from lighting to work plane
L = length of room (m)
W = room width (m)

The amount of light flux required in a room is calculated using the following formula.

$$\Phi \text{ Room} = (\text{E Room} \times A) / (CU \times LLF) \quad (2)$$

Where :

Φ Room = Luminous flux produced in a space (Lumen)
E Room = Nominal illumination required in a room (Lux)
A = Area of a room (m^2)
CU = Coefficient of Utilization/ coefficient of utilization of the luminaire
LLF = Total light loss factor

Meanwhile, to calculate the number of lights needed in a room, you can use the following formula.

$$\text{N Rooms} = \Phi \text{ Rooms} / \Phi \text{ Lamps} \quad (3)$$

Where:

N room = Number of lights needed in a room
Φ Room = Light flux produced in a room (Lumen)
Φ Lamp = Luminous flux of the lamp to be selected (Lumen).

RESULTS AND DISCUSSION

Measurement of lighting levels in each room on the ship is carried out by considering the physical conditions of the room, such as width, height, length, and area of the room. In addition, the determination of the illumination value is carried out in accordance with the applicable standards for each room. As previously explained, the generator on the ship functions to provide the electrical power needed for various purposes, including lighting, operation of pumping installations, and power for telecommunications and monitoring systems. This analysis focuses on lighting needs with the aim of evaluating the comparison of power consumption between fluorescent lamps and LED lamps on tugboats, based on lighting guidelines issued by ABS. The total power requirement for lighting on the KMP Bambit using fluorescent lamps on each deck is 24.31 kW.

Table 3. Standardized Lighting Load on LED Lamps

No	*Deck*	Power
1	Engine Room	0.407 Kw
2	Main Deck	0.624 Kw
3	Deck Navigation	0.133 Kw
Amount		1,164 Kw

From table 1, it can be seen that after conducting a study on the use of LED lamps to replace the use of fluorescent lamps, a decrease in generator power was found, which was previously 24.31 kW to 19.62 kW as shown in table 2.

Table 4. Lighting Load on Emergency Lights

No	*Deck*	Power
1	Engine Room	0.141 Kw
2	Main Deck	0.66 Kw
3	Deck Navigation	0.44 Kw
Amount		1,241 Kw

From table 3 aand table 4, it shows that the results of the comparison of power requirements of LED lamps

and fluorescent lamps are more accurate when compared to fluorescent lamps. For example, in the engine room / double bottom
, which initially used a total of 8.44 kW of fluorescent lamps , after using the LED cavity (Lumen) , the LED lamps were reduced to 5.86 kW, 1.99 kW to 1.12 kW, and Navigation Deck 8.8 kW to 7.06 kW. and fluorescent lamps are more accurate when compared to fluorescent lamps . For example, in the engine room / double bottom, where the total number of fluorescent lamps used was initially 8.44 kW, after the cavity method (Lumen) was used, the LED lamps were reduced to 5.86 kW, 1.99 kW to 1.12 kW. and Navigation Deck 8.8 kW to 7.06 kW.

For the total generator power requirements at ASL Bara, see table 5 for fluorescent lamps and table 6 for LED lamps.

Table 5. Lighting Load on Fluorescent Lamps

Continuous load (kW)	0.4	0.8	0.6	-
Intermittent Load (kW)	6.8	6.6	6.6	0.2
Diversity Factor(0.7)	4.8	4.6	4.6	0.1
Total Load (kW)	5.1	5.2	5.2	0.1
Total Generator Power (kW)	1x	1x	1x	1x
Available Power	6.4	6.4	6.4	0.17
Capacity (kW)	6	6	6	12
Generator Load Factor	80%	85%	81%	84.7%

From table 5 it can be seen that the saving effect of *LED* lamps is proven to be able to be 6.4 kW, this is proven to be able to reduce ship operational costs in terms of fuel consumption of 6000 watt generator engines.

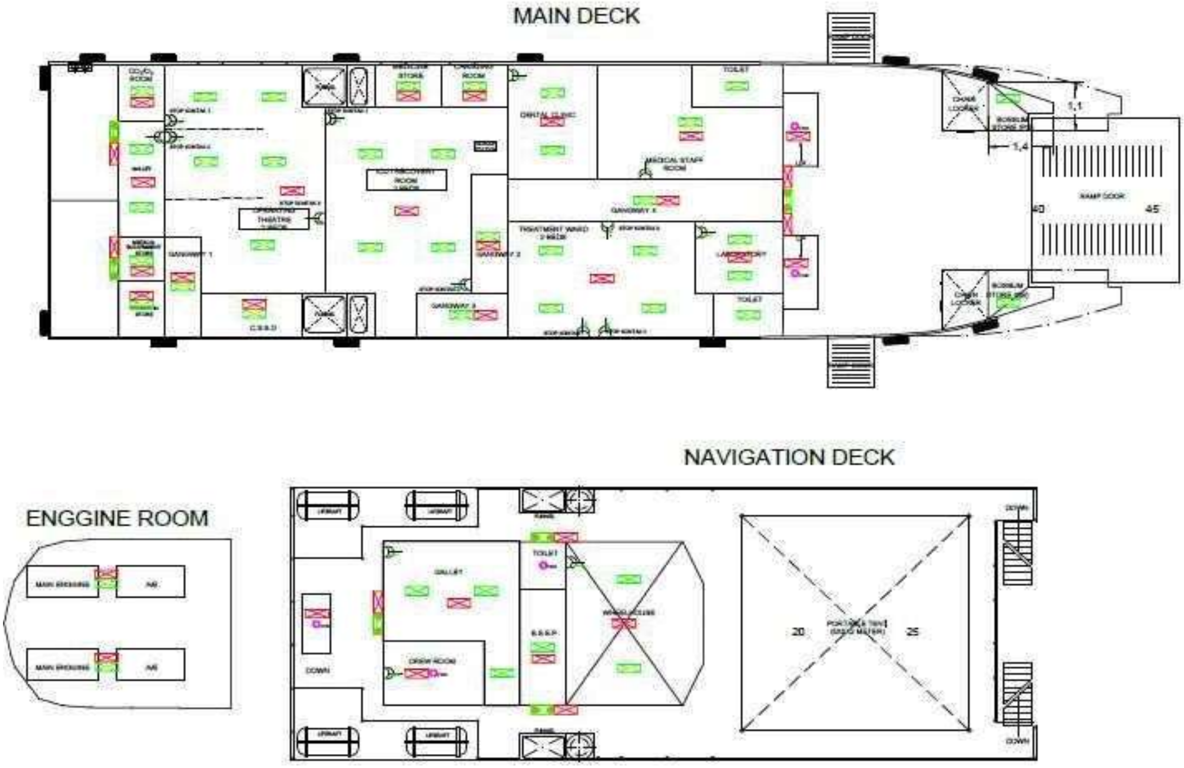

Figure 4. 2D Main Deck Plan, Engine Room, Navigation Deck LED Lights

CONCLUSION

Based on the analysis of the lighting power planning on the Batola 2 ship using LED lighting , the results show that the total accumulated lighting electrical load on each deck is 1.164 kW. For emergency lighting with LED lights , the electrical load required reaches 0.243 kW. Furthermore, in the wiring system, the power requirements connected to the Main Switchboard (MSB) consist of JL 1 of 3.89 kW, JL 2 of 2.506 kW, and JL 3 of 0.442 kW. Meanwhile, the power allocated to the Emergency Switchboard (ESB) for JE needs is 0.472 kW. Considering the total power requirements of the entire ship's electrical system using LED lights, the type of generator chosen is the Honda Generator Set 7000. The selection of this generator is based on its ability to meet electrical power needs efficiently, both for general and emergency lighting. These results indicate that the use of LED lights provides good energy efficiency, thus supporting ship operations with an optimal electrical system.

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