FOREWORD

The improvement of Ship Energy Efficiency has been a major issue for the global Shipping Industry mainly for two reasons; primarily, because the fuel expenses of merchant ships are a major part of the ship's total expenses, following the continuous increase in bunker price. Secondarily, because of the fact that the conventional Diesel Engines and Gas Turbines emit great amounts of Greenhouse Gases (GHGs); these emissions have a dramatic impact on the atmosphere, as they dissolve the ozone layer, thus intensifying the Climate Change.

The objective of this Diploma Thesis is to contribute to the identification of methods and techniques which can improve the Energy Efficiency of existing ships, taking into account the results of Energy Audits performed on them by specialized engineers.

Initially, in the first chapter, a brief introduction is made to the environmental issues raised. In addition the action taken by the International Maritime Organization (IMO) and the legal framework proposed during the relevant Sessions, are extensively explained.

The second chapter describes the concept and the application of the two main indicators proposed by the IMO; the one for existing ships, EEOI (Energy Efficiency Operational Indicator), and the one for newbuildings, EEDI (Energy Efficiency Design Index).

The third chapter contains an overview of some Energy Saving Potentials for ships; many of these potentials are widely known, yet not exploited. It is important to note that, by using the term ''potentials'', we refer to both devices and techniques.

The fourth chapter describes the basic principles and the purpose of the Ship Energy Efficiency Management Plan, which is mandatory for all existing ships. The chapter also contains a typical list of Energy Efficiency Measures included in a SEEMP for an existing Oil/Chemical Tanker.

The fifth chapter describes the procedure and purpose of the Energy Audit, which is conducted onboard by authorized engineers. After the completion of the Energy Audit, a respective Energy Audit Report is written by the auditors, as guidance for the ship operators. The Energy Audit Report is used by ship operators in order to achieve the best performance of machinery and systems onboard, and, ultimately, the lowest primary energy consumption possible. The chapter contains references from an actual Energy Audit Report, made for an existing VLCC.

The sixth chapter contains an actual Energy Audit Report for a car carrier. The respective Energy Audit was carried out during the year 2012 by Alpha Marine Services Ltd.The Energy Audit was conducted as part of the EU-funded research project "Targeted Advanced Research for Global Efficiency of Transportation Shipping" ("TARGETS"), with a view to assess the Energy Saving Potentials onboard the ship. The Energy Audit Report is presented for supervisory purposes only, in order to assist the reader in familiarization with the procedure of Energy Audit. In this respect, the details of the audited ship, such as her Name, Port of Registry, Flag and IMO number, as well as the details of the shipowner company, are deliberately omitted, due to the fact that those are treated as confidential.

The seventh and final chapter of this Diploma Thesis, examines the impact of the proposals of the Energy Audit on the improvement of Energy Management of the audited ship. The base of comparison will be the Energy Efficiency Operational Indicator (EEOI). More specifically, the EEOI is calculated before and after the implementation of the proposed energy saving practices, in order to assess the change of the ship's energy footprint.

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I would like to specially thank my father Stelios Marantis, Naval Architect and Marine Engineer of NTUA, who offered me the opportunity to appreciate this profession and helped me with his valuable experience to be adapted in the shipping industry philosophy. Finally, I would like to thank my family and everyone who supported me and helped in the timely completion of this Thesis.

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CONTENTS

ABBREVIATIONS AND SYMBOLS

Abbreviations

Abbreviation	Explanation
A/B	Auxiliary Boiler
ACS	Air Cushion System
BHP	Brake Horse Power
CFL	Compact Fluorescent Lamp
CSR	Common Structural Rules
D/G	Diesel Generator
DSME	Daewoo Shipbuilding & Marine Engineering
EA	Energy Audit
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EEMs	Energy Efficiency Measures
EIAPP	Engine International Air Pollution Prevention
EMSA	European Maritime Safety Agency
EnMS	Energy Management System
EPA	Environmental Protection Agency
ESP	Energy Saving Potential
EU	European Union
EuroDEEM	European Commission Database for Energy Efficiency Motors
FLCV	Fuel Lower Calorific Value
GHG	Greenhouse Gases
HFO	Heavy Fuel Oil
HSVA	Hamburgische Schiffbau-Versuchsanstalt (Hamburg Ship Model Basin)
HVAC	Heating, Ventilation and Air Conditioning
ICAO	International Civil Aviation Organization
ICCP	Impressed Current Cathodic Protection
IEA	International Energy Agency
IG	Inert Gas
IGS	Inert Gas System
IHI	Ishikawajima Harima Heavy Industries
IMO	International Maritime Organization
INTERTANKO	International Association of Independent Tanker Owners
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardization Organization
KPI	Key Performance Indicator
LNG	Liquefied Natural Gas
MARPOL	Marine Pollution
M/E	Main Engine
MEPC	Marine Environment Protection Committee
MHI	Mitsubishi Heavy Industries
OCIMF	Oil Companies International Marine Forum
PMS	Preventive Maintenance System
PTO	Power Take Off
SEEMP	Ship Energy Efficiency Management Plan
SMS	Safety Management System
UNFCCC	United Nations Framework Convention on Climate Change
USD/US$	United States Dollar
VSE	Voluntary Structural Enhancement
WHR	Waste Heat Recovery

Symbols

Symbol	Explanation
B	Breadth of the ship
C_F	Carbon conversion factor
D	Depth of the ship
DO	Diesel Oil
DWT	Deadweight of the ship
f_j	Power correction factor used for normalization of installed main engine power(used in EEDI formula)
f_i	Capacity correction factor(used in EEDI formula)
f_w	Weather correction coefficient(used in EEDI formula)
FC	Fuel consumption
FO	Fuel Oil
FW	Fresh Water
L_{OA}	Length Over All
L_{PP}	Length Between Perpendiculars
M	Mass
MCR	Maximum Continuous Rating
NCR	Nominal Continuous Rating
nm	Nautical Mile
P_{AE}	Power of Auxiliary Engines
P_{eff}	Power produced by energy saving technologies, which reduces the power required from Main Engine
P_{AEeff}	Power produced by energy saving technologies, which reduces the power required from Auxiliary Engines
P_{ME}	Power of Main Engine
P_{PTI}	Power of Power Take In (PTI) electrical motors
RPM	Revolutions per minute
SFC_{AE}	Specific Fuel Oil Consumption of Auxiliary Engines
SFC_{ME}	Specific Fuel Oil Consumption of Main Engine
$SFC/SFOC$	Specific Fuel Oil Consumption
SW	Sea Water
MT or t	Ton (metric)
T	Draft of the ship
TEU	Twenty feet-equivalent unit
V_{ref}	Ship reference speed
∇_{CARGO}	Volume of cargo

1. INTRODUCTION

1.1. Background and environmental issues

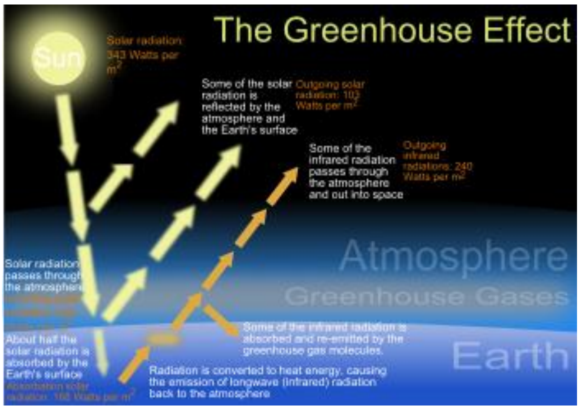
1.1.1. Climate Change

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions or the distribution of events around that average (e.g., more or fewer extreme weather events). Climate change may be limited to a specific region or may occur across the whole Earth. The climate changes in response to changes in the global energy balance. On the broadest scale, the rate at which energy is received from the sun and the rate at which it is lost to space determine the equilibrium temperature and climate of Earth. This energy is then distributed around the globe by winds, ocean currents, and other mechanisms to affect the climates of various regions.

Factors that can shape climate are called climate forcings or "forcing mechanisms". These include such processes as variations in solar radiation, deviations in the Earth's orbit, mountain -building and continental drift, and changes in greenhouse gas concentrations. There are a variety of climate change feedbacks that can either amplify or diminish the initial forcing. Some parts of the climate system, such as the oceans and ice caps, respond slowly in reaction to climate forcings, while others respond more quickly **[4]**.

1.1.2. Greenhouse Gases and Greenhouse Effect

A **greenhouse gas** (abbreviated **GHG**) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect (see also Picture 1.1). The primary greenhouse gases in the Earth's atmosphere are **water vapor, carbon dioxide, methane, nitrous oxide, and ozone**. Greenhouse gases greatly affect the temperature of the Earth; without them, Earth's surface would be on average about 33 °C (59 °F) colder than at present.



Picture 1.1-Greenhouse effect [4]

The contribution of each gas to the greenhouse effect is affected by the characteristics of the gas, its abundance, and any indirect effects it may cause. For example, on a molecule-for-molecule basis the direct radiative effect of methane is about 72 times stronger than carbon dioxide over a 20 year time frame, but it is present in much smaller concentrations so that its total direct radiative effect is smaller.

The four most important gases ranked by their direct contribution to the greenhouse effect are written in Table 1.1 **[6]**:

Table 1.1 –Contribution of certain gases to the Greenhouse effect

Gas	**Formula**	**Contribution (%)**
Water Vapor	H_2O	36-72%
Carbon Dioxide	CO_2	9-26%
Methane	CH_4	4-9%
Ozone	O_3	3-7%

Since 2000 fossil fuel related carbon emissions have equaled or exceeded the IPCC's "A2 scenario", except for small dips during two global recessions. In 2010, global CO_2 emissions exceeded the IPCC's worst case scenario, leading to concerns on whether dangerous climate change can be avoided.

1.1.3. The Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body which provides comprehensive assessments of current scientific, technical and socio-economic information worldwide about the risk of climate change caused by human activity, its potential environmental and socio-economic consequences, and possible options for adapting to these consequences or mitigating the effects. Thousands of scientists and other experts contribute on a voluntary basis to writing and reviewing reports, which are reviewed by representatives from all the governments, with summaries for policy makers being subject to line-by-line approval by all participating governments. Typically this involves the governments of more than 120 countries.

The IPCC does not carry out its own original research, nor does it do the work of monitoring climate or related phenomena itself. A main activity of the IPCC is publishing special reports on topics relevant to the implementation of the UN Framework Convention on Climate Change (UNFCCC), an international treaty that acknowledges the possibility of harmful climate change. Implementation of the UNFCCC led eventually to the Kyoto Protocol **[5]**.

1.1.4. The Kyoto Protocol

The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change, aimed at fighting global warming. The Protocol was initially adopted on 11 December 1997 in Kyoto, Japan, and entered into force on 16 February 2005. As of September 2011, 191 states have signed and ratified the protocol. The only remaining signatory not to have ratified the protocol is the United States. Other states yet to ratify Kyoto include Afghanistan, Andorra and South Sudan, after Somalia ratified the protocol on 26 July 2010 **[7]**.

Under the Protocol, 37 countries ("Annex I countries") commit themselves to a reduction of four greenhouse gases (carbon dioxide, methane, nitrous oxide, sulfur hexafluoride) and two groups of gases (hydrofluorocarbons and perfluorocarbons) produced by them, and all member countries give general commitments. Annex I countries agreed to reduce their collective greenhouse gas emissions by 5.2% with respect to the 1990 level.

The Kyoto Protocol contains provisions for reducing GHG emissions from international aviation and shipping and treats these sectors in a different way to other sources due to their global activities. Emissions from domestic aviation and shipping are included in national targets for Annex I countries. ICAO and IMO regularly report progress on their work to UNFCCC.

1.1.5. Environmental Impact of Shipping

The environmental impact of shipping includes greenhouse gas emissions and oil pollution. Carbon dioxide emissions from shipping are currently estimated at 4 to 5 % of the global total, and estimated by the International Maritime Organization (IMO) to rise by up to 72% by 2020 if no action is taken.

Shipping accounts for approximately 3% of manmade green-house gas (GHG) emissions and therefore is considered to have a significant contribution to climate change past years **[1]**. As a result, a number of proposals have been put forward to limit or reduce the climate impact of shipping. In order to evaluate these proposals adequately, it is essential to have good data about the costs of abatement and the abatement potential, preferably in a flexible way so that ad-hoc analysis can be made per ship type, for different ship sizes and age **[3]**.

1.2. Action taken by IMO

1.2.1. IMO begins work on GHG emissions

[1]*In September 1997, an International Conference of Parties to the MARPOL Convention, which adopted the Protocol of 1997 to amend the MARPOL Convention (MARPOL Annex VI), also adopted resolution 8 on* CO_2 *emissions from ships. This resolution invited the Marine Environment Protection Committee (MEPC) to consider what* CO_2 *reduction strategies might be feasible in light of the relationship between* CO_2 *and other atmospheric and marine pollutants. The resolution also invited IMO, in cooperation with the UNFCCC, to undertake a study of* CO_2 *emissions from ships for the purpose of establishing the amount and relative percentage of* CO_2 *emissions from ships as part of the global inventory of* CO_2 *emissions.*

In 2000, the first IMO GHG Study on GHG emissions from ships was published, which estimated that ships engaged in international trade in 1996 contributed about 1.8 per cent of the world total anthropogenic CO_2 *emissions* **[8]**.

Picture 1.2-The International Maritime Organization

1.2.2. Adoption of Resolution

In December 2003, the IMO Assembly adopted Resolution A.963 (23) on IMO Policies and practices related to the reduction of greenhouse gas emissions from ships, which urged MEPC to identify and develop the mechanisms needed to achieve the limitation or reduction of GHG emissions from international shipping. In the ensuing years, MEPC has since been energetically pursuing measures to limit and reduce GHG emissions from international shipping.

1.3. Outcome of IMO's relevant meetings

1.3.1. First Intersessional Meeting of IMO's Working Group on GHG Emissions from ships, June 2008

The 1st Intersessional Meeting was held in Oslo, Norway (23 to 27 June 2008) and made progress towards developing a mandatory regime to control GHG emissions from international shipping. The meeting was attended by more than 210 delegates, comprising experts from all over the world.

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[1] Statements or paragraphs written in italics are copied from the relevant sources cited in the text.

The Intersessional Meeting had been tasked with developing the technical basis for reduction mechanisms that may form part of a future IMO regime to control GHG emissions from international shipping, and with developing drafts of the actual reduction mechanisms themselves. The Intersessional Meeting reported to MEPC 58 (October 2008).

In particular, the Intersessional Meeting made progress on developing a mandatory CO_2 *Design Index for ships and an interim* CO_2 *operational index, and held extensive discussions on best practices for voluntary implementation and economic instruments with GHG-reduction potential.*

1.3.2. Marine Environment Protection Committee - 58th session, October 2008

In the context of the ongoing efforts of the international community to address the phenomena of climate change and global warming (in particular through the mechanisms of UNFCCC), and in the light of the mandate given to IMO in the Kyoto Protocol to address the limitation or reduction of GHG emissions from ships, the Committee maintained momentum on the issue and made substantive progress in developing technical and operational measures to address such emissions, including the development of an energy efficiency design index for new ships(EEDI) and an energy efficiency operational index(EEOI), with associated guidelines for both, an efficiency management plan suitable for all ships and a voluntary code on best practice in energy efficient ship operations.

The Committee approved the usage of the draft Interim Guidelines on the method of calculation of the EEDI for new ships for calculation/trial purposes with a view to further refinement and improvement.

1.3.3. Second Intersessional meeting of IMO’s Working Group on GHG Emissions from ships, March 2009

The Intersessional Meeting made significant progress in the development of measures to enhance energy efficiency in international shipping, and thereby reduce GHG emissions. The Intersessional Meeting reported to MEPC 59 (July 2009).

The Intersessional Meeting was attended by more than 200 experts from all over the world and concentrated on the technical and operational measures to reduce GHG from ships - two of the three pillars of IMO's GHG work.

The main focus was the further refinement of the EEDI for new ships, on the basis of experience gained through its trial application over the past six months. The EEDI is meant to stimulate innovation and technical development of all the elements influencing the energy efficiency of a ship, thus making it possible to design and build intrinsically energy efficient ships of the future.

The group also considered how to improve the EEOI, which enables operators to measure the fuel efficiency of an existing ship and, therefore, to gage the effectiveness of any measures adopted to reduce energy consumption. The EEOI has been applied by Member States and the shipping industry, on a trial basis and since 2005, to hundreds of ships in operation; it provides a figure, expressed in grams of CO_2 *per tonne mile, for the efficiency of a specific ship, enabling comparison of its energy or fuel efficiency to similar ships.*

1.3.4. Marine Environment Protection Committee - 59th session, July 2009

The Committee agreed to disseminate a package of interim and voluntary technical and operational measures to reduce GHG emissions from international shipping;

The agreed measures were intended to be used for trial purposes until MEPC 60 (March 2010), when they will be refined, as necessary, with a view to facilitating decisions on their scope of application and enactment. The measures include:

- *interim guidelines on the method of calculation, and voluntary verification, of the EEDI for new ships, which is intended to stimulate innovation and technical development of all the elements influencing the energy efficiency of a ship from its design phase; and*
- *guidance on the development of a SEEMP, for new and existing ships, which incorporates best practices for the fuel efficient operation of ships; as well as guidelines for voluntary use of the EEOI for new and existing ships, which enables operators to measure the fuel efficiency of a ship.*

1.3.5. Marine Environment Protection Committee - 60th session, March 2010

The Committee concluded that more work needed to be done before completing its consideration of the proposed mandatory application of technical and operational measures designed to regulate and reduce emissions of GHGs from international shipping.

The Committee agreed to establish an Intersessional Working Group to build on the significant progress that had been made during the meeting on technical and operational measures to increase the energy efficiency of ships. The Working Group reported back to the MEPC 61 (September 2010).

Although the meeting was able to prepare draft text on mandatory requirements for the EEDI for new vessels and on the SEEMP for all ships in operation, the Committee noted in particular, that, among other things, issues concerning ship size, target dates and reduction rate in relation to the EEDI requirements all required finalization.

The Committee agreed on the basic concept that a vessel's attained EEDI shall be equal or less (e.g. more efficient) than the required EEDI, and that the required EEDI shall be drawn up based on EEDI baselines and reduction rates yet to be agreed. The Committee noted guidelines for calculating the EEDI baselines using data from existing ships in the Lloyd's Register Fairplay database.

1.3.6. Marine Environment Protection Committee - 61st session, September/October 2010

Having considered means by which technical and operational measures could be introduced in the Organization's regulatory regime, the Committee noted the intention of certain member States to MARPOL Annex VI to request the Secretary-General to circulate proposed amendments, to make mandatory for new ships the EEDI and the SEEMP, both of which have already been disseminated for voluntary use. The circulated draft amendments would then be considered by the Committee's next session with a view to adoption under MARPOL Annex VI. The Committee also noted, however, that some other States did not support the circulation of the proposed amendments.

1.3.7. Third Intersessional Meeting of IMO's Working Group on GHG Emissions from ships, March 2011

The Intersessional Meeting held extensive exchange of views on issues related to the desirability of MBMs providing: certainty in emissions reductions or carbon price; revenues for mitigation, adaptation and capacity building activities in developing countries; incentives for technological and operational improvements in shipping; and offsetting opportunities.

1.3.8. Marine Environment Protection Committee - 62nd session, July 2011

The Committee considered and adopted amendments to MARPOL Annex VI for inclusion of regulations on energy efficiency for ships (resolution MEPC.203(62)), which are expected to enter into force on 1st January 2013 upon their deemed acceptance on 1 July 2012. The amendments to MARPOL Annex VI – Regulations for the prevention of air pollution from ships, add a new chapter 4 to Annex VI on Regulations on energy *efficiency for ships making the Energy Efficiency Design Index (EEDI) mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships in operation. The new regulations apply to all merchant ships of 400 gross tonnage and above regardless of the national flag they fly or the nationality of the owner.*

A work plan was agreed by the Committee to develop further the guidelines related to EEDI and SEEMP and to include development of the remaining EEDI and SEEMP related guidelines and an EEDI framework for ship types and sizes and propulsion systems not covered by the current EEDI requirements. For that purpose it was also agreed by the Committee to hold an Intersessional Meeting of the Working Group on Energy Efficiency Measures. The Intersessional Meeting will take place in January 2012 and its report should be submitted to MEPC 63 (February/March 2012).

1.4. Benefits from improving Energy Efficiency

1.4.1. General

Efficient energy use, sometimes simply called **energy efficiency**, is the goal of efforts to reduce the amount of energy required to provide products and services. Improvements in energy efficiency are most often achieved by adopting a more efficient technology or production process.

There are various motivations to improve energy efficiency. Reducing energy use reduces energy costs and may result in a financial cost savings to consumers if the energy savings offset any additional costs of implementing an energy efficient technology. Reducing energy use is also seen as a key solution to the problem of reducing emissions. According to the International Energy Agency, improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases.

Energy efficiency and renewable energy are said to be the twin pillars of sustainable energy policy. In many countries energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may slow down the rate at which domestic energy resources are depleted **[9]**.

1.4.2. Economic benefits

Energy efficiency improvements are attainable with the best available technology and practice. Energy efficient systems can pay for themselves in energy savings, sometimes within months, and further reduce operation and maintenance costs in the long term.

The International Energy Agency (IEA) says we should place the highest priority on becoming energy efficient, as this offers the highest potential for reducing carbon emissions, at the lowest cost.

In practice, however, it can be challenging to capture these benefits. Governments, businesses and individuals all play a role, but there's no easy way to coordinate their actions. Barriers to investing in energy efficiency include lack of knowledge, lack of resources and limited capital.

One of the biggest contributors to energy efficiency for ship operators is ABB's Azipod ship propulsion system. When launched in 1990, Azipod opened up a new dimension in marine technology as the world's first rotating propulsion device fitted to the outside of a ship's hull.

The energy-saving reputation of this system is such that it is now installed on half of all cruise liners built over the past two decades. The system typically reduces energy consumption of open-water vessels by 5 to 15 percent, but savings as high as 25 percent have been recorded **[2]**.

1.4.3. Conservation of natural reserves

Natural resources are materials and components that can be found within the environment. Every man-made product is composed of natural resources. A natural resource may exist as a separate entity such as fresh water, and air, as well as a living organism such as a fish, or it may exist in an alternate form which must be processed to obtain the resource such as metal ores, oil, and most forms of energy **[10]**.

Renewability is a very popular topic and many natural resources can be categorized as either renewable or non-renewable:

- Renewable resources are those that can be replenished naturally. Some of these resources, like sunlight, air, wind, etc., are continuously available and their quantity is not noticeably affected by human consumption. Though many renewable resources do not have such a rapid recovery rate, these resources are susceptible to depletion by over-use. Resources from a human use perspective are classified as renewable only so long as the rate of replenishment/recovery exceeds that of the rate of consumption.
- Non-renewable resources are resources that form extremely slowly and those that do not naturally form in the environment. Minerals are the most common resource included in this category. By the human use perspective resources are non-renewable when their rate of consumption exceeds the rate of replenishment/recovery, a good example of this are fossil fuels which are in this category because their rate of formation is extremely slow (potentially millions of years), which means they are considered non-renewable from a human use perspective. Some resources actually naturally deplete in amount without human interference, the most notable of these are the radio-active elements such as uranium, which naturally decay into heavy metals. Of these, the metallic minerals can be re-used by recycling them**, but coal and petroleum cannot be recycled.**

1.4.4. Reduction of GHG emissions

Shipping is permanently engaged in efforts to optimize fuel consumption. And, while ships are universally recognized as the most fuel-efficient mode of bulk transportation, the Second IMO GHG Study, in 2009, identified a significant potential for further improvements in energy efficiency, mainly through the use of already existing technologies such as more efficient engines and propulsion systems, improved hull designs and larger ships: or, in other words, through technical- and design-based measures that can achieve noteworthy reductions in fuel consumption and resulting CO_2 emissions on a capacity basis (tonne-mile). The study also concluded that additional reductions could be obtained through operational measures such as lower speed, voyage optimization, etc.

1.5. References

[1] Circular MEPC 61/INF.18 (REDUCTION OF GHG EMISSIONS FROM SHIPS) (2010)
[2] ‘’The Benefits of Energy Efficiency’’-The ABB Group (2010)

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[3] http://en.wikipedia.org/wiki/Environmental_impact_of_shipping
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[7] http://en.wikipedia.org/wiki/Kyoto_protocol
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[10] http://en.wikipedia.org/wiki/Natural_resource

2. DESCRIPTION OF ENERGY EFFICIENCY DESIGN INDEX (EEDI) AND ENERGY EFFICIENCY OPERATIONAL INDICATOR (EEOI)

2.1. Energy Efficiency as part of Ship Design and Engineering process

Energy- and environmental efficiency is today one of the key competence factors for ship operators and therefore these aspects also have to be one of the core elements in ship design process. Ship design and optimization is a complex task where many different parameters need to be taken into consideration. At the beginning of the design process certain capacities and main dimensions are selected for the ship and the concept will be developed, through several project phases for a detailed contract specification based on which the ship will be finally built.

Energy efficiency development has to be a merged part of the process. Energy efficiency is not only introduction of certain calculation, index or technology. Experience has shown that in order to ensure best results, development of energy efficiency needs to be a constant process within the newbuilding project, starting from definition of key performance indicators and finally ending with commissioning of onboard performance management system and training of onboard crew at ship delivery. The most important thing is that the process is constant and consistent in a way that development is always built on work carried out earlier in the design process.

The first step on energy efficiency development has to be definition of key performance indicators for ship efficiency. EEDI or EEOI could be suitable indicators, but typically shipowners have also their own performance indicators which they prefer to use for measuring efficiency of ships **[1]**.

2.2. The Energy Efficiency Design Index (EEDI)

2.2.1. Basics of the EEDI formula

The intention of the EEDI is to represent ship CO_2 specific emissions at design point. The simplest way of presenting EEDI formula is:

$$EEDI = \frac{IMPACT\ TO\ THE\ ENVIRONMENT}{BENEFIT\ FOR\ THE\ SOCIETY} = \frac{Ship\ CO_2\ emissions}{Performed\ work} \tag{2.1}$$

On top of the division line there are CO_2 emissions of main- and auxiliary engines at certain power, defined by the ships operation speed. This is divided with "benefit for the society", which is transportation of capacity at certain reference speed V_{ref}. The simplified formula can be further written into form:

$$EEDI = \frac{(CO_2)_{ME} + (CO_2)_{AE}}{Capacity \cdot V_{ref}} \tag{2.2}$$

The main (ME) and auxiliary engine (AE) emissions are calculated from fuel consumption of the main and auxiliary engines ***(FC)*** and a carbon conversion factor C_F, which connects the consumed fuel to the generated amount of CO_2 emissions. Introducing these factors in Eq. (2.2), the following equation is obtained:

$$EEDI = \frac{FC_{ME} \cdot C_{FME} + FC_{AE} \cdot C_{FAE}}{Capacity \cdot V_{ref}} \tag{2.3}$$

Fuel consumption of an engine depends on the power produced by the engine and on efficiency of the engine. Consumed fuel can be calculated as a product of produced power ***(P)*** and specific fuel consumption ***(SFC)***. When these factors are placed into the formula, the expression can be further written as:

$$EEDI = \frac{P_{ME} \cdot SFC_{ME} \cdot C_{FME} + P_{AE} \cdot SFC_{AE} \cdot C_{FAE}}{Capacity \cdot V_{ref}} \tag{2.4}$$

Certain ships are fitted with power take in electrical motors $\boldsymbol{P_{PTI}}$ on propeller shaft and the environmental impact of these devices needs to be included into the formula. It is also possible that a ship is equipped with innovative energy saving technologies such as sails, solar panels or a waste heat recovery system, which reduce the power required either from main or auxiliary engines ($\boldsymbol{P_{eff}}$ and $\boldsymbol{P_{AEeff}}$). These matters are taken into consideration in the formula by subtracting the emission reduction due to innovative technologies with aid of additional factors. The EEDI formula then has additional elements and is written as follows:

$$EEDI = \frac{(P_{ME} \cdot SFC_{ME} \cdot C_{FME}) + (P_{AE} \cdot SFC_{AE} \cdot C_{FAE}) + [(P_{PTI} - P_{AEeff}) \cdot SFC_{AE} \cdot C_{FAE}] - (P_{eff} \cdot SFC_{ME} \cdot C_{FME})}{Capacity \cdot V_{ref}} \tag{2.5}$$

Ships with special design elements (e.g. ice-class) may require additional installed main engine power. This is taken into consideration by introducing a power correction factor (f_j) which is used to normalize the installed main engine power. It is also possible that capacity of the ship is limited due to technical or regulatory reasons, and therefore a capacity correction factor (f_i) is included in the formula. As ships are designed for various operation conditions of wave height, wave frequency and wind speed, a weather correction coefficient (f_w) is also included for normalizing speed of the ship. When these non-dimensional factors are included in the formula, the expression is:

$$EEDI = \frac{f_j \cdot (P_{ME} \cdot SFC_{ME} \cdot C_{FME}) + (P_{AE} \cdot SFC_{AE} \cdot C_{FAE}) + [f_j \cdot (P_{PTI} - P_{AEeff}) \cdot SFC_{AE} \cdot C_{FAE}] - (P_{eff} \cdot SFC_{ME} \cdot C_{FME})}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w} \tag{2.6}$$

Finally, as mathematical symbols for taking into consideration multiple engines and factors are included, the formula is written as it has been presented in IMO MEPC.1/Circ.681 **[2]**:

$$EEDI = \frac{\left(\prod_{j=1}^{M} f_j\right) \cdot \left(\sum_{i=1}^{nME} P_{ME}(i) \cdot SFC_{ME}(i) \cdot C_{FME}(i)\right) + (P_{AE} \cdot SFC_{AE} \cdot C_{FAE}) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{n_{PTI}} P_{PTI}(i) - \sum_{i=1}^{n_{eff}} f_{eff}(i) P_{AEeff}(i)\right) \cdot SFC_{AE} \cdot C_{FAE}\right) - \left(\sum_{i=1}^{n_{eff}} f_{eff} \cdot P_{eff} \cdot SFC_{ME} \cdot C_{FME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w} \tag{2.7}$$

The EEDI formula, which may appear very complex at a first glance, is actually a rather simple representation of ship CO_2 emissions as separate factors are put together. The unit of EEDI can also be derived from the formula:

$$[EEDI] = \frac{gCO_2 / hour}{(t \cdot nm) / hour} = \frac{gCO_2}{t \cdot nm} \tag{2.8}$$

2.2.2. Calculation principles

According to Annex 1 of the Resolution MEPC 63/4/11, there are several modifications needed regarding the formula and calculation of the attained EEDI for new ships.

Specifically, the updated formula for EEDI is

$$EEDI = \frac{\left(\prod_{j=1}^{M} f_j\right)\cdot\left(\sum_{i=1}^{nME} P_{ME}(i)\cdot SFC_{ME}(i)\cdot C_{FME}(i)\right) + (P_{AE}\cdot SFC_{AE}\cdot C_{FAE}) + \left(\left(\prod_{j=1}^{M} f_j\cdot\sum_{i=1}^{n_{PTI}} P_{PTI}(i) - \sum_{i=1}^{n_{eff}} f_{eff}(i) P_{AEeff}(i)\right)\cdot SFC_{AE}\cdot C_{FAE}\right) - \left(\sum_{i=1}^{n_{eff}} f_{eff}(i)\cdot P_{eff}(i)\cdot SFC_{ME}\cdot C_{FME}\right)}{f_i\cdot f_c Capacity\cdot V_{ref}\cdot f_w} \tag{2.9}$$

- *If part of the Normal Maximum Sea Load is provided by shaft generators, SFC_{ME} and C_{FME} may be used -for that part of power- instead of SFC_{AE} and C_{FAE}.*
- *In case of $P_{PTI}>0$, the average weighted value of $SFC_{ME}\cdot C_{FME}$ and $SFC_{AE}\cdot C_{FAE}$ should be used for calculation of P_{eff}.*

It is important to note that Eq.(2.9) may not be able to apply to Diesel-electric propulsion, turbine propulsion or hybrid propulsion system **[4]**.

The factors that appear in the updated formula are explained in detail below **[4]**:

1) ***C_F*** *is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content, the same with that of the first EEDI formula.*

2) ***V_{ref}*** *is the ship speed, as described in the first EEDI formula*

3) ***Capacity*** *is defined as follows:*

 3.1) *For bulk carriers, tankers, gas tankers, ro-ro cargo ships, general cargo ships, refrigerated cargo carrier and combination carriers, deadweight should be used as Capacity.*

 3.2) *For passenger ships and ro-ro passenger ships, gross tonnage in accordance with the International Convention of Tonnage Measurement of Ships 1969, Annex I, regulation 3 should be used as Capacity* **[4]**.

 3.3) *For containerships, 70 per cent of the deadweight (DWT) should be used as Capacity.*

4) ***P*** *is the power of the main and auxiliary engines, measured in kW. The subscripts ME and AE refer to the main and auxiliary engine(s), respectively. The summation over i is for all main engines, with the number of engines being nME.*

 4.1) ***$P_{eff}(i)$*** *is the output of the innovative mechanical energy efficient technology for propulsion at 75 per cent main engine power. Mechanical recovered waste energy directly coupled to shafts need not be measured, since the effect of the technology is directly reflected in the* ***V_{ref}***.

 In case of a ship equipped with dual-fuel engine or a number of engines, C_{FME} and SFC_{ME} should be the power weighted average of all the main engines.

 4.2) ***$P_{AEeff}(i)$*** *is the auxiliary power reduction due to innovative electrical energy efficient technology (e.g. solar power, wind power) measured at $P_{ME}(i)$.*

 4.3) ***P_{AE}*** *is the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation, e.g. main engine pumps, navigational systems and equipment and living on board, but excluding the power not for propulsion machinery/systems, e.g. thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g. reefers and cargo hold fans, in the condition where the ship engaged in voyage at the speed* ***V_{ref}*** **[4]**.

For ships with a main engine power of 10,000 kW or above, P_{AE} *is defined as:*

$$P_{AE(MCR_{ME} \geq 10000kW)} = \left(0.025 \cdot \left(\sum_{i=1}^{nME} MCR_{MEi} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75} \right) \right) + 250 \tag{2.10}$$

For ships with a main engine power below 10,000 kW, P_{AE} *is defined as:*

$$P_{AE(MCR_{ME} < 10000kW)} = \left(0.05 \cdot \left(\sum_{i=1}^{nME} MCR_{MEi} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75} \right) \right) \tag{2.11}$$

For ships where the P_{AE} *value calculated by Equations (2.10) or (2.11) is significantly different from the total power used at normal seagoing, e.g. in cases of passenger ships, the* P_{AE} *value should be estimated by the consumed electric power (excluding propulsion) in conditions when the ship is engaged in a voyage at reference speed (* V_{ref} *) as given in the electric power table, divided by the average efficiency of the generator(s) weighted by power.*

5) V_{ref}*, Capacity and P should be consistent with each other.*

6) ***SFC*** *is the certified specific fuel consumption, measured in g/kWh, of the engines. The subscripts ME(i) and AE(i) refer to the main and auxiliary engine(s), respectively.*

For ships where the P_{AE} *value calculated by Equations (2.10) or (2.11) is significantly different from the total power used at normal seagoing, e.g. conventional passenger ships, the Specific Fuel Consumption* SFC_{AE} *of the auxiliary generators is that recorded in the test report included in a* NO_x *technical file for the engine(s) at 75 per cent of MCR power of its torque rating.* SFC_{AE} *is the power-weighted average among* SFC_{AE} *of the respective engines.*

For those engines which do not have a test report included in a NO_x *technical file because their power is below 130 kW, the SFC specified by the manufacturer and endorsed by a competent authority should be used. At the design stage, in case of unavailability of test report in the* NO_x *file, the SFC specified by the manufacturer and endorsed by a competent authority should be used.*

For LNG driven engines of which the Specific Fuel Consumption is measured in kJ/kWh, SFC should be corrected to the SFC value of g/kWh using the standard lower calorific value of the LNG (48000 kJ/kg), referring to the 2006 IPCC Guidelines **[4].**

7) f_j *is a correction factor to account for ship specific design elements.*

7.1) *The power correction factor,* f_j*, for ice-classed ships should be taken as the greater value of* f_{j0} *and* $f_{j,min}$ *as tabulated in Table 2.1, but not higher than* $f_{j,max}=1.0$ **[4].**

Table 2.1-Correction factor (for Power) f_j for ice-classed ships [4].

Ship Type	f_{j0}	$f_{j,min}$ depending on the ice class			
		IA Super	IA	IB	IC
Tanker	$\frac{0.308 \cdot L_{PP}^{1.920}}{\sum_{i=1}^{nME} P_{ME(i)}}$	$0.15 \cdot L_{PP}^{0.30}$	$0.27 \cdot L_{PP}^{0.21}$	$0.45 \cdot L_{PP}^{0.13}$	$0.70 \cdot L_{PP}^{0.06}$
Bulk Carrier	$\frac{0.639 \cdot L_{PP}^{1.754}}{\sum_{i=1}^{nME} P_{ME(i)}}$	$0.47 \cdot L_{PP}^{0.09}$	$0.58 \cdot L_{PP}^{0.07}$	$0.73 \cdot L_{PP}^{0.04}$	$0.87 \cdot L_{PP}^{0.02}$
General Cargo Ship	$\frac{0.0227 \cdot L_{PP}^{2.483}}{\sum_{i=1}^{nME} P_{ME(i)}}$	$0.31 \cdot L_{PP}^{0.16}$	$0.43 \cdot L_{PP}^{0.12}$	$0.56 \cdot L_{PP}^{0.09}$	$0.67 \cdot L_{PP}^{0.07}$

7.2) *The factor f_j, for shuttle tankers with propulsion redundancy should be f_j=0.77. This correction factor applies to shuttle tankers between 80000 and 160000 DWT with propulsion redundancy. The Shuttle Tankers with Propulsion Redundancy are tankers used for loading of crude oil from offshore installations equipped with dual-engine and twin-propellers needed to meet the requirements for dynamic positioning and redundancy propulsion class notation.*

7.3) *For other ship types, f_j should be taken equal to 1.0.*

8) ***f_w*** is *a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed (e.g. Beaufort Scale 6)* **[4].**

9) ***$f_{eff(i)}$*** *is the availability factor of each innovative energy efficiency technology. In particular, **$f_{eff(i)}$** for waste energy recovery system should be one (1.0).*

10) ***f_i*** *is the capacity factor for any technical/regulatory limitation on capacity, and should be assumed to be one (1.0) if no necessity of the factor is granted* **[4].**

10.1) *The capacity correction factor, f_i, for ice-classed ships should be taken as the lesser value of f_{i0} and $f_{i,max}$ as tabulated in Table 2.2, but not lower than* $f_{i,min}$ = *1.0* **[4].**

Table 2.2- Capacity correction factor f_i for ice-classed ships [4].

Ship Type	f_{i0}	$f_{i,max}$ depending on the ice class			
		IA Super	IA	IB	IC
Tanker	$\frac{0.00138 \cdot L_{PP}^{3.331}}{Capacity}$	$2.10 \cdot L_{PP}^{-0.11}$	$1.71 \cdot L_{PP}^{-0.08}$	$1.47 \cdot L_{PP}^{-0.06}$	$1.27 \cdot L_{PP}^{-0.04}$
Bulk Carrier	$\frac{0.00403 \cdot L_{PP}^{3.123}}{Capacity}$	$2.10 \cdot L_{PP}^{-0.11}$	$1.80 \cdot L_{PP}^{-0.09}$	$1.54 \cdot L_{PP}^{-0.07}$	$1.31 \cdot L_{PP}^{-0.05}$
General Cargo Ship	$\frac{0.0377 \cdot L_{PP}^{2.625}}{Capacity}$	$2.18 \cdot L_{PP}^{-0.11}$	$1.77 \cdot L_{PP}^{-0.08}$	$1.51 \cdot L_{PP}^{-0.06}$	$1.28 \cdot L_{PP}^{-0.04}$
Container ship	$\frac{0.1033 \cdot L_{PP}^{2.329}}{Capacity}$	$2.10 \cdot L_{PP}^{-0.11}$	$1.71 \cdot L_{PP}^{-0.08}$	$1.47 \cdot L_{PP}^{-0.06}$	$1.27 \cdot L_{PP}^{-0.04}$
Gas Carrier	$\frac{0.0474 \cdot L_{PP}^{2.590}}{Capacity}$	1.25	$2.10 \cdot L_{PP}^{-0.12}$	$1.60 \cdot L_{PP}^{-0.08}$	$1.25 \cdot L_{PP}^{-0.04}$

13) f_c *is the cubic capacity correction factor and should be assumed to be one (1.0) if no necessity of the factor is granted* **[4].**

14) ***Length between perpendiculars***, L_{BP} *means 96% of the total length on a waterline at 85 per cent of the least moulded depth measured from the top of the keel, or the length from the foreside of the stem to the axis of the rudder stock on that waterline, if that were greater. In ships designed with a rake of keel, the waterline on which this length is measured should be parallel to the designed waterline. The length between perpendiculars* L_{BP} *should be measured in metres* **[4].**

2.2.3. Interpretation of EEDI value

The EEDI value simply expresses the CO_2 specific emissions of a ship at one design point. This is the simplest way to regulate design efficiency since definition of regulatory baselines would be more or less impossible for more detailed emission calculation for real operation.

Therefore, the index values do not represent the actual transportation CO_2 efficiency of the ship since the operation profile and capacity utilization is not taken into account in the calculation.

Similarly, different types of ships should not be directly compared against each other since the index represents only one point of the total operation profile. A good example is comparison of general cargo ships and RoRo ships. If index values and baseline curves of general cargo and RoRo ships are set against each other, it seems that RoRo transportation is not as efficient as transporting cargo with general cargo ships. First conclusion is that speed of RoRo ships is higher compared to general cargo and also ship lightweight/deadweight ratio is different. However, for RoRo ships there is usually cargo moving in both directions for all voyages where as for general cargo ships it is more difficult to obtain cargo for all voyages as the traffic can be more spot trading. This would actually mean that in many cases the actual transportation efficiency, measured in $gCO_2/t*nm$, could be much worse for general cargo ships than for a RoRo ship even though in index point of view the situation is opposite **[1].**

2.2.4. Degrees of freedom for EEDI optimization

Before examining the sensitivity of EEDI, it needs to be understood which of the factors are such design criteria that cannot be affected. Excluding these parameters from the scope of EEDI optimization will finally show the potential for EEDI optimization that can be made by the designer.

- ***Capacity:*** Since ship is always designed for a certain transportation task, capacity of the ship could be considered as a fixed parameter which cannot be affected unless the whole concept is redesigned.
- **V_{ref},P_{ME}** :Speed and main engine power are connected to each other. Speed/power relation is actually one way of measuring efficiency of the ship. If a ship is designed for a certain speed, the required engine power will be determined then by that speed and other related design criteria. From the designer's point of view, the speed is usually given as design criteria, and the possibilities to affect on power depend on designer's skills and degrees of freedom for hydrodynamic optimization.
- ***SFC***: The specific fuel consumption depends mainly on selection of machinery. Two stroke and four stroke engines have different specific fuel consumption and the gap depends on size of individual engines. These alternatives also differ slightly from propulsion train efficiency point of view. When the engine type is selected, there are only small possibilities to affect the actual SFC to be used on the calculation.
- **C_F:** Fuel selection is one of the first decisions made by the shipowner regarding the power plant. Sometimes HFO is the only practical alternative, but in certain areas and for certain ship types, LNG is becoming a true alternative. Fuel selection between regular bunker fuel and LNG will heavily affect the specific CO_2 emissions. However, in a global scale considering all ship types, the practical possibilities for using LNG are still quite limited today.
- **P_{AE}:** Auxiliary power could be affected to some extent by means of optimization of auxiliary systems. However, since the basic approach in EEDI calculation for cargo ships is to derive **P_{AE}** directly as a certain percentage of **P_{ME}**, there are practically no chances to affect this value independently.
- **P_{Aeff}, P_{eff}:** Introduction of innovative technologies can be considered as an issue which can be affected by the designer.
- **f_i, f_j, f_w** :The correction factors should not be parameters for EEDI optimization since their purpose is to normalize speed, power and capacity requirements or limitations set by the special design criteria.

The conclusion from the aforementioned is that the main parameters which a ship designer can affect without considerable changes in the initial design criteria are: speed/power performance and introduction of innovative technologies. Additionally there are issues such as use of PTO and/or PTI which affect the EEDI value and can be configured by the designer. The rest of the EEDI formula parameters are actually design criteria and alternatively the possibility to affect them is very small **[1].**

2.3. The Energy Efficiency Operational Indicator (EEOI)

2.3.1. Objective of EEOI

The objective of the Energy Efficiency Operational Indicator (EEOI) is to provide with assistance in the process of establishing a mechanism to achieve the limitation or reduction of greenhouse gas emissions from ships in operation.

The relevant Guidelines (MEPC.1-Circular 684) present the concept of an indicator for the energy efficiency ***of a ship in operation****, as an expression of efficiency expressed in the form of CO_2 emitted per unit of transport work. The Guidelines are intended to provide an example of a calculation method which could be used as an objective, performance-based approach to monitoring the efficiency of a ship's operation.*

These Guidelines are recommendatory in nature and present a possible use of an operational indicator. However, shipowners, ship operators and parties concerned are invited to implement either these Guidelines or an equivalent method in their environmental management systems and consider adoption of the relevant principles when developing plans for performance monitoring **[3]**.

2.3.2. Definition of EEOI

In its most simple form the Energy Efficiency Operational Indicator is defined as the ratio of mass of CO_2 emitted per unit of transport work:

$$Indicator = \frac{M_{CO_2}}{Transport\ work} \tag{2.12}$$

Fuel consumption

Fuel consumption, FC, is defined as all fuel consumed at sea and in port or for a voyage or period in question, e.g., a day, by main and auxiliary engines including boilers and incinerators.

Distance sailed

Distance sailed means the actual distance sailed in nautical miles (deck log-book data) for the voyage or period in question.

Ship and cargo types

The Guidelines are applicable for all ships performing transport work.

1) Ships:

- *dry cargo carriers*
- *tankers*
- *gas tankers*
- *containerships*
- *ro-ro cargo ships*
- *general cargo ships*
- *passenger ships including ro-ro passenger ships*

2) Cargo:

Cargo includes but not limited to: all gas, liquid and solid bulk cargo, general cargo, containerized cargo (including the return of empty units), break bulk, heavy lifts, frozen and chilled goods, timber and forest products, cargo carried on freight vehicles, cars and freight vehicles on ro-ro ferries and passengers (for passenger and ro-ro passenger ships)

Cargo Mass Carried or Work Done

In general, cargo mass carried or work done is expressed as follows:

- *for dry cargo carriers, liquid tankers, gas tankers, ro-ro cargo ships and general cargo ships, metric tonnes (t) of the cargo carried should be used;*

- *for containerships carrying solely containers, number of containers (TEU) or metric tons (t) of the total mass of cargo and containers should be used;*
- *for ships carrying a combination of containers and other cargos, a TEU mass of 10t could be applied for loaded TEUs and 2 t for empty TEUs; and*
- *for passenger ships, including ro-ro passenger ships, the number of passengers or gross tonnes of the ship should be used;*

In some particular cases, work done can be expressed as follows:

- *for car ferries and car carriers, number of car units or occupied lane metres;*
- *for containerships, number of TEUs (empty or full); and*
- *for railway and ro-ro vessels, number of railway cars and freight vehicles, or occupied lane metres.*

For vessels such as, for example, certain ro-ro vessels, which carry a mixture of passengers in cars, foot passengers and freight, operators may wish to consider some form of weighted average based on the relative significance of these trades for their particular service or the use of other parameters or indicators as appropriate.

Voyage

Voyage generally means the period between a departure from a port to the departure from the next port. Alternative definitions of a voyage could also be acceptable **[3].**

2.3.3. Establishing an EEOI

The EEOI should be a representative value of the energy efficiency of the ship operation over a consistent period, which represents the overall trading pattern of the vessel. In order to establish the EEOI, the following main steps will generally be needed:

1) define the period for which the EEOI is calculated;*
2) define data sources for data collection;
3) collect data;
4) convert data to appropriate format; and
5) calculate EEOI.

** Ballast voyages, as well as voyages which are not used for transport of cargo, such as voyage for docking service, should also be included. Voyages for the purpose of securing the safety of a ship or saving life at sea should be excluded.*

2.3.4. Calculation of EEOI based on operational data

The objective of this paragraph is to provide guidance on calculation of the Energy Efficiency Operational Indicator (EEOI) based on data from the operation of the ship.

Data sources

Primary data sources selected could be the ship's log-book (bridge log-book, engine log- book, deck log-book and other official records).

Fuel mass to CO_2 mass conversion factors (C_F)

C_F is a conversion factor between fuel consumption measured in t and CO_2 emissions also measured in t based on carbon content. Values of **C_F** are given in Table 2.1 **[2]**, **[3]:**

Table 2.3- Values of Conversion Factor C_F.

Type of Fuel	Reference	Carbon Content(by mass)	$C_F \left(t_{CO_2} / t_{Fuel} \right)$
Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
Liquefied Petroleum Gas	Propane Butane	0.819 0.827	3.000000 3.030000
Liquefied Natural Gas		0.75	2.750000

Calculation of EEOI

The basic expression for EEOI for a voyage is defined as:

$$EEOI = \frac{\sum_j FC_j \cdot C_{Fj}}{m_{CARGO} \cdot D} \tag{2.13}$$

Where average of the indicator for a period or for a number of voyages is obtained, the Indicator is calculated as:

$$Average\ EEOI = \frac{\sum_i \sum_j (FC_{ij} \times C_{Fj})}{\sum_i (m_{CARGO,i} \times D_i)} \tag{2.14}$$

where:

- *j is the fuel type;*
- *i is the voyage number;*
- *FC_{ij} is the mass of consumed fuel j at voyage i;*
- *C_{Fj} is the fuel mass to CO_2 mass conversion factor for fuel j;*
- *m_{CARGO} is cargo carried (tones) or work done (number of TEU or passengers) or gross tones for passenger ships; and*
- *D_i is the distance in nautical miles corresponding to the cargo carried or work done.*

The unit of EEOI depends on the measurement of cargo carried or work done, e.g $\frac{t_{CO_2}}{t \cdot nm}, \frac{t_{CO_2}}{TEU \cdot nm}, \frac{t_{CO_2}}{person \cdot nm}$,etc.

2.4. References

[1] DELTAMARIN Report: EEDI Tests & Trials for EMSA(2009)

[2] MEPC.1/Circular 681 (INTERIM GUIDELINES ON THE METHOD OF CALCULATION OF THE ENERGY EFFICIENCY DESIGN INDEX FOR NEW SHIPS) (2009)

[3] MEPC.1/Circular 684 (GUIDELINES FOR VOLUNTARY USE OF THE SHIP ENERGY EFFICIENCY OPERATIONAL INDICATOR (EEOI)) (2009)

[4] MEPC 63/4/11 (AIR POLLUTION AND ENERGY EFFICIENCY (Report of the second Intersessional Meeting of the Working Group on Energy Efficiency Measures for Ships)) (2012)

3. ENERGY SAVING POTENTIALS

3.1. General

This chapter contains an overview of some Energy Saving Potentials for ships; many of these potentials are widely known, yet not widely exploited, for certain reasons to be analyzed later in the chapter. It is important to note that, by using the term ''potentials'', we refer to both devices and techniques. An indicative summary of these potentials, is presented in the Table 3.1 **[1]**.

Table 3.1- Energy Saving Potentials.

Operational Speed Reduction (10%)
Operational Speed Reduction (20%)
Weather Routing
Autopilot upgrade/adjustment
Propeller polishing at regular intervals
Propeller polishing when required (include monitoring)
Hull cleaning
Hull coating 1
Hull coating 2
Air lubrication
Propeller rudder upgrade
Propeller boss cap fin
Propeller upgrade
Common Rail
Main Engine Tuning
Waste Heat Recovery
Wind engine
Wind kite
Solar Power
Speed control pumps and fans
Energy saving lighting
Optimization water flow

Certain of these potentials are explained in detail in the present chapter.

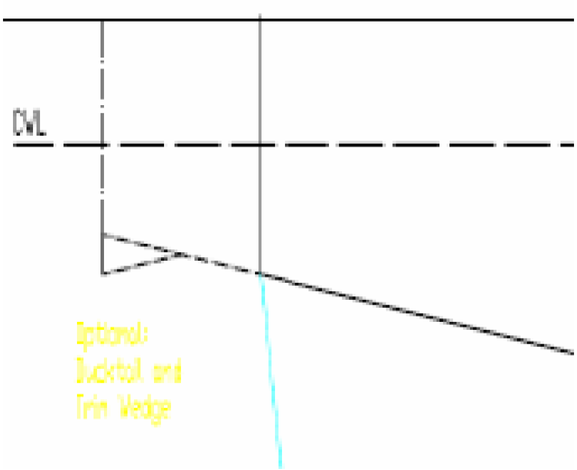
3.2. Energy Saving Devices

3.2.1. Appendages to reduce stern waves

Hull appendages which reduce the stern wave and, respectively, the wave resistance almost 2-5% are shown in Pictures 3.1-3.3 **[2]**. As a result of the reduction of resistance, it is achieved:

- either a higher velocity for the same Engine Power Output,
- or a reduced power demand for the same speed.

Picture 3.1- Ducktail [2].



Picture 3.2- Wedge [2].

Picture 3.3- Ducktail with Interceptor [2].

These appendages result in the following modifications regarding the afterbody flow:

- Flow velocity under the hull decreased
- Pressure recovery increased
- Transom exit velocity increased.

Regarding the wave system, the modifications are:

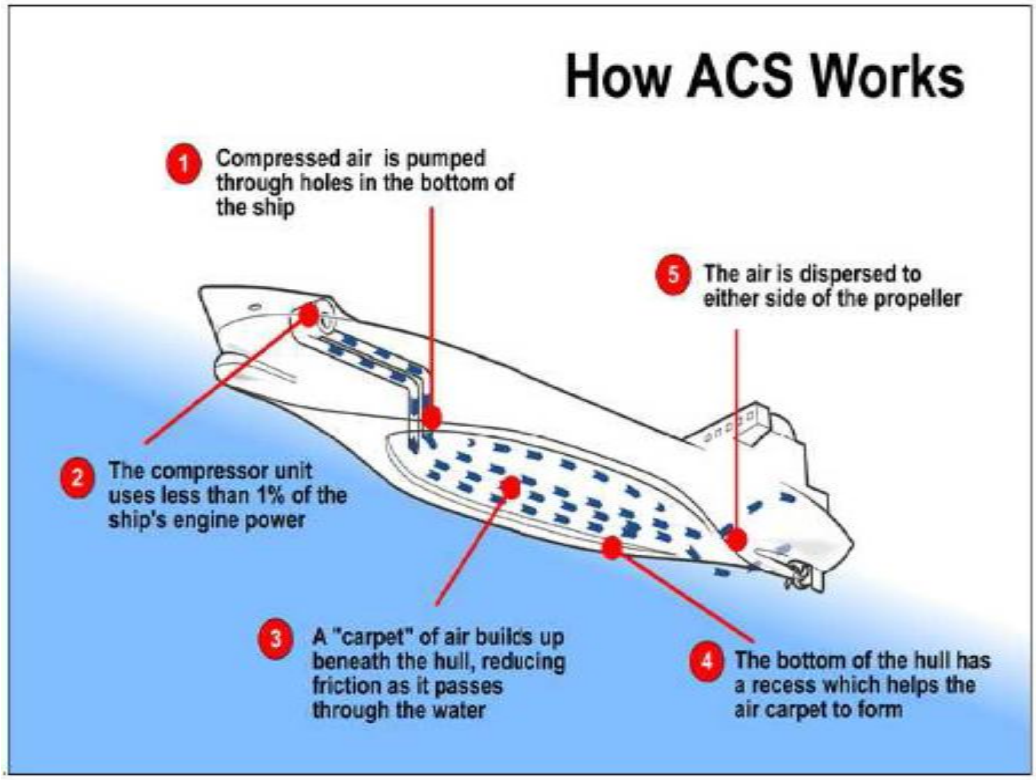
- Localized transom wave system altered
- Near field wave heights reduced
- Far field wave energy reduced.

The secondary stern flap/ducktail hydrodynamic effects are the following:

- Ship length increased
- Beneficial propulsion interactions
- Ship trim modified
- Ship sinkage is reduced.

3.2.2. Air Cushion System on the bottom

The function of the ACS is shown in the Picture 3.4.



Picture 3.4- Function of the ACS [2].

The friction resistance reduction, for certain types of merchant ships, is estimated as follows:

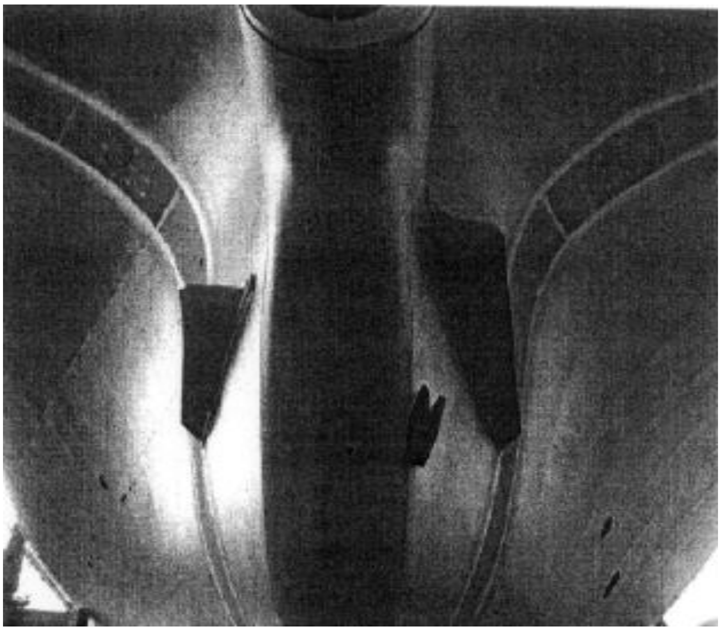
- Tanker: 15%
- Bulker: 15%
- LNGC : 7 ~ 9%

- Containership: 5 ~ 7%

3.2.3. Fins in front of a propeller

- Wake Acceleration (WA) Fin (Oshima)

This fin, shown in Picture 3.5, reduces the swirl resistance of the full hull form.



Picture 3.5- Wake Acceleration Fin [2].

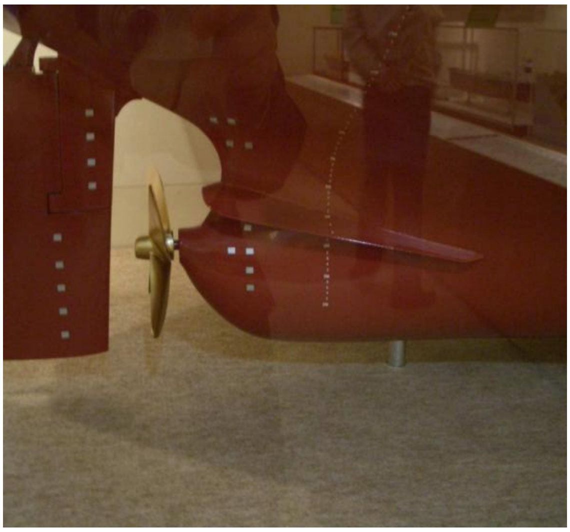
- IHI(Ishikawajima Harima Heavy Industries) Low Viscous Fin

Picture 3.6- Low Viscous Fin [2].

This fin reduces the swirl resistance of the full hull form. A reduction of 2% is estimated for tankers and bulk carriers **[2]**.

- Namura Fin

The Namura Fin, shown in Picture 3.7, reduces swirl resistance of the full hull form. A reduction of 2% is estimated for tankers and bulk carriers **[2]**.



Picture 3.7- Namura Fin [2].

- Wake equalizing duct

The Duct shown in Picture 3.8 prevents the separation of flow in front of semiduct with gathering and accelerating flow. Duct produces thrust with receiving the oblique downward flow due to bilge vortices.

Picture 3.8- Wake Equalizing Duct [2].

- Fin and Duct

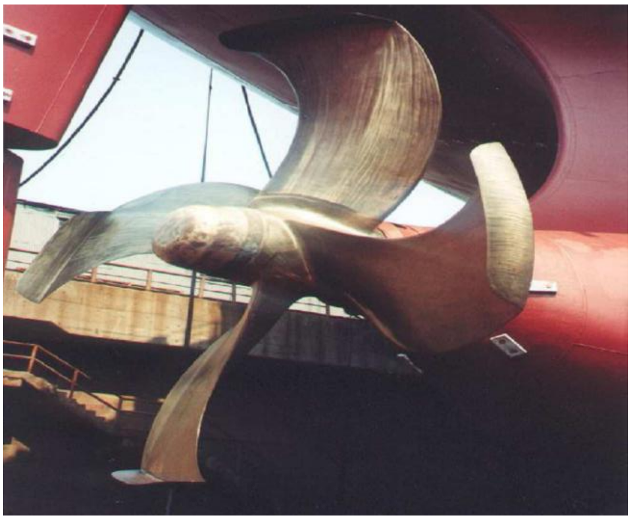
Contra fins pre-twist the flow towards propeller and cancel rotational flow behind flow. Semi-duct prevents the separation of flow in front of semiduct with gathering and accelerating flow.

Picture 3.9- Fin and Duct [2].

3.2.4. Special propellers

- CLT(Contracted and Loaded Tip)

The pitch in the CLT propeller (shown in Picture 3.10), is increased monotonously towards the tip so that the blade tip bears a substantial load. This is possible thanks to the existence of the tip plate that actuates as a barrier avoiding the communication of water between both sides of the blade. Tip plate is located on the pressure side of the blade with the aim to obtain a higher overpressure downstream. The Claimed gain is 6-12% **[2].**



Picture 3.10- CLT Propeller [2].

- KAPPEL

The KAPPEL (shown in Picture 3.11) is a special propeller with blades curved towards the suction side integrating the fin or winlet into the propeller blade. The claimed gain is 4 - 6% **[2].**

Picture 3.11- KAPPEL propeller [2].

3.2.5. Stators behind the propeller

- Propeller Boss Cap Fin (PBCF)

This stator shown in Picture 3.12 eliminates the hub vortex and recovers the kinetic energy of rotation flow around the boss, thus increasing thrust by 1% and reducing shaft torque by more than 3% **[2].**

Picture 3.12- Propeller Boss Cap Fin [2].

- Contra-Rotating Propeller

The contra-rotating propeller, shown in Picture 3.13, recovers the kinetic energy due to the rotational flow **[2].**

Picture 3.13- Contra-rotating propeller [2].

- Thrust Fin

The thrust fin, shown in Picture 3.14, recovers the kinetic energy due to the rotational flow **[2].**

Picture 3.14- Thrust Fin [2]

- Rudder Stator Fin

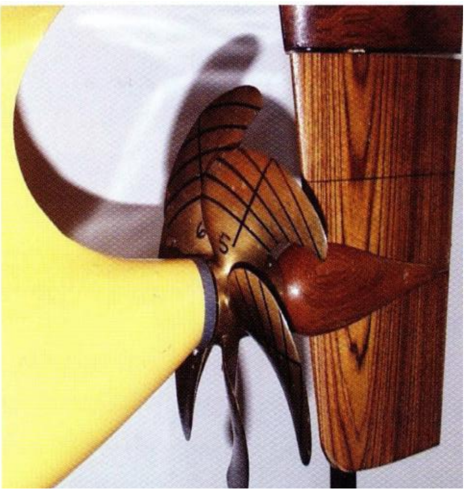
The Rudder Stator Fin, shown in Picture 3.15, recovers the kinetic energy due to the rotational flow **[2].**

Picture 3.15- Rudder Stator Fin [2].

3.2.6. Rudder bulb

- Twisted rudder with bulb

The twisted rudder with bulb, shown in Picture 3.16, reduces the hub vortex, increases the wake fraction and reduces the contraction of the propeller slipstream. According to HSVA, the gain (expressed as a percentage of the total power consumption reduction) is 2% for the twisted rudder plus 2% for the bulb **[2].**



Picture 3.16- Twisted Rudder with Bulb [2].

- Efficiency Rudder (Wärtsilä)

The efficiency rudder, shown in Picture 3.17, reduces the propeller inflow velocity; a more uniform and less contracted slipstream behind the propeller reduces losses in kinetic energy and the hub drag is reduced by avoiding flow separation. The claimed gain, according to HSVA is up to 6% **[2].**

Picture 3.17- Efficiency Rudder [2].

- Rudder Bulb Hubcap (Rolls-Royce)

The Rudder Bulb Hubcap, shown in Picture 3.18, increases propulsive efficiency and manoeuvrability and reduces pressure pulse. The claimed gain for a single-screw chemical tanker is 3-6% and for a twin-screw Ro-Ro is 1-2% **[2].**

Picture 3.18- Rudder Bulb Hubcap [2].

3.3. Energy Saving Practices

In this section, certain abatement measures are described briefly in the order shown in Table 3.1. A technical description is given, applicability to ship types and/or size categories and market maturity are indicated. If known, abatement potential and cost data are described.

The abatement potential is given in the percentage of CO_2 emission reduction on a per ship basis. Two types of costs are differentiated, non-recurring and annual recurring costs:

Non-recurring costs are the costs associated with purchasing and installing a measure. Annually recurring costs are annual operational costs associated with the measure **[1]**.

3.3.1. Operational Speed Reduction

By operating at lower speeds, ships reduce their power requirement and hence their fuel consumption. As a rule of thumb, power requirement is related to ship speed by a third power function. This means that a 10% reduction in speed results in an approximate 27% reduction in shaft power requirements. However, a ship sailing 10% slower would use approximately 11% more time to cover a certain distance. If this is taken into account, a new rule of thumb can be drafted stating that per tonne mile, there is a quadratic relation between speed and fuel consumption, so that a 10% decrease in speed would result in a 19% reduction in fuel consumption.

Using these data, we arrive at the relation between ship speed, engine load and fuel consumption, given in Table 3.2.

Table 3.2- Relation of ship speed, engine load and fuel consumption

Speed (% of design speed)	Engine Power (% of MCR)	Fuel Consumption
100%	75%	100%
90%	55%	81%
80%	38%	64%
70%	26%	49%

The potential to reduce speed is limited. Engines cannot be operated at any load without adjustments to the engine. The minimum load depends on the technical specification of the manufacturer for each individual engine. From a technical point of view, a ship operating on slow steaming is most probably operating at so-called off-design conditions. Sailing at off-design conditions may in some circumstances cause engine damage. Electronically controlled engines are more flexible to operate at off-design and can generally be operated at lower loads than mechanically controlled engines.

- Applicability: Subject to the constraints with regards to sailing in off-design conditions, slow steaming can be applied by all ship types and size categories. Ships that have to maintain a route/time schedule, for example cruise vessels and ferries, will probably not make use of this measure.
- Technical maturity: Slow steaming is currently implemented by many shipping companies facing high fuel costs and low transport demand. It can thus be considered a technically mature option.

3.3.2. Weather Routeing

There are weather routeing services available that help to optimize the route a ship takes, given the corresponding weather conditions. Reduction of travel time leads to a reduction of fuel consumption.

- Applicability: ocean-going vessels that have route flexibility.
- Power consumption reduction potential: 0.1-4%.However, a significant portion of the world's fleet already employs this technology. Therefore, the actual abatement potential is much lower.
- Costs: USD 800-1600 per annum. Costs are the same for all vessel types.

3.3.3. Autopilot Adjustment

Adjusting the autopilot to the route and the operation area prevents unnecessary use of the rudder for keeping the ship on course.

- Power consumption reduction potential: 0.5-3%. However, a significant portion of the world's fleet already employs this technology. Therefore, the actual abatement potential is much lower.
- Payback time: short.

3.3.4. Propeller Maintenance

Propeller polishing

Propeller surfaces can be cleaned to reduce roughness and the accumulation of organic materials. This can be done on a regular basis or when monitoring of the propeller performance gives an indication to do so. Propeller polishing has widely been used over the last 5 years. It is estimated that half of the maximum abatement potential has already been captured. Estimates are based on industry interviews.

Polishing on a regular basis

- Power consumption reduction potential: 2-5%
- Costs: USD 3000-5000 per polishing for a single screw vessel; a quantity discount may be provided.

Polishing when required (including monitoring)

- Power consumption reduction potential: 2.5-8%

3.3.5. Hull Cleaning

By reducing the frictional resistance of a hull, consumption of bunker fuel and thus emissions of CO_2 can be reduced; this is often the outcome of a hull resistance management program. One way of reducing the frictional resistance is to enhance the smoothness of a hull by means of coatings that prevent/reduce fouling (see above). In addition, the hull can be cleaned periodically. This is considered here.

- Reduction potential:1-10%
  However, a significant portion of the world's fleet already employs this measure. Therefore, the actual abatement potential is much lower.
- Costs: cleaning the entire hull costs USD 35-45 per foot of the ship based on the length overall L_{OA}. This is based on interviews with hull-cleaning companies.

3.3.6. Main Engine Tuning

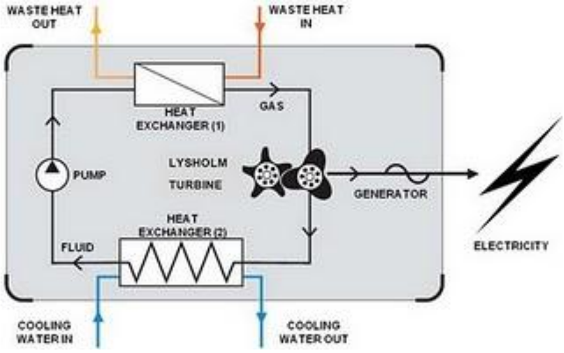
In main engine turning, the most commonly used load ranges have to be determined and then the main engine is optimized for operation at that load. This measure requires a different engine mapping and entails changes in cam profiles and injection timing. This measure can reduce overall fuel, although there may be a fuel use penalty under seldom-used full load operations.

- Applicability: All types of ships except ferry and cruise
- Technical maturity: available on the market.
- Reduction potential: 0.1-0.8%.
- Payback time: short.

3.3.7. Waste Heat Recovery

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its “value”. The strategy of how to recover this heat depends in part on the temperature of the waste heat fluid and the economics involved.

Large quantity of hot flue gases is generated from boilers, kilns, ovens and furnaces. If a certain amount of this waste heat could be recovered, a considerable amount of primary fuel could be saved.



Picture 3.19- Rankine Cycle for electricity production by Waste Heat Recovery

With a waste heat recovery (WHR) system, the waste heat of the engines can be used to cover thermal loads, and, if sufficient heat is recoverable, to drive turbines for electricity production, leading to less fuel consumption by the auxiliary engines.

- Applicability: A WHR system is reasonably applied to ships with a high production of waste heat and a high consumption of electricity.
- Technical maturity: available on the market.
- Power consumption reduction potential: As to the emission reduction potential, different numbers can be found in the literature. For higher output engines Wärtsilä assesses a high efficiency WHR plant to be able to recover up to about 12% of the engine shaft power. When the efficiency of an engine is improved or speed is reduced, less waste heat is discharged, leading to lower abatement potential **[3].**

3.3.8. Wind Power

With a kite that is attached to the bow of a ship wind energy can be used to substitute power of the ship engines.

- Applicability: Can be used on vessels with a minimum length of 30 m and works best on ships with an average speed no higher than 16 knots. Due to this speed restriction, only tankers (crude oil, product, chemical, LPG, LNG, other) and bulk carriers are considered as potential users. The system can be retrofitted.
- Technical maturity: Until now, kites that have an area of up to 640 m^2 for cargo vessels, fishing trawlers and yachts are available. By now, kite systems have been installed to a small number of commercial ships (multipurpose cargo vessel and fishing trawler). All vessels are equipped with a 160 m^2 kite. Kites up to an area of 5,000 m^2 are planned. For the calculation of the cost efficiency and the maximum abatement potential of a towing kite, we assume that by 2030 kites up to 5,000 m^2 will be available in the market.
- Power consumption abatement potential: It is difficult to determine the potential reduction of fuel consumption of a towing kite, since the potential does not only depend on the area of a kite applied, but also on the route a vessel takes and the respective weather conditions. In Table 3.3 **[1]**, the engine equivalent powers we used for the different kite sizes are given. These numbers hold under standard conditions described in **[1].**

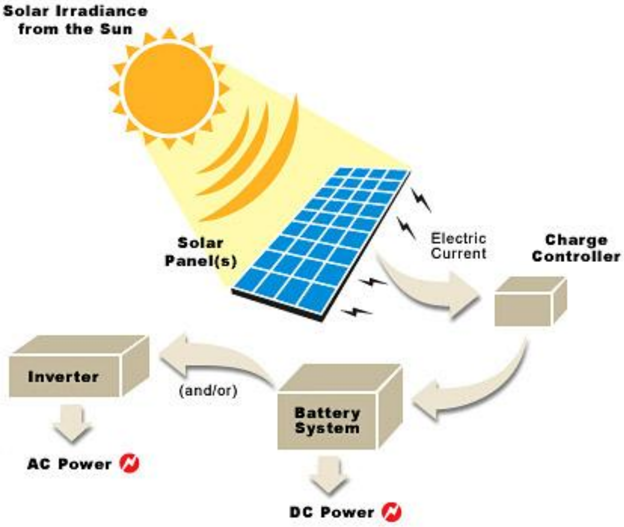
Table 3.3- Equivalent Power regarding different kite sizes [1].

Kite Area (m^2)	Engine Equivalent Power (kW)
160	600
320	1200
640	2500
1280	4900
2500	9600
5000	19200

Picture 3.20- SkySails towing kite propulsion on the MS Beluga Skysails

3.3.9. Solar Power

Solar energy can be used to deliver electricity for the onboard power demand. Applicability: Solar cells can only be placed on ships that have sufficient deck space available. Therefore it is assumed that they can be used by tankers, vehicle carriers, and Ro-Ro vessels.



Picture 3.21- System arrangement including solar panels

- Technical maturity: Under development.
- Power consumption abatement potential: Since investment costs are only known from the installation of solar cells to a Japanese car carrier, we assume the abatement potential due to the 40 kW that have been installed in this case. This solar-powered car carrier is called **M/V Auriga Leader**. It features 328 solar panels mounted on its top deck. Auriga Leader is part of a demonstration project

developed by the Port of Long Beach, Toyota and NYK Line, a shipping company with headquarters in Tokyo. Replacing 40 kW of the auxiliary engines by solar cells, the abatement potential of the solar cells is within a range of 0.2 and 3.75%.

Picture 3.22- M/V Auriga Leader

- Costs: For the car carrier Auriga Leader that installed 40kW of solar cells the investment costs are known to be 1.67 million USD. The cost of solar power may decrease in the future when the technology is mature and applied to large scales of ships. A 15% learning rate is applied to capture its effect. This learning rate is based on onshore solar power analysis.

3.4. Barriers to improving Shipboard Energy Efficiency

In this chapter the barriers to implementing shipboard energy improvements are examined. Broadly speaking, the barriers to implementing technical and operational measures that reduce energy consumption by ships can be divided into technology constraints and nontechnology constraints, which are institutional and financial. The non-technology constraints that prevent the adoption of technical and operational measures to increase the energy efficiency could potentially be resolved through economic and/or regulatory policy instruments, at least theoretically. Whereas technology constraints can be resolved only through technological breakthroughs.

When considering the barriers to introduction/expanded use ***it is worth noting that almost all of the current proposed approaches to shipboard energy efficiency improvement being discussed were being proposed and/or tried back in the late 1970s / early 1980s*** *(if not a lot earlier) in response to the oil price increases at that time. There were numerous reasons why these proposed approaches were or were not fully exploited. Those same barriers to implementation are at work today. Issues such as technical concerns regarding the reliability of the approach in the maritime environment, over stated benefit claims, market issues, and economics were some of the common barriers.*

Many of the proposed approaches (as proposed in the 1970s and still being put forth as ''proposed approaches'' today) were implemented (e.g., hull cleaning, propeller polishing, weather routing, auto-pilot optimization, etc.). Therefore, consideration of the current penetration of the proposed approach needs to be taken into account when considering the overall impact of the approach on maritime industry's fuel consumption. For example, propeller polishing may improve propulsive efficiency (i.e., fuel consumption) by up to five percent over an in service propeller that has never been polished. However, numerous vessel operators polish their propellers on a regular basis. Thus, it is unlikely that propeller polishing will provide industry wide fuel savings of five percent because a significant portion of the fleet has already implemented that approach.

The barriers identified, from prior introduction experience and current analysis, fall into three broad categories as follows:

- *Technological– Concerns over the ability of the energy efficiency improvement approach to work (particularly in the marine environment) and/or provide the claimed benefits or if the approach requires the installation of equipment that would interfere with the normal working of the ship (e.g., cargo handling or stowage).*
- *Institutional – Regulatory and/or commercial arrangements that serve to impede the introduction and/or expanded use of the energy efficiency improvement approach.*
- *Financial – Some approaches are only financially viable (i.e., providing a positive net present value) when oil prices reach a specific level and are expected to stay above a specific level long enough to provide an adequate financial return on the investment in the energy efficiency improvement approach.*

Each of these types of barriers is described in greater detail in the balance of this chapter **[1].**

3.4.1. Technological Barriers

The technological barriers may be real or perceived. For example, wide spread reporting of a failure of an early installation (test or not) can delay future implementation. Reported problems with the early large size azimuth pods on several cruise ships, including the Queen Mary 2, may cause shipowners to delay investing in the technology. Similarly, contra-rotating propellers have also been labeled as having *bearing problems. The vessel type can impact the ability to install certain fuel saving approaches. For example, wind engines, such as a Flettner rotor, require a lot of deck space for installation. However, container ships and dry bulkers require large, removable hatch covers for access to cargo holds. Therefore, the deck space is not available for the installation of a wind engine.*

Another issue to consider is that certain approaches are mutually exclusive or are only applicable to certain types of ships. This is best understood through a brief description of ship resistance, which determines engine power requirements and fuel consumption. In general, ship resistance is composed of frictional resistance (between water and the ship's hull) and wave making resistance. As vessel speed increases the wave making resistance increases and becomes a higher percentage of total ship resistance. The wave making resistance is related to the natural period of the wave generated as the vessel moves through the water. All else equal, the longer the ship the longer the wave generated which has a higher natural frequency and, therefore, lower wave making resistance (because the longer ship generated wave wants to move faster). For comparison purposes, wave making resistance is roughly proportional to the speed-length ratio (ship speed divided by the square root of its length although the more complex Froude number is a better comparison). For vessels with higher speed-length ratios (e.g., containerships, RO-ROs, cruise ships, etc.) approaches directed at wave making resistance (e.g., bulbous bows, optimizing hull configuration, etc.) will have greater impact. Conversely, vessels with relatively low speed-length ratios (VLCCs, Capesize bulkers, etc.) will benefit more from approaches to reducing frictional resistance (e.g., hull cleaning, air cavity, etc.). Therefore, for example, implementing vessel speed reduction will reduce the benefits of an approach that targets reducing wave making resistance.

3.4.2. Institutional Barriers

Perhaps one of the biggest institutional barriers to implementing fuel saving projects that require capital investments (e.g., waste heat recovery systems) is the divided responsibility or ''split incentive'' between shipowner and charterer for fuel costs. Ships are typically hired (chartered) in one of the four manners listed below:

- *Spot or voyage charter – the shipowner agrees to move a specific cargo on a specific ship from port A to port B. In this arrangement the shipowner is responsible for all vessel and voyage costs.*
- *Term or time charters – the shipowner provides a specific fully manned vessel to the charterer for a fixed amount of time (typically six months to five years). The shipowner pays the vessel costs and the charterer pays the voyage costs.*
- *Bare boat charters – a shipowner provides a specific ship without crew to the charterer. The charterer is responsible for vessel (except capital) and voyage costs. Bareboat charterers are common in lease financing arrangements.*
- *Contracts of Affreightment (COAs) – a shipowner agrees to move a specific amount of cargo over a specific time from port A to port B without specifying the ship. The shipowner pays vessel and voyage costs. Because COAs may cover a longer time frame (one or more years) they will sometimes have bunker escalation clauses in which the freight rate is adjusted to cover higher than base fuel costs.*

The split incentive refers to a situation in which the people benefiting from energy efficiency are not the people paying for it. In the shipping industry, it occurs when there is a disconnect between the vessel owner, who controls capital spending and energy conservation efforts, and the operator, who is responsible for fuel cost. This primarily occurs when vessels—especially bulk carriers, tankers, and containerships—are hired under contract for a limited period of time (known as a time charter), or when only the vessel but not the crew is hired (known as a bareboat *charter). In such cases, it is the charterer who pays for fuel but the ship owner who is responsible for any investment in energy-efficiency equipment.*

Ships that are more energy efficient could theoretically have higher charter rates in the market, in practice this is difficult due to the diversity of the charter market of the difficulty guaranteeing an improved fuel consumption on a vessel whose speed is heavily impacted by the vagaries of sea conditions (e.g., weather). However, most of the major charterers are basing hire decisions on notional voyage economics and, therefore, are taking fuel consumption/speed guarantees into account in the hire decision.

Some economically viable fuel-saving efforts are route-specific and influenced by other factors (e.g., wave and weather conditions). Real fuel savings are very difficult to predict, hence a charterer is unlikely to pay a premium without a fuel-saving guarantee.

Shipowners will typically employ their vessels in a mix of spot and term charters. A shipowner only bears full responsibility for fuel costs in spot voyage charters. The current chartering system typically has industry standard speed and fuel consumption guarantees, therefore, in a term charter the shipowner may not receive a premium for a ship that is more fuel efficient than the industry standard. This reduces the incentive for a shipowner to make a capital investment in a fuel saving approach as the benefits (fuel cost savings) will not necessarily accrue to the shipowner. Recently, however, the trend in the industry is towards recognizing the value in energy efficient ships.

Another issue is that shipowners do not typically expect to own a vessel for its entire life. This can limit the time over which a shipowner is willing to include fuel cost saving benefits in analyzing the investment in a fuel saving approach. It is not guaranteed that shipowners can obtain a premium for a ship in a second hand sale that has better than expected fuel efficiency (or that the buyer will view the benefit of reduced fuel consumption in the same manner as the seller). This may have the added impact of causing shipowners to evaluate investments in energy saving equipment using a payback period approach instead of the more accurate net present value approach.

In liner shipping, tramp contracts, cruise lines, and Ro-Pax ferries, freight rates sometimes include fuel surcharges. These pass at least part of the fuel costs on to consumers, another form of split incentive.

Another chartering related barrier to fuel savings occurs when a vessel on a spot charter is moving to a discharge port with a known congestion or other problem that will delay the berthing of the vessel when it reaches the port. Under the current system, the shipowner is responsible if the vessel arrives outside of the originally designated discharge window (although the charterer has little actual recourse against the shipowner). If the vessel sails at normal speed to the discharge port and arrives within the designated window but the terminal is not ready to discharge the cargo, the time counts as laytime and once the specified allowed laytime is exceeded, the charterer must pay the shipowner demurrage at a rate (typically US$ per day or fraction thereof) specified in the charter. The opportunity to save fuel by sailing slower and arriving when the berth is ready for the vessel is lost in the current system. To address this issue, INTERTANKO, the shipowners‘ association of independent (i.e., non-oil company) tanker owners, and OCIMF (Oil Companies International Marine Forum) have developed an approach called ‘’Virtual Arrival’’ that seeks to remove the barrier to slow down operations under a spot charter arrangement. ‘’Virtual Arrival’’, can show how the shipowner-charterer problem costs the industry and how the energy efficiency will be improved if the problem could be resolved. Early trials have resulted in significant savings, in one case a 27% reduction in fuel costs were found. ‘’Virtual Arrival’’ requires inclusion of the specific agreement in the charter party and includes demurrage compensation for the added time related to slower steaming for the shipowner and shared benefits between the shipowner and charterer for reduced fuel consumption. It remains to be seen if this approach will succeed but it demonstrates *the concern by the industry regarding the institutional barriers to one of the most effective fuel saving approaches (INTERTANKO, 2009).*

Implementing slower speed operation of a ship is a trade-off between the fuel cost savings and the cost of additional ships to replace the vessel capacity lost with slower sailing speeds. Typically, slow down is implemented when there is the combination of high fuel prices 1970s / early 1980s in the tanker industry. At least one major oil company operated its long-haul crude oil fleet (owned and time chartered) in slow down mode to reduce overall shipping costs.

The same situation has emerged in the international container (liner) shipping industry beginning in late 2008. Fuel costs are relatively high combined with relatively low charter rates brought on by reduction in demand and the delivery of a large number of containerships ordered barriers to implementing slower vessel operations are arising in the container shipping industry. Shippers of containers (e.g., large box retail stores) have seen impacts on their supply chains of longer transit times and are resisting changes to slower speeds (i.e., longer transit times).

Another potential barrier to reduced speed operation is an emerging shortage of seafarers. This may push vessels back to full speed to maximize deliverability and minimize the number of crew required.

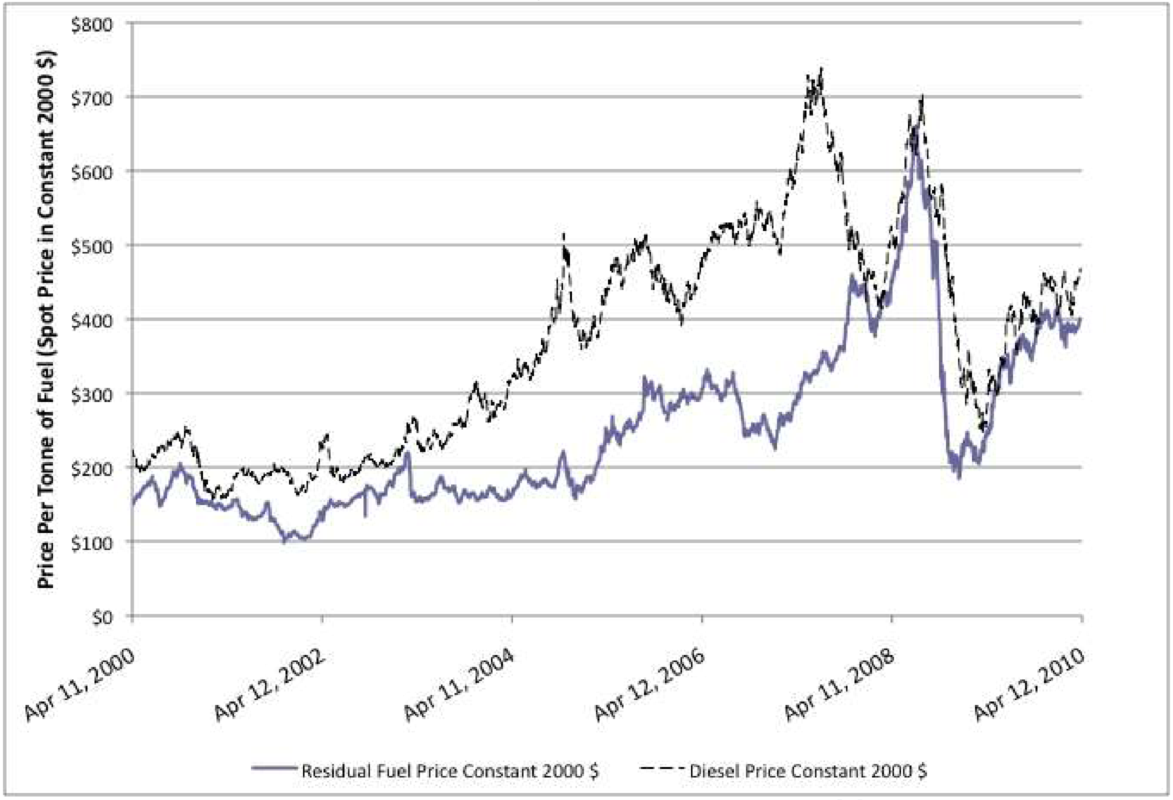
There are also regulatory barriers to employing certain fuel saving approaches. For example, in ports in California hull cleaning is not allowed in State waters (within three miles of shore) if the vessel has certain types of hull coatings that have been determined by the State to harm the environment (the hull cleaning residue is released into the water surrounding the vessel). This forces the operation offshore that significantly increases the cost.

Just as regulatory barriers can serve as a barrier to implementation of an energy efficiency improvement, governments have introduced incentives to improve the energy efficiency of vessels. For example, one consultant, whose firm participated in repowering about 40 domestic vessels and convert both 4-stroke and 2-stroke mechanically injected engines to electronically controlled engines, estimated that these refits had payback periods of 15 to 20 years in most cases, with the returns coming primarily from fuel savings and secondarily from relatively small maintenance cost improvements. To provide financial incentive to repower their ships and achieve emission related offsets in the Port of New York/New Jersey, the U.S. EPA and the Port Authority of New York and New Jersey funded most of these projects under programs that paid for nearly 100% of the cost of the new engines, while the vessel owners covered the costs associated with installation resulting in approximately 65% to 75% of the total project being funded. With these incentives the payback periods, based on current fuel costs, were in the four- to seven-year range. Even a four-year payback time is insufficient incentive to many ship owners.

The Ports of Los Angeles and Long Beach and the State of California have similar programs for assisting harbor vessel owners to re-power with lower emission engines.

3.4.3. Financial Barriers

*In order to invest in energy saving approaches shipowners expect to receive a financial benefit that earns them a risk adjusted rate of return on the investment. Many energy saving approaches have been rejected because of low expected returns on the investment. The benefit that offsets the cost of the investment is future reduced fuel costs. Future reduced fuel costs involve savings in fuel consumption (tons or barrels per day) and the cost of the fuel (*USD *per ton or barrel). Fuel costs fluctuate significantly. Within the last few years crude oil prices have ranged from nearly USD 150 per barrel to as low as USD 40 per barrel. Residual and diesel fuels have had similar variations as shown in Figure 3.23. Fuel costs, therefore, insert significant uncertainty (i.e., risk or uncertain price signals) into an investment in a shipboard energy efficiency improvement. This has served as a barrier in the past. For example,* *waste heat recovery systems were not perceived as having a positive net present value when considered in the late 1970s / early 1980s.*



Picture 3.23- Fuel Price in the recent decade [1].

Another rather obvious barrier is related to shipping market cycles. Virtually all sectors of the shipping industry go through boom/bust cycles. During boom times, when profits are high, shipowners have the funds to make investments in energy saving technology. However, shipowners are reluctant to take a vessel out of service (and miss out on high freight rates) for more than the minimum regulatory period and may not make investments that will increase the time out of service. During the bust part of the cycle, when profits are low, shipowners are reluctant to make investments and may not have access to the capital required for the investment. The boom/bust cycle issue may have a different impact in that an energy saving approach, during the boom part of the cycle may be used to increase the speed of the vessel rather than reduce its fuel consumption. For example, if a shipowner cleans the hull of a ship, one of two things will occur. The shipowner will either continue to operate the main engine at the same power level resulting in a small increase in speed due to the reduced resistance of the hull or the shipowner will reduce the power (operating RPM) level of the main engine to maintain the same pre-cleaning speed resulting in reduced fuel consumption. It has typically been the former resulting in increased speed or, as a shipowner would say, return to design speed. It is also possible that a small shipowner will not be able to obtain financing for the capital costs of an energy-efficiency improvement measure.

If a vessel is designed for a particular route, on which it will operate for the majority of its lifetime, then optimizing energy-efficiency using specific technologies is easier. However, most ships are used on many different routes under varying physical conditions, which makes the benefit of any given technology hard to assess. Given the need for flexible vessels, trading along different trade routes leads to design and construction of ships that are not necessarily optimized for specific voyages. Within each size category of vessels (e.g., Aframax and Suezmax tankers), ships have been growing in size but it is clear that they are carrying larger parcels of cargo (i.e., they are not sailing fully loaded). The size of the parcel is determined between the buyer and the seller of the cargo. The ship is selected based upon the ability to load the full *cargo but not necessarily to fill the ship. Filling a larger ship or using a smaller ship loaded fully would be more fuel efficient. However, the current commodities trading market does not fully integrate vessel fuel efficiency into its trading patterns.*

3.4.4. Conclusions

There are numerous barriers to the implementation of a more fuel efficient global shipping fleet. As described, some of the barriers are technical in nature and many of them are institutional in nature. In the end most of the barriers are of a financial nature. Institutional barriers have a way of falling when the economics are favorable, or when there are specific regulatory requirements that necessitate or foster change.

3.5. References

[1] Circular MEPC 61/INF.18 (REDUCTION OF GHG EMISSIONS FROM SHIPS) (2010)
[2] DSME (Daewoo Shipbuilding & Marine Engineering) presentation: ''Energy Saving Devices'' (2008)

Websites:
[3] http://www.em-ea.org/Guide%20Books/book2/2.8%20Waste%20Heat%20Recovery.pdf

4. DESCRIPTION OF SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP)

4.1. Introduction

There are around 70000 ships engaged in international trade and this unique industry carries 90% of world trade. Sea transport has a justifiable image of conducting its operations in a manner that creates remarkably little impact on the global environment. Compliance with the MARPOL Convention and other IMO instruments and the actions that many companies take beyond the mandatory requirements serve to further limit the impact. It is nevertheless the case that enhancement of efficiencies can reduce fuel consumption, save money and decrease environmental impacts for individual ships. While the yield of individual measures may be small, the collective effect across the entire fleet will be significant.

In global terms it should be recognized that operational efficiencies delivered by a large number of ship operators will make an invaluable contribution to reducing global carbon emissions.

A Ship Energy Efficiency Management Plan provides a possible approach for monitoring ship and fleet efficiency performance over time and some options to be considered when seeking to optimize the performance of the ship **[1].**

4.2. Purpose of SEEMP

The International Maritime Organization (IMO) finalized and adopted Guidance on the Development of a Ship Energy Efficiency Management Plan (SEEMP) under MEPC.1/Circ.683, which provides the framework for shipboard energy conservation activities.

The Ship Energy Efficiency Management Plan (SEEMP), being developed in harmony with the above framework and requirements, outlines the best practice approach for optimizing the vessel’s energy efficiency, and provides specific guidance for implementation of energy conservation measures on board the vessel. It advocates measurement and monitoring techniques for ensuring and demonstrating compliance to best practice **[2].**

The purpose of a Ship Energy Efficiency Management Plan (SEEMP) is to establish a mechanism for a company and/or a ship to improve the energy efficiency of a ship’s operation.

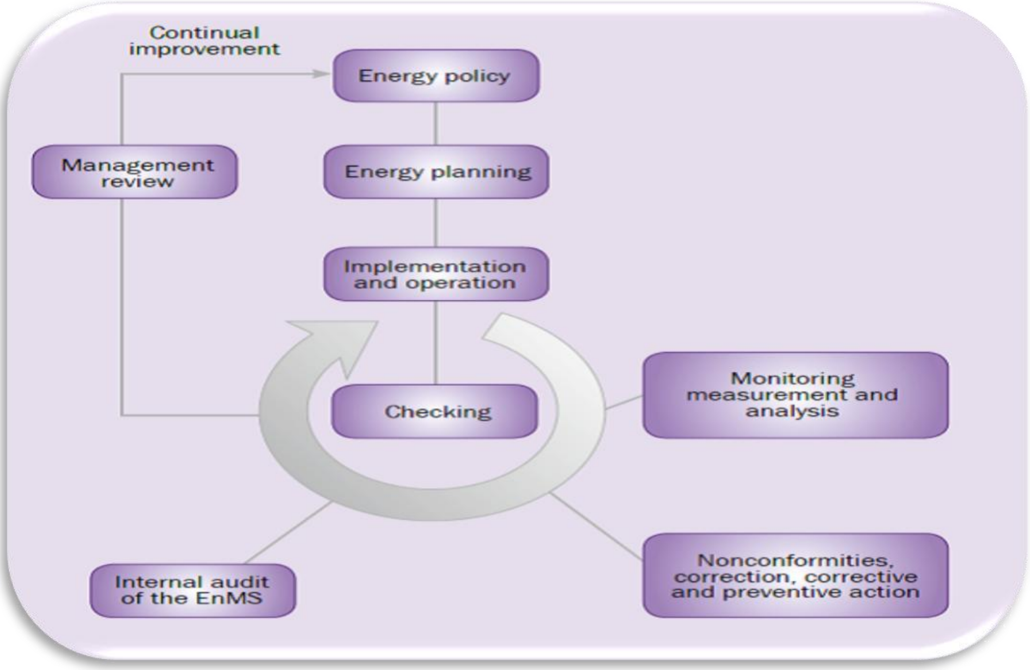
Preferably, the ship-specific SEEMP is linked to a broader corporate energy management policy for the company that owns, operates or controls the ship, recognizing that no two shipping companies or shipowners are the same, and that ships operate under a wide range of different conditions.

Many companies will already have an environmental management system (EnMS) in place under ISO14001 which contains procedures for selecting the best measures for particular vessels and then setting objectives for the measurement of relevant parameters, along with relevant control and feedback features. Monitoring of operational environmental efficiency should therefore be treated as an integral element of broader company management systems.

The SEEMP is intended to be a management tool to assist a company in managing the ongoing environmental performance of its vessels and as such, it is recommended that a company develops procedures for implementing the plan in a manner which limits any onboard administrative burden to the minimum necessary.

The SEEMP should be developed as a ship-specific plan by the shipowner, operator or any other party concerned, e.g., charterer. The SEEMP seeks to improve a ship’s energy efficiency through four steps: ***planning***, ***implementation***, ***monitoring***, **and** ***self-evaluation and improvement***. These components play a critical role in the continuous cycle to improve ship energy management. With each iteration of the cycle, some elements of the SEEMP will necessarily change while others may remain as before.

This key process required for the continuous optimization of primary energy consumption, encompassed in the SEEMP in accordance with the requirements of IMO MEPC.1/Circ.683, is shown in the SEEMP Continuous Process figure (Picture 4.1) **[3]**.



Picture 4.1-Planning, Implementation, Monitoring, Self evaluation and Improvement cycle [3].

4.3. Application of SEEMP

4.3.1. Planning

Planning is the most crucial stage of the SEEMP, in that it primarily determines both the current status of ship energy usage and the expected improvement of ship energy efficiency. Therefore, it is encouraged to devote sufficient time to planning so that the most appropriate, effective and implementable plan can be developed.

Ship-specific measures

Recognizing that there are a variety of options to improve efficiency - speed optimization, weather routeing and hull maintenance, for example - and that the best package of measures for a ship to improve efficiency differs to a great extent depending upon ship type, cargos, routes and other factors, the specific measures for the ship to improve energy efficiency should be identified in the first place. These measures should be listed as a package of measures to be implemented, thus providing the overview of the actions to be taken for that ship.

During this process, therefore, it is important to determine and understand the ship's current status of energy usage. The SEEMP then identifies energy-saving measures that have been undertaken, and determines how effective these measures are in terms of improving energy efficiency. The SEEMP also identifies what measures can be adopted to further improve the energy efficiency of the ship. It should be noted, however, that not all measures can be applied to all ships, or even to the same ship under different operating conditions and that some of them are mutually exclusive. Ideally, initial measures could yield energy (and cost) saving results that then can be reinvested into more difficult or expensive efficiency upgrades identified by the SEEMP.

Also, in the planning process, particular consideration should be given to minimize any onboard administrative burden.

Company-specific measures

The improvement of energy efficiency of ship operation does not necessarily depend on single ship management only. Rather, it may depend on many stakeholders including ship repair yards, shipowners, operators, charterers, cargo owners, ports and traffic management services.

Human resource development

For effective and steady implementation of the adopted measures, raising awareness of and providing necessary training for personnel both on shore and on board are an important element. Such human resource development is encouraged and should be considered as an important component of planning as well as a critical element of implementation.

Goal setting

The last part of planning is goal setting. It should be emphasized that the goal setting is voluntary, that there is no need to announce the goal or the result to the public, and that neither a company nor a ship are subject to external inspection. The purpose of goal setting is to serve as a signal which involved people should be conscious of, to create a good incentive for proper implementation, and then to increase commitment to the improvement of energy efficiency. The goal can take any form, such as the annual fuel consumption or a specific target of Energy Efficiency Operational Indicator (EEOI). Whatever the goal is, the goal should be measurable and easy to understand **[1].**

4.3.2. Implementation

Establishment of implementation system

After a ship and a company identify the measures to be implemented, it is essential to establish a system for implementation of the identified and selected measures by developing the procedures for energy management, by defining tasks and by assigning them to qualified personnel. Thus, the SEEMP should describe how each measure should be implemented and who the responsible person(s) is. The development of such a system can be considered as a part of planning, and therefore may be completed at the planning stage.

Implementation and record-keeping

The planned measures should be carried out in accordance with the predetermined implementation system. Record-keeping for the implementation of each measure is beneficial for self-evaluation at a later stage and should be encouraged. If any identified measure cannot be implemented for any reason(s), the reason(s) should be recorded for internal use **[1].**

4.3.3. Monitoring

Monitoring tools

The energy efficiency of a ship should be monitored quantitatively. This should be done by an established method, preferably by an international standard. The EEOI developed by the Organization is one of the internationally established tools to obtain a quantitative indicator of energy efficiency of a ship and/or fleet in operation, and can be used for this purpose. Therefore, EEOI could be considered as the primary monitoring tool, although other quantitative measures also may be appropriate.
If used, the EEOI should be calculated in accordance with the Guidelines developed by the Organization (MEPC.1/Circ.684). If deemed appropriate, a Rolling Average Index of the EEOI values may be calculated to monitor energy efficiency of the ship over time.
In addition to the EEOI, if convenient and/or beneficial for a ship or a company, other measurement tools can be utilized. In the case where other monitoring tools are used,

the concept of the tool and the method of monitoring may be determined at the planning stage.

Establishment of monitoring system

It should be noted that whatever measurement tools are used, continuous and consistent data collection is the foundation of monitoring. To allow for meaningful and consistent monitoring, the monitoring system, including the procedures for collecting data and the assignment of responsible personnel, should be developed. The development of such a system can be considered as a part of planning, and therefore should be completed at the planning stage.

It should be noted that, in order to avoid unnecessary administrative burdens on ships' staff, monitoring should be carried out as far as possible by shore staff, utilizing data obtained from existing required records such as the official and engineering log-books and oil record books, etc. Additional data could be obtained as appropriate **[1].**

4.3.4. Self-evaluation and improvement

Self-evaluation and improvement is the final phase of the management cycle. This phase should produce meaningful feedback for the coming first stage, i.e. planning stage of the next improvement cycle.

The purpose of self-evaluation is to evaluate the effectiveness of the planned measures and of their implementation, to deepen the understanding on the overall characteristics of the ship's operation such as what types of measures can/cannot function effectively, and how and/or why, to comprehend the trend of the efficiency improvement of that ship and to develop the improved SEEMP for the next cycle.

For this process, procedures for self-evaluation of ship energy management should be developed. Furthermore, self-evaluation should be implemented periodically by using data collected through monitoring. In addition, it is recommended to invest time in identifying the cause-and-effect of the performance during the evaluated period for improving the next stage of the management plan.

Voluntary reporting/review

Some shipowners/operators may wish to make public the results of the actions they have taken in their SEEMP and how those actions have impacted the efficiency of their ship(s). These efforts should be incentivized as voluntary reporting and review, which could have a number of benefits. Some national Administrations, ports or partnerships may wish to recognize the efforts of these leading shipowners/operators. For example, some ports now offer environmentally-differentiated harbour fees or other rewards to those ships that qualify as "green" and a growing number of consumer products companies increasingly utilize only verifiably green transportation options in moving their products to market. Such a proposed framework is complementary to and can easily coexist with currently successful national and international energy efficiency and emissions reductions programmes outside IMO **[1].**

4.4. Energy Efficiency Measures-Part of a SEEMP for an existing Oil/Chemical Tanker

The tables presented in the current section, are part of a SEEMP for an existing Oil/Chemical Tanker. The tables provide *details of the energy efficiency measures which aim to improve, in practice, the efficiency of the ship* in relation to the following aspects:

- Operational Management **(OM)**
- Cargo **(CG)**
- Hull / Propeller **(HP)**
- Machinery / Equipment **(ME)**
- Accommodation **(AC)**
- Training **(CT)**

In tables, the responsibilities of shipboard and office staff in way of implementation and monitoring will be abbreviated as follows:

I = Implementation Responsibility
M = Monitoring Responsibility
IM = Implementation & Monitoring Responsibility

4.4.1. Operational measures

Table 4.1- Operational Energy Efficiency Measures for an Oil/Chemical Tanker [2]

CAT	ENERGY EFFICIENCY MEASURES	SCOPE OF IMPLEMENTATION / ACTIONS	COMPLIANCE MEASURES, RECORDING AND MONITORING	RESPONSIBLE PERSON(S)
OM1	Vessel Routeing	Weather Routeing - use of best route by consideration of wind, currents, tides, sea condition, ice impact for the intended passage prior and during the voyage (possible use of weather routeing services) Route Optimization - avoidance of weather systems and strong adverse currents where possible	Voyage / Passage Plan to be prepared onboard and to be evaluated and updated by Weather Routeing Services (if used). Vessel's track to be monitored and routeing to be amended where required Voyage / Passage Plan Meetings to be held prior to and after completion of the voyage for evaluation. Plans to be retained onboard for future reference	Master (IM)
OM2	Speed Optimization	Speed to be adjusted to maintain agreed charter speed unless particularly ordered by charterer to increase/ avoidance of unnecessary over-speeding during the voyage, resulting in waiting time on anchorages Optimized arrival time to be achieved, supported by good planning by all parties involved - charterers, agents, Master, managers/ owners, port authorities etc.	Measurement, recording and reporting of the timing of ship's events, including periods of times during sea passage, waiting periods at anchorage, port stay, bunkering etc., and consumptions / performance Monitoring of ship's "duty cycle" including durations of passage, port, waiting, bunkering etc., benchmarking against sister or similar vessels (where applicable)	Master (I) Office (M)
OM3	Voyage Management	Performing the voyage in accordance to the agreed voyage / passage planning Evaluation/Assessment of recommendations for amendments to actual voyage planning when advised by Weather Routeing Services (if used)	Recording of all relevant voyage data, i.e. speed versus time, weather / sea conditions, waiting periods, etc. Analysis of voyage performance in terms of voyage profile, duration of various operations, waiting times,	Master (I) Office (M)

			consumptions, etc.	
OM4	Heading Control	Selecting autopilot setting for open-sea efficiency	Monitoring of weather and sea impact on vessel's movement and heading, and change of settings when deemed necessary to optimize autopilot operation	Master (IM)
OM5	Ballast Management	Avoidance of unnecessary ballast water quantities as far as practical Evaluating ballast levels / vessel's trim and stability against good / safe steering, autopilot settings and optimal trim Optimizing vessel's trim for loaded and ballast passages Identification of optimal trim for each loading/ballast - speed combination via analysis and best practice operational knowledge capture	Thorough calculations of vessel's trim and stability prior to and after loading / discharging in view of required ballast water intake Monitoring actual trim against calculated optimal trim (requires accurate draft readings and trim / stability calculations) Analyzing voyage performance for various loaded / ballast voyages in terms of speed / consumptions resulting from data collected Creation of a vessel-specific database for future reference and information	Master (IM) Office (M)

4.4.2. Cargo measures

Table 4.2- Cargo Energy Efficiency Measures for an Oil/Chemical Tanker [2]

CAT	ENERGY EFFICIENCY MEASURES	SCOPE OF IMPLEMENTATION / ACTIONS	COMPLIANCE MEASURES, RECORDING AND MONITORING	RESPONSIBLE PERSON(S)
CG1	Cargo Heating Optimization	Cargo Heating - optimization in view of resulting fuel consumptions and operation times of associated cargo equipment in line with C/P requirements Optimized boiler operation	Vessel's staff to establish required heating cycles for various cargo types (cargo does not need to be heated up to discharge temperature during the entire voyage unless otherwise ordered by charterer/shipper) Checks on correct and proper working condition of steam traps Cargo temperature readings to be recorded at regular intervals, records to be kept for future reference Thermal efficiency of oil-fired boilers to be reviewed / assessed to avoid any excessive loss of additional energy	Master (IM) Chief Officer (M) Office (M)
CG2	Optimized	Cargo Temperature -	Vessel's cargo system	Master (IM)

	Temperature Control	optimization of cargo heating and temperature control by means of effective cargo tank / cargo piping system insulation	insulation to be inspected at regular intervals for overall condition and efficiency Any damages on insulation to be identified and repaired	Chief Officer (M)
CG3	Cargo Pumps Usage	Use of cargo pumps to be optimized in line with discharge requirements	Vessel's staff to establish discharge routines in view of number of cargo pumps used to maintain required discharge pressure Pumping records to be maintained and retained on board for future reference Experience factors for various discharge terminals and respective discharge requirements to be maintained	Master (IM) Chief Officer (M)
CG4	Cargo Handling	Port / Cargo Operations optimization in view of reduction of port stay duration and associated use of energy	All port / cargo operations to be reviewed and assessed in view of possible reduction of duration, optimization of equipment use (where applicable) and fuel / energy consumption	Master (IM) Office (M)
CG5	Cargo Equipment Maintenance	Equipment Maintenance - cargo equipment, such as cargo pumps, heating / washing equipment, valves and associated hydraulic systems, to be always maintained to high standards in order to avoid unscheduled delays during loading, discharging or lashing operations, resulting in additional fuel consumption during the port stay	Vessel's staff to establish effective maintenance procedures for all cargo equipment, including inspection routines of all cargo equipment	Master (IM) Chief Officer (M) Office (M)
CG6	Cargo Tank Cleaning	Cleaning Procedures - best and most effective cargo tank cleaning methods to be applied to avoid unnecessary energy consumption or non-acceptance of tanks for loading, resulting in vessel's delay and associated additional fuel consumptions and costs	Industry guidelines / practices in terms of cleaning procedures for specific cargoes to be followed Vessel to establish ship-specific cleaning procedures for various cargoes in order to optimize time and equipment / materials used All cleaning operations to be sighted and approved, records of cleaning operations to be maintained for future reference, and to be sent as information to the fleet where applicable	Master (IM) Chief Officer (M) Office (M)

4.4.3. Hull and Propeller measures

Table 4.3- Hull and Propeller Energy Efficiency Measures for an Oil/Chemical Tanker [2]

CAT	ENERGY EFFICIENCY MEASURES	SCOPE OF IMPLEMENTATION / ACTIONS	COMPLIANCE MEASURES, RECORDING AND MONITORING	RESPONSIBLE PERSON(S)
HP1	Hull Performance Optimization	Hull Performance Assessment at regular intervals Underwater Hull / Propeller Condition Assessment Underwater Hull / Propeller Cleaning	Vessels to report all required performance data at monthly intervals Hull performance assessments in terms of data analysis to be carried out at monthly intervals to identify trends and to compare against benchmarks set Underwater Hull / Propeller condition assessments to be carried out during Class Intermediate and Special Surveys, either while vessel is afloat or dry-docked Underwater Hull / Propeller Cleaning to be carried out based on condition assessment when deemed necessary Records of underwater inspections and hull cleaning to be maintained	Office (IM) Chief Engineer (M)
HP2	Hull/Propeller Coatings	Investigation on use of various foul release hull / propeller coating systems in terms of reduction of hull resistance Aim for use of advanced hull and propeller coatings to increase efficiency	Data analysis in terms of savings and cost effectiveness Monitoring of correct ICCP readings, data to be sent to manufacturers	Office (IM) Chief Engineer (M)
HP3	Diversion of Air Flow	Reduction of Fuel Oil usage	Assessment/Feasibility Study about advanced Accomodation designs or means to divert air flow for optimized resistance	Office (M)

4.4.4. Machinery/Equipment measures

Table 4.4- Machinery/Equipment Energy Efficiency Measures for an Oil/Chemical Tanker [2]

CAT	ENERGY EFFICIENCY MEASURES	SCOPE OF IMPLEMENTATION / ACTIONS	COMPLIANCE MEASURES, RECORDING AND MONITORING	RESPONSIBLE PERSON(S)
ME1	Engine Condition Monitoring	Engine condition monitoring by use of DieselDoctor system (Main and Auxiliary Diesels) Review and assessment of collected data in order to identify and rectify any problems	Records of all data to be established, submitted to the Office at monthly intervals (or on specific request from Office), and to be retained onboard	Chief Engineer (IM)
ME2	Engine Performance Assessment	Engine Performance Assessment to be undertaken at regular intervals Measurement and Analysis of engine performance parameters, including Specific Fuel Oil Consumption (SFOC), maximum cylinder pressures (Pmax), turbocharger parameters, charge air pressure, etc. Measurement and analysis of Lubrication Oil consumption for each cylinder against manufacturer's recommendation in order to achieve optimization Identification of required actions to be taken following the performance assessment Engine partial load optimization	Performance assessments to be carried out based on reports sent by vessels at monthly intervals, including measurement / analysis of all engine parameters Retention of engine performance reports in order to create vessel specific history Monitoring engine performance trends in order to assess / evaluate effects of actions taken to optimize performance (if any) Consultation of engine makers to evaluate optimization of engine performance during partial load periods	Office (IM)
ME3	Auxiliary Engine Usage Optimization	Auxiliary Engine Efficiency - avoidance of low loads on more than one A/E unless needed for safety or regulatory compliance. In case two generators are run at low loads (less than 45%), a reduction of auxiliary loads	Monitoring Auxiliary Engine performance and load factors Analysis of Auxiliary Engine running hours Benchmarking of running hours against sister / similar vessels with comparable operations Retention of records for future reference	Chief Engineer (IM) Office (IM)

		is to be assessed in order to keep one generator running only Evaluation of power requirements for various shipboard operations, assessment of consolidation of operations / activities to avoid unnecessary running of additional Auxiliary Engines		
ME4	Boiler and Economizer Optimization	Elimination of steam leaks Maintenance on boiler / economizer surfaces, burners and other associated equipment Checks of steam traps condition at regular intervals	Regular visual inspections on steam piping, valves, steam traps and insulation Adjustment of Start/Stop pressures as needed Recording / monitoring of boiler running hours	Chief Engineer (IM)
ME5	Fuel Tank Heating	Assessment of fuel tank heating requirements in order to avoid too much / unnecessary heating Implementation of a fuel tank heating plan, raising temperatures to required levels only when required Avoidance of heating bunker, supply and service tanks above required temperatures	Review of compliance with bunker heating requirements Recording of fuel tank temperatures on a daily basis	Chief Engineer (IM)
ME6	Heat Recovery	Generation of maximum quantity of distilled water via heat recovery (where applicable)	Evaluation of possibilities to generate fresh water by use of waste heat of Auxiliary Diesels during waiting periods, i.e. drifting /anchorage (if water quality allows) Record and retain data on fresh water generation and use / consumption	Chief Engineer (IM)
ME7	Pumps/Fans Usage Optimization	Pumps and fans running according to Operational requirements Reduction of pumps / fans running hours Avoidance of unnecessary operation of pumps / fans while in port	Review and benchmarking of pumps / fans running hours against operational requirements and sister / similar vessels and data derived from electric balance tables	Chief Engineer (IM) Office (M)
ME8	Air Compressors	Elimination of any air leaks	Inspection and maintenance to be carried out at regular	Chief Engineer (IM)

	Usage Optimization	Fresh air supply to compressor area(s) to be sufficient in order to keep area(s) as cool as possible	intervals, following AVECS PMS Review and benchmarking of air compressor running hours against operational requirements and sister / similar vessels	Office (M)
ME9	Purifier Usage Optimization	Use of Purifiers according to operational requirements Frequency of de-slugging to be adjusted to the most optimum performance	Recording / monitoring of Purifier running hours Review and benchmarking of Purifier running hours against operational requirements and sister / similar vessels	Chief Engineer (IM) Office (M)
ME10	Inert Gas System Optimization	Optimization of IGS efficiency in accordance with operational requirements	Recording of IGS operational data, including fuel consumption Maintenance on IGS following AVECS PMS Condition assessments / inspections of IGS to be carried out at regular intervals, depending frequency of system usage Checks on IG leakages on tanks during the voyage	Chief Engineer (IM)
ME11	Incinerator Usage Optimization	Sludge to be discharged to shore facilities whenever possible to avoid increased emissions to the atmosphere	Recording / monitoring of incinerator running hours Evaluation of shore sludge disposal in terms of storage capacities on board, voyages, trading area etc.	Chief Engineer (IM) Office (M)
ME12	Bow Thruster Use	Reduction of Stand-By times of bow thruster and enhanced equipment	Review of port / maneuvering operations in terms of bow thruster usage requirements / stand-by times Recording of operation times and power requirements in association with bow thruster use Avoiding unnecessary stand-by time when tug boats are used	Master (IM) Chief Engineer (IM)
ME13	Fuel Quality	Improvement of engine efficiency by using high quality fuels Prevention of engine degradation	Assessment of availability / usage of high quality fuels against low quality fuels, based on engine performance and efficiency parameters	Office (IM)
ME14	Fuel Additives	Use of fuel additives to improve engine performance and combustion	Evaluation on usage of fuel additives (where applicable) by using engine performance records	Office (IM)
ME15	Air Condition/ Refrigeration	Optimization of refrigeration / air condition equipment usage Reduction of	Inspection and maintenance in order to avoid refrigerant leakages Recording of operational data and refill quantities	Chief Engineer (IM)

		shipboard emissions	Evaluation of operational needs in terms of cooling / refrigeration requirements (half or full compressor capacity needed to keep required temperatures)	
ME16	Alternative Fuels	Reduction of Fuel Oil usage	Assessment / Feasibility Study about usage of alternative fuels, such as LNG or Biodiesels (Dual Fuel Technology)	Office (IM)
ME17	Alternative Propulsion	Reduction of Fuel Oil usage	Assessment / Feasibility Study about propulsion systems used in addition to conventional propulsion, i.e. “SkySails”	Office (IM)

4.4.5. Accommodation measures

Table 4.5- Accommodation Energy Efficiency Measures for an Oil/Chemical Tanker [2]

CAT	ENERGY EFFICIENCY MEASURES	SCOPE OF IMPLEMENTATION / ACTIONS	COMPLIANCE MEASURES, RECORDING AND MONITORING	RESPONSIBLE PERSON(S)
AC1	Lighting Systems Optimization	Use of energy saving bulbs where possible Avoidance of unnecessary lighting	Exchange of conventional light bulbs and tubes by energy saving lighting systems Routine inspection rounds through public spaces and cabins to avoid unnecessary lighting when not in use	Chief Engineer (IM) Chief Officer (M) Office (I)
AC2	Galley, Laundry & Accommodation Appliances	Optimized use of electrical appliances - switching off appliances when not in use (includes galley equipment, recreation equipment, computers / screens, etc.) Optimized efficiency of laundry / pantry equipment - dryers, washing machines and dishwashers to be filled to full capacity before starting the programs Limited access to cold storages / reefer chambers - improvement of cooling efficiency	Routine inspection rounds through public spaces and cabins to avoid unnecessary power consumption when appliances not in use Avoiding unnecessary opening of reefer chambers / cold storages doors Recording of cold storage / reefer chamber temperatures and reefer compressor running hours	Chief Engineer (IM) Chief Officer (M)
AC3	Computer Screens	LCD Computer Screens to be used to improve efficiency	Old CRT computer screens to be gradually replaced by latest technology LCD screens Replacement program to be established	Office (IM)
AC4	Temperature	Automated	Evaluation of installation of	Office (IM)

	Control	temperature controls for public spaces and cabins onboard to improve on A/C Compressors efficiency Improvement on accommodation insulation Minimization of air flow in accommodation spaces and staircases	temperature control means for accommodation spaces Assessment and evaluation of insulation means for accommodation spaces Routine inspection rounds through public spaces to ensure that accommodation weather tight and internal doors are kept closed properly Maintenance on door-closing mechanisms	Chief Officer (M)

4.4.6. Crew Training measures

Table 4.6- Crew Training Energy Efficiency Measures for an Oil/Chemical Tanker [2]

CAT	ENERGY EFFICIENCY MEASURES	SCOPE OF IMPLEMENTATION / ACTIONS	COMPLIANCE MEASURES, RECORDING AND MONITORING	RESPONSIBLE PERSON(S)
CT1	Energy Efficiency Training	Including Energy Efficiency Training subjects in existing onboard training scheme All crew to be aware of contents of SEEMP	Creation of Energy Efficiency computer-based training (CBT), amendments to be made in Career Development Scheme (CDS) Familiarization with SEEMP contents to be included in Familiarization Checklist for new crew Onboard Instructions to be held by Master in regard to the SEEMP, legal background and company environmental management program Training records for all crew to be maintained	Office (IM) Master (IM)

4.5. Typical SEEMP Review and Endorsement checklist used by Flag State Surveyors

In this section, a typical SEEMP Review and Endorsement checklist is presented. This checklist is used by Flag State Surveyors, or by the Surveyors issuing Certificates on behalf of the Flag, to assess the completeness of a SEEMP made for a ship. The checklist is based on the requirements of MEPC.1/Circular 683 **[1].**

Table 4.7- SEEMP Review and Endorsement checklist used by Flag State Surveyors [4]

	Main Ship's Particulars			
	Ship Name			
	Flag			
	IMO No			
	Call sign			
	Ship Type			
	Deadweight			
	Port of registry			
I	General	**Yes**	**No**	Comments
1.1.	Layout			
1.1.1	Does the SEEMP follow a consistent and simple layout throughout?			
	• Introduction – setting out the purpose and management of the document as well as any requirements it is intended to satisfy (charterer or other)	☐	☐	
	• Operational measures – relating to the impact of vessel operations on energy efficiency	☐	☐	
	• Hull and propeller measures – energy efficiency relating to underwater parameters	☐	☐	
	• Machinery / equipment measures – energy efficiency relating to operation, maintenance and usage of machinery and equipment used in support of the vessel's primary function	☐	☐	
	• Accommodation services measures – energy efficiency relating to equipment and services designed for accommodating crew	☐	☐	
	• Training and investigation measures – relating to training requirements of all staff in order to effectively implement energy efficiency improvement for the vessel as well as specific energy conservation projects	☐	☐	
1.2	Corporate Energy Management			
1.2.1	Does the SEEMP refer to a corporate energy management plan (for example Environmental Management System under ISO 14001)?	☐	☐	
1.2.2	Is the SEEMP consistent with this plan?	☐	☐	
1.3	Alignment with industry guidelines			
1.3.1	Does the SEEMP relate to the 'Guidance on Best Practices for Fuel-Efficient Operation of Ships' as defined within MEPC.1/Circ.683?	☐	☐	
1.3.2	Does the SEEMP incorporate recommended best-practice as outlined in relevant industry guidelines (e.g. OCIMF Energy Efficiency and Fuel Management or INTERTANKO	☐	☐	

	Tanker Energy Efficiency Management Plan (TEEMP))?			
II	Planning Section			
2.1	Overview			
2.1.1	Does the SEEMP demonstrate understanding of current energy usage onboard?	☐	☐	
2.1.2	Does the SEEMP identify areas for energy improvement based upon actual ship-specific data?	☐	☐	
2.2	Ship-specific Energy Efficiency Measures (EEMs)			
2.2.1	EEMS should follow the SMART principles as outlined below:			

	Continued	Yes	No	Comments
	• Specific – relate to the energy efficiency of the ship in question	☐	☐	
	• Measurable – be quantifiable in order to benchmark any change in efficiency	☐	☐	
	• Achievable – they must be sensible measures and not things that have no chance of success	☐	☐	
	• Realistic – given resources, money and other constraints e.g. operational	☐	☐	
	• Time framed – there should be a specific period in which to implement them. They should not be open-ended otherwise they will never get done.	☐	☐	
2.3	Company-specific measures			
2.3.1	Do the EEMs consider involvement of all stakeholders as may be appropriate?	☐	☐	
2.3.2	Has appropriate management of the EEMs been delegated to shore-based staff?	☐	☐	
2.3.3	Does the SEEMP make reference to a fleet energy management plan as appropriate?	☐	☐	
2.4	Human resource development			
2.4.1	Have training requirements been addressed as part of the planning stage and do they cover aspects related to crew/shore-staff instruction and training and familiarisation of new procedures/systems?	☐	☐	
2.5	Goal setting (optional)			
2.5.1	Where goals have been set, either overall or against specific EEMs, have these been	☐	☐	

	clearly stated and are they measurable?			
2.5.2	Are the goals consistent with the company energy management plan?	☐	☐	
2.5.3	Do the goals follow the SMART principle (see 2.2.1 above)?	☐	☐	
III	Implementation			
3.1	Establishment of implementation system			
3.1.1	Have tasks been defined for the implementation of each EEM?	☐	☐	
3.1.2	Has responsibility for the implementation of each task been assigned to specific staff?	☐	☐	
3.2	Implementation and record keeping			
3.2.1	Has the mechanism for keeping a record of the implementation of each EEM been established within the SEEMP?	☐	☐	
IV	Monitoring			
4.1	Monitoring tools			
4.1.1	For each EEM, have specific parameters been defined that allow quantitative measurement of the energy efficiency?	☐	☐	
4.1.2	Has a suitable monitoring tool been specified for measuring the EEMs (preferably an international standard such as the EEOI) and does it specify use of rolling averages?	☐	☐	
4.1.3	Has a monitoring frequency been specified for each EEM (daily, weekly, monthly etc)?	☐	☐	
4.1.4	Does the SEEMP detail how the EEMs will be benchmarked (e.g. engine performance versus sea trial curves)?	☐	☐	
	Continued	Yes	No	Comments
4.2	Establishment of monitoring system			
4.2.1	Have adequate procedures been developed for use of the monitoring system perhaps as part of the planning stage)?	☐	☐	
4.2.2	Has the workload of ship's staff been considered when establishing implementation of the monitoring system?	☐	☐	

4.2.3	In the case where a measurement tool other than the EEOI is specified, has the concept and methodology been adequately defined (perhaps as part of the planning stage)?	☐	☐	
4.2.4	Has suitable use of existing records (log books, oil record books etc) been stipulated in order to help reduce duplication and additional workload?	☐	☐	
V	Self-Evaluation and Improvement			
5.1	Self-evaluation and improvement			
5.1.1	Does the SEEMP adequately address the evaluation process of the EEMs in regard to the following:			
	• How will feedback be used to assess success/failure of EEMs?	☐	☐	
	• Who will have responsibility for evaluating the EEMs and consolidating as part of the overall energy efficiency assessment of the ship?	☐	☐	
	• What frequency of review and evaluation has been determined and does it meet the requirement as a continuous process?	☐	☐	
	• Is there a clear link back to the next planning stage?	☐	☐	
VI	Completion			
6.1	Review			
6.1.1	Does the SEEMP demonstrate a clear set of objectives and encompass the following principles:			
	• Planning	☐	☐	
	• Implementation	☐	☐	
	• Monitoring	☐	☐	
	• Evaluation	☐	☐	

4.6. References

[1] MEPC.1/Circular 683 (GUIDELINES FOR THE DEVELOPMENT OF A SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP)) (2009)
[2] Ship Energy Efficiency Management Plan (SEEMP) for an Oil/Chemical Tanker
[3] Presentation ''A structured methodology to improve energy efficiency'', S.Dimakopoulos 15/11/2011 (Greener Shipping Summit: Gearing up for a Greener World) (2011)
[4] SEEMP Review and Endorsement Checklist- Lloyd's Register (2011)

5. DESCRIPTION AND CONTENT OF AN ENERGY AUDIT (EA)

5.1. Energy Audit general information

5.1.1. Purpose

The purpose of the energy audit is to assess the following:

- The vessel's trade - operational pattern relative to energy performance and in particular the identification of consumptions and energy efficiency.
- The operational pattern, energy efficiency and consumption characteristics of the main energy consuming machinery onboard.
- Crew operational practices affecting the energy consumption onboard.

The basic goals of the energy audit are to:

- Establish energy consumption **Key Performance Indicators (KPIs)**, calculate corresponding values and compare against reference values from sea and shop trials regarding the vessel's main energy consumers. These KPIs and calculated values may also be used for comparison with any future measurements thus timely identifying deteriorating trends and prompting corrective actions to be taken. Such KPIs are, for example, the diesel engines SFOC, (Specific Fuel Oil Consumption) the generator and electric motors load factor, utilization factor and power factor, the vessel fuel consumption per mile or metric tonne of cargo transported, etc.
- Identify a number of **Energy Saving Potentials (ESPs)**. The latter are identified by comparing the vessel's and the machinery's energy performance as well as crew energy practices with relevant industry standards, best practices and the technological state of the art. At this point it must be stated that although ESPs are identified by a feasibility grade and financial evaluation, these are the result of a preliminary estimation whose purpose is to provide an idea of the work and costs involved. Especially in cases where a considerable amount of capital investment is required, detailed investigation and calculations, application of relevant models etc. are required before actually implementing the proposals.

5.1.2. Energy Audit Schedule

The energy audit is carried out in two phases and five stages, as follows:

Phase I

- Stage 1: Selection of the ship to be audited further to a discussion with Owner / Managers
- Stage 2: Acquisition of ship' documentation and drawings. Acquisition of the vessel's operational / voyage data within the last year. Review of collected data and identification of areas for further investigation. Identification of preliminary Energy Saving Opportunities (ESPs).

Phase II

- Stage 3: Onboard Energy Audit: Acquisition of data and measurements from the various processes, machinery and systems to be audited for verification. Preliminary verification of Phase I ESPs and identification of additional ESPs.
- Stage 4: Analysis of data collected during stages 2 and 3. Final verification / assessment of feasibility study and selection / categorization of ESPs. Preliminary investigation of financial feasibility of ESPs.
- Stage 5: Preparation of deliverable Energy Audit Report.

5.1.3. Conversion factors and prices

The following list of conversion factors, prices etc. shown in Table 5.1 is made for a specific Energy Audit Report, and is only applied to that Report.

Table 5.1- Conversion factors and prices for a specific Energy Audit [1]

Item	Value
1 PS	0.736 kW
1 kcal	4.1868 kJ
CO_2 conversion factor for DO grade DMB:	3.206 t_{CO_2} / t_{DO}
CO_2 conversion factor for FO grade RMG 380:	3.1144 t_{CO_2} / t_{FO}
RMG 380 price (380 cSt @ 40 ^{0}C):	472 USD/t
DMB price	630 USD/t
FLCV for RMG 380 as per FO analysis (during shipboard audit):	40070 kJ/kg
Euro to US dollar conversion ratio (current):	1.00€ = 1.36 USD

5.1.4. List of measuring instruments during shipboard audit

The list shown in Table 5.2, indicates the most frequently used measuring instruments during shipboard audit.

Table 5.2- List of measuring instruments during shipboard audit [1]

Instrument
3-phase power analyzer
Single phase power analyzer
Digital recording multi meter
IR camera
IR thermometer
Flue Gas Analyzer
Lux / Air flow Meter
Humidity / Temperature Meter
Tachometer

All instruments should be calibrated from the manufacturer or from approved Institutes with procedures traceable to relevant international standards.

5.2. Energy-related definitions and ESP categorization

5.2.1. Energy-related definitions

Energy Saving Potential (ESP): The room for improvement (to procedures, processes and equipment) identified when measuring and analyzing an energy consuming / converting system, which can lead to increased energy efficiency and decreased energy wastage and consumption.
The implementation of an ESP requires changes to processes and procedures and replacement of equipment with more efficient and/or better sized units.

Energy Efficiency: A ratio between an output of performance, service, goods, energy and an input of energy. “Doing more with less”.

Energy Savings: An amount of saved energy, determined by measuring before and after implementation of energy efficiency improvement measures.

Energy Conservation: Reduction in energy consumption associated with reduction of services and quantity of goods.

5.2.2. ESP categorization

Energy Saving Potentials are categorized according to the following criteria:

- Cost
- Benefit (environmental and financial).
- Feasibility.

The **cost or the benefit** of an ESP is characterized as:

- "Low" when the yearly corresponding amount is between USD 0 and USD 2500
- "Medium" when the yearly corresponding amount is between USD 5000 and USD 25000 and
- "High" when the yearly corresponding amount is over USD 25000.

Thus we can identify:

- **Low cost/Low benefit ESPs**: ESPs that can be easily and quickly applied with minimal costs incurred. Usually the energy efficiency impact of these ESPs is small. Feasibility of actual implementation is high.
- **Low or medium cost/ High benefit ESPs:** Normally these are ESPs, which are relatively easily applied by making a capital investment once or spending a small amount of money periodically and the benefit accumulates over a long operation period. Feasibility of actual implementation is medium to high.
- **High cost / Medium & High benefit ESPs:** These are ESPs involving replacement of significant machinery items or a large number of machinery items, in order to upgrade to a higher energy efficiency standard. Taking into account the young age of the audited ship, this kind of ESPs is mentioned in this report more with a view to study and implement in possible future new building projects, rather than actually carrying out modifications onboard this specific ship.
- **High cost / Low benefit ESPs:** These are ESPs only regarding the energy efficiency and environmental point of view. Usually the environmental benefit is very small. Such ESPs are not feasible at all from the financial point of view.
- **Operational ESPs:** These ESPs require operational and organizational changes rather than technological or hardware changes to be effected.

As a rule of thumb, changes difficult or complicated (and costly) to implement, have a significant energy efficiency impact while easily implemented (and low cost) ones have a less significant energy efficiency impact.

5.3. Example of identified ESPs based on an actual Energy Audit

The following Table is taken from an Energy Audit Report and consists of the identified ESPs. For each ESP, the Table contains the estimated annual fuel savings, and the subsequent avoided cost, the equivalent CO_2 emission reduction, the estimated capital investment, the cost/benefit characterization as described above, and finally the feasibility of the ESP.

Table 5.3- Summary of identified ESPs [1]

ESP	Description	Est. Fuel Savings $\left(t/year\right)$	Eqv. CO_2 Reduction $\left(t/year\right)$	Estimated Avoid. Cost $\left(USD/year\right)$	Est. Capital Investment (USD)	Cost / Benefit	Materiali-zation Feasibility
01	Minimization of speed overrun (ballast condition)	593.8	1850	280282	-	Zero / High	Medium
02	Minimization of speed overrun (laden condition)	25.2	78.51	11898	-	Zero / Medium	Medium
03	Critical SFOC reduction to benefit from M/E overhaul	36.7	114.4	17342	50000 (every 3 years)	High / Medium	High
04	Estimated benefit from D/G maintenance (Improvement of SFOC)	23.4	72.9	11051	27.000 (every 3 years)	Medium / Medium	Medium
05	Estimated benefit from D/G optimized use. (During the EA)	3.45	10.75	5075.6	-	Zero / Medium	High
06	Installation of High Efficiency Motors	4.87 (Total)	15.156 (Total)	2297 (Total)	2900 (Total)	Low / Low	Medium
07	E/R fan efficient operation management	50.09	156	23.64	-	Zero / High	High
08	Optimum setting for A/B burners excess air	93.9	292.4	44317	-	Zero / High	High
09	Use of auxiliary boilers for the incineration of sludge residues	18.0	57.6	11324.7	-	Zero / Medium	High
10	Installation of FUEL MILL MC Homogenizer	51.8	-	24457.9	50000	High/ Medium	High
11	Minimization of compressed air service system leakages	3.6	11.2	1702	300	Low / Low	Medium
12	Optimum adjustment of HVAC fresh / return air ratio.	9.5	29.5	4469	-	Zero / Low	High
13	Minimization of HVAC system operation during medium ambient temperature conditions	4.7	14.6	2214	-	Zero / Low	High
14	Accommodation's lighting loads optimization	9.6	29.8	4521	-	Zero / Low	High
15	Very low occupancy spaces lighting optimization	6.0	18.8	2847	-	Zero / Low	High
16	Replacement of incandescent lamps by CFLs	10.2	31.7	4809	726	Low / Low	High

5.4. Description of the audited ship and systems

5.4.1. Main particulars and operation pattern of the audited ship

In this paragraph of the Energy Audit Report, the main particulars of the audited ship are presented, as listed in Table 5.4.

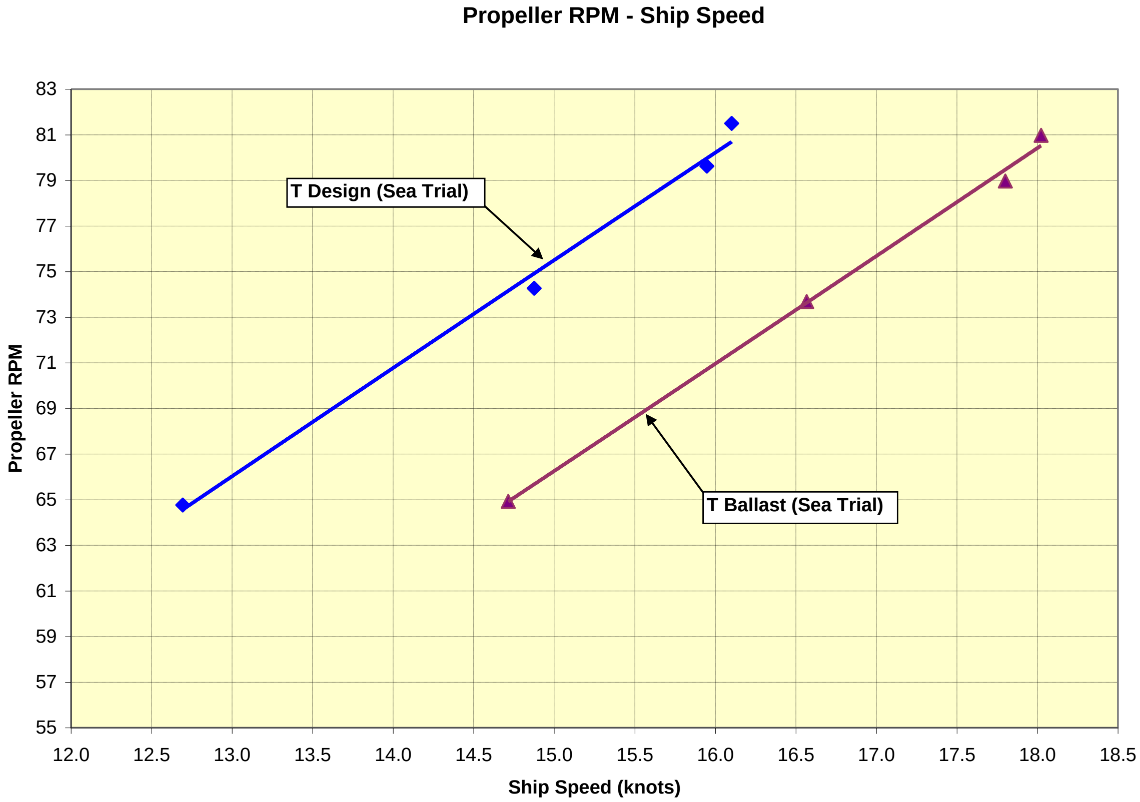
Table 5.4-Main Particulars of the audited ship [1]

Vessel Name
Vessel Type
L_{OA}
L_{BP}
B
D
T
DWT
Volume of Cargo $\left(\nabla_{CARGO}\right)$
Speed (at 90% MCR as taken from the sea trial records)
Class
Builder

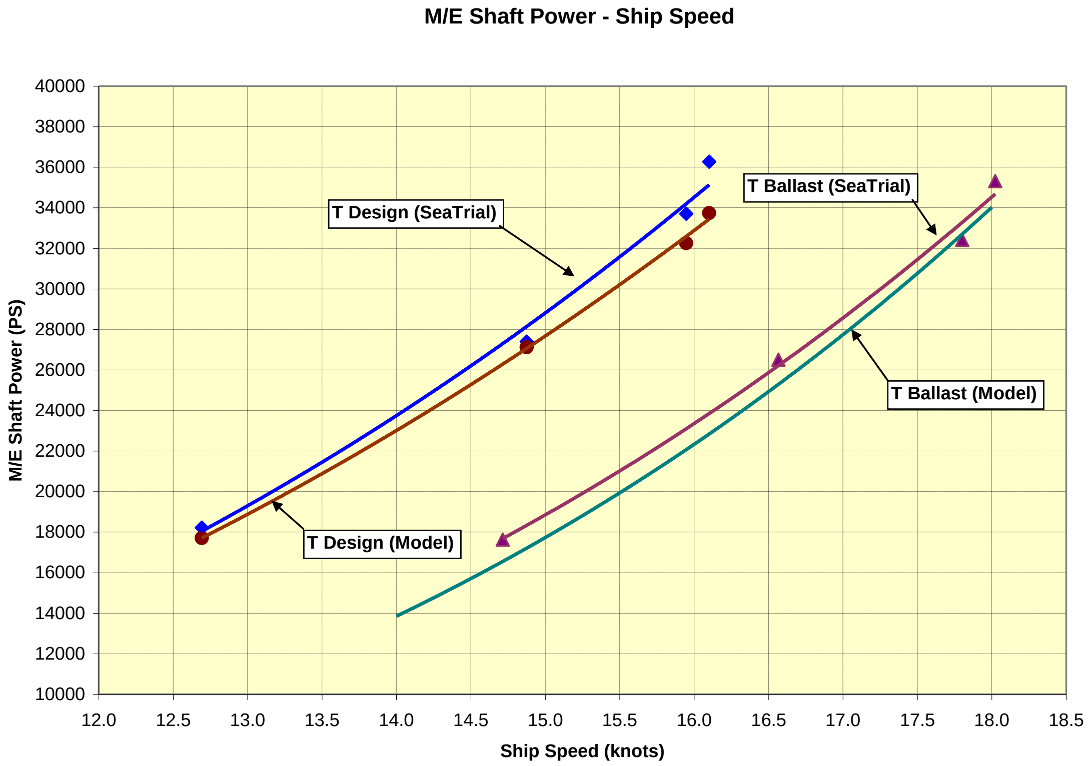
In addition, the following two curves are presented, as obtained from the sea trial results (conducted at design and ballast draft condition):

- Propeller RPM related to ship's speed
- Main Engine BHP related to ship's speed

Examples of these curves are shown in Figures 5.1 and 5.2, taken from an actual Energy Audit Report for a typical VLCC **[1].**



Picture 5.1-Example curve: Propeller RPM versus Ship Speed (for design and ballast draft) [1]

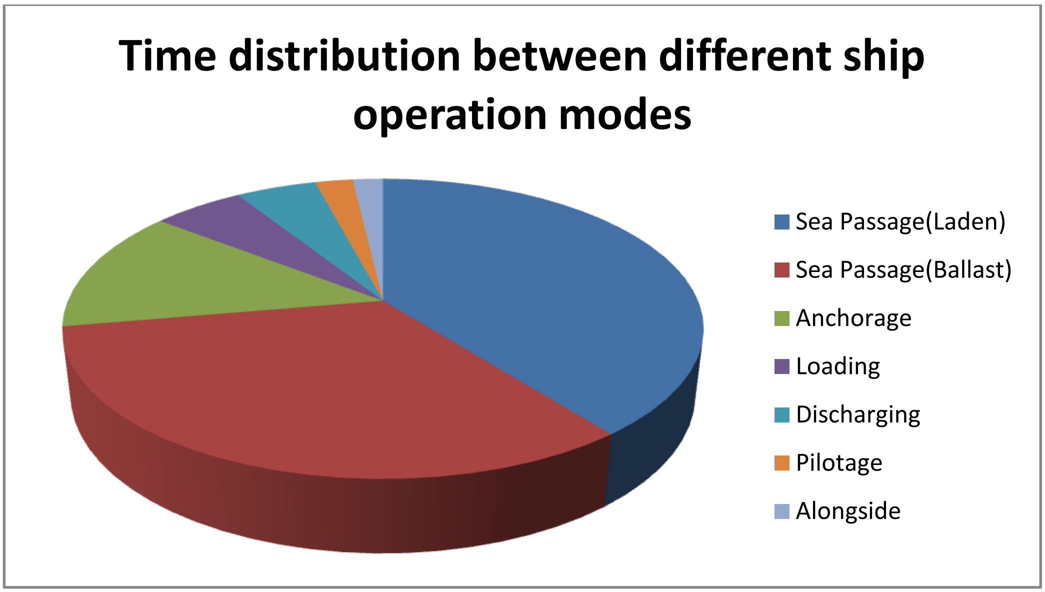


Picture 5.2-Example curve: M/E BHP versus Ship Speed (T: draft) [1]

Regarding now the operation pattern of the audited ship, it is a common practice to divide the vessel's operation into a number of modes (e.g. loading, sea passage, anchorage etc.). In example, for a typical VLCC, these modes are:

- Sea passage (laden and ballast)
- Anchorage
- Loading
- Discharging
- Pilotage
- Alongside

The average time distribution between these modes is provided in the pie chart of Picture 5.3, taken from an Energy Audit Report for an existing VLCC:



Picture 5.3- Time distribution between different operation modes for a typical VLCC [1]

The sea passage time (in ballast and laden condition) corresponds to 72.3% while the cargo operations to 10.4 %. About 13.3 % of the time is spent at the anchorage or drifting at waiting areas. This anchorage – drifting waiting time can be attributed to congestion at the loading/discharging terminals, delays in vessel chartering or due to weather conditions. Pilotage time corresponds to 2.3% of the voyage time and includes maneuvering. Finally alongside time corresponds to 1.8% of the voyage time only. This time includes ship preparation for loading/unloading, agreement with the terminal on the safety matters, cargo tank gauging/inspections and cargo calculations, pilot and tugs waiting time, unberthing maneuvers etc.

5.4.2. Consumption and distribution of fuels

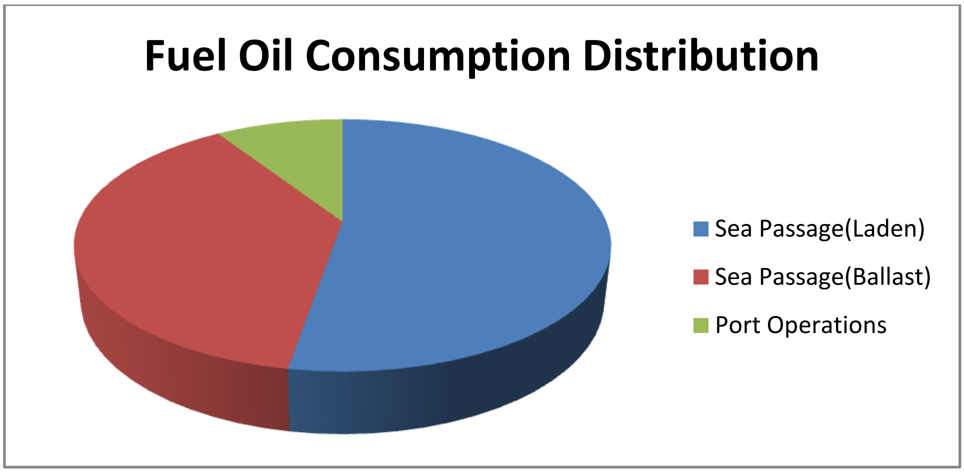
In this paragraph of the Energy Audit Report, type(s) of fuel used onboard are reported, as well as the main machinery onboard which operates under the internal combustion principle. For a typical VLCC, such machinery, and the respective fuel used are shown in the Table 5.5, taken from an actual Energy Audit Report **[1].**

Table 5.5- Machinery and the respective fuel used for different operations [1]

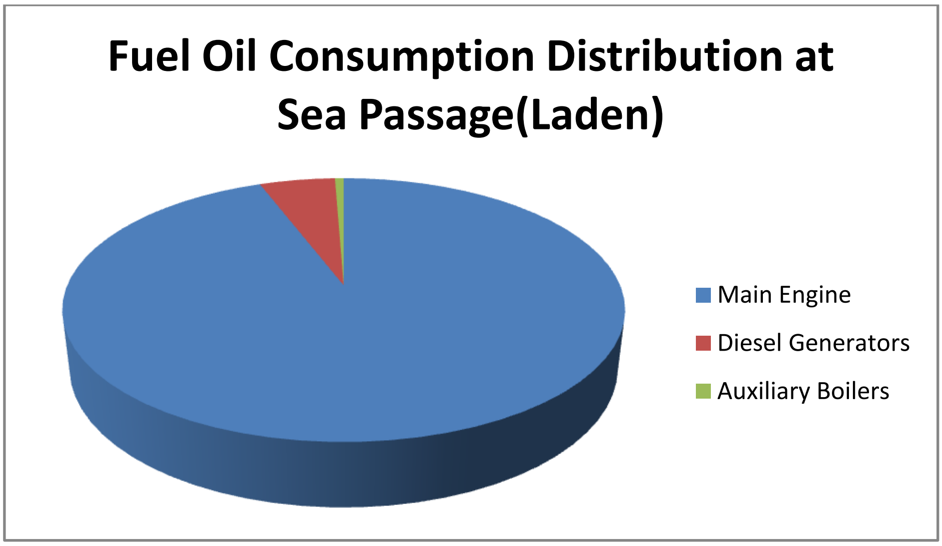
Machinery	**Operation**	**Fuel Used**
M/E	Maneuvering	FO grade RMG 380
	Navigation	FO grade RMG 380
D/G	Start / Stop	FO grade RMG 380
	Normal Operation	FO grade RMG 380
	Prolonged Shutdown	DO grade DMB
A/Bs	Pilot Burner	DO grade DMB
	Main Burner	FO grade RMG 380
IG Generator	IG generation & Topping up	DO grade DMB
Incinerator	Garbage & Sludge incineration	DO grade DMB

The consumption distribution of fuels for a typical VLCC is shown in Pictures 5.4- 5.8 [1]:

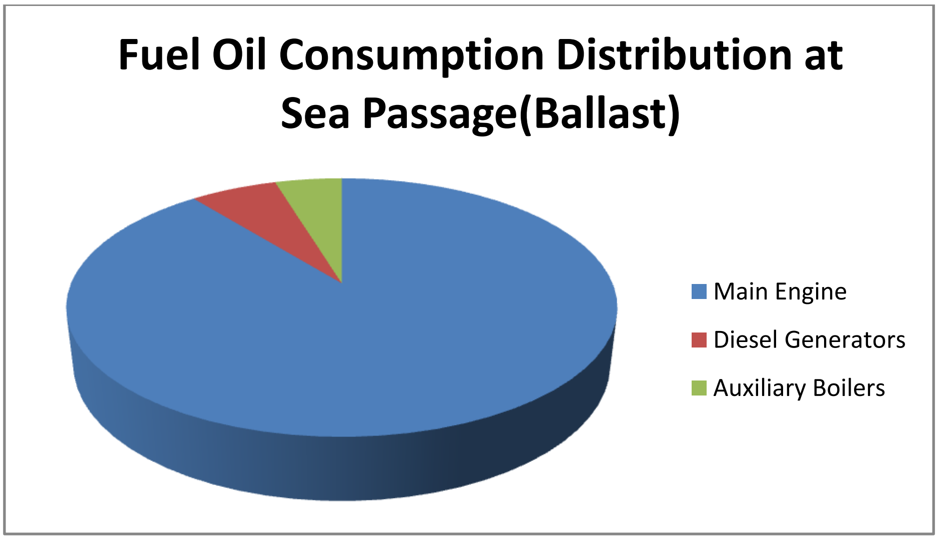
- Initially, <u>between different operation modes</u> (e.g. sea passage, port operations) and
- Finally, <u>between different machines</u> (M/E, D/G and A/B) <u>for a specific operation mode</u>



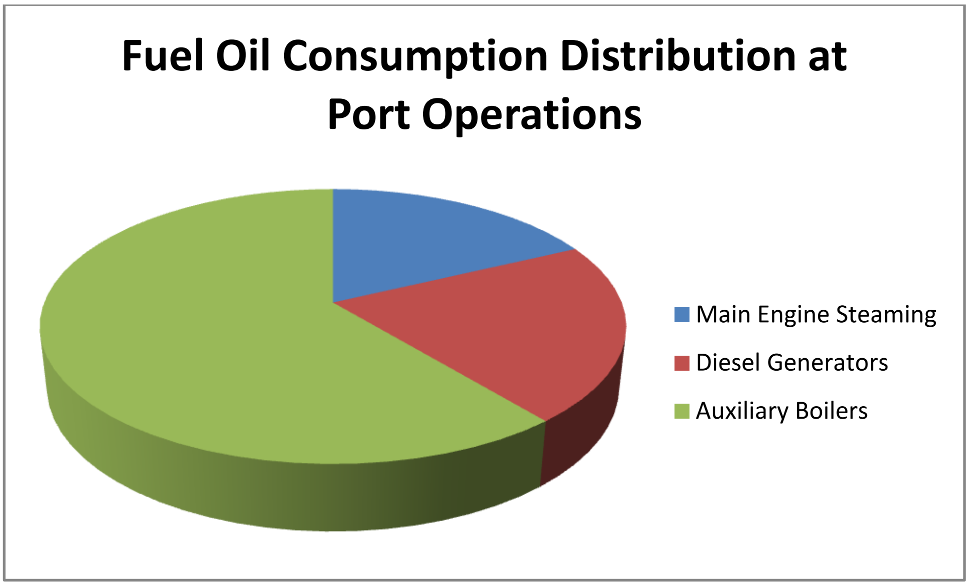
Picture 5.4-FO consumption distribution between different operation modes [1]



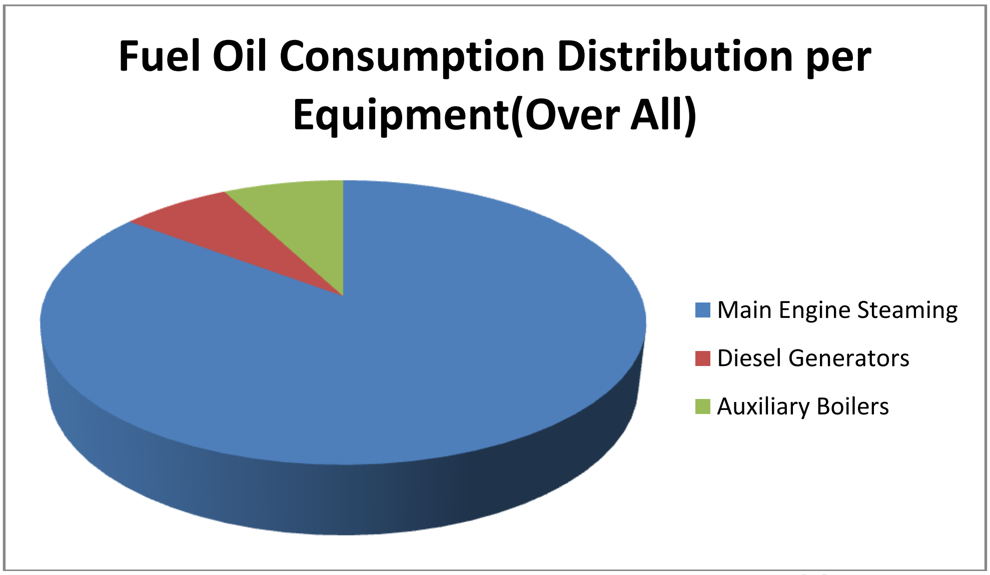
Picture 5.5-FO consumption distribution at Sea Passage (Laden) [1]



Picture 5.6-FO consumption distribution at Sea Passage (Ballast) [1]



Picture 5.7-FO consumption distribution at Port Operations [1]



Picture 5.8-FO consumption distribution per Equipment [1]

About 7.0% of the FO is consumed by the D/Gs, 7.7% by the auxiliary boilers and the rest (85,3%) by the main engine. No significant quantities of diesel oil are required to be burnt in the D/Gs, A/Bs and the incinerator (0.1% of the total fuel consumed). Also the consumption of FO is distributed as follows: 52.7% during laden sea passage, 38.1 % during ballast sea passage and the remaining 9.2 % at port operations.

The consumption of FO at port operations can be further analyzed to fuel consumed by the D/Gs (21.1 %), the A/Bs (61%) and M/E steaming (17.9%).

5.4.3. Main Engine and Diesel Generator particulars

For the purpose of conduction of Energy Audit, the following details of ship's Maine Engine are necessary:

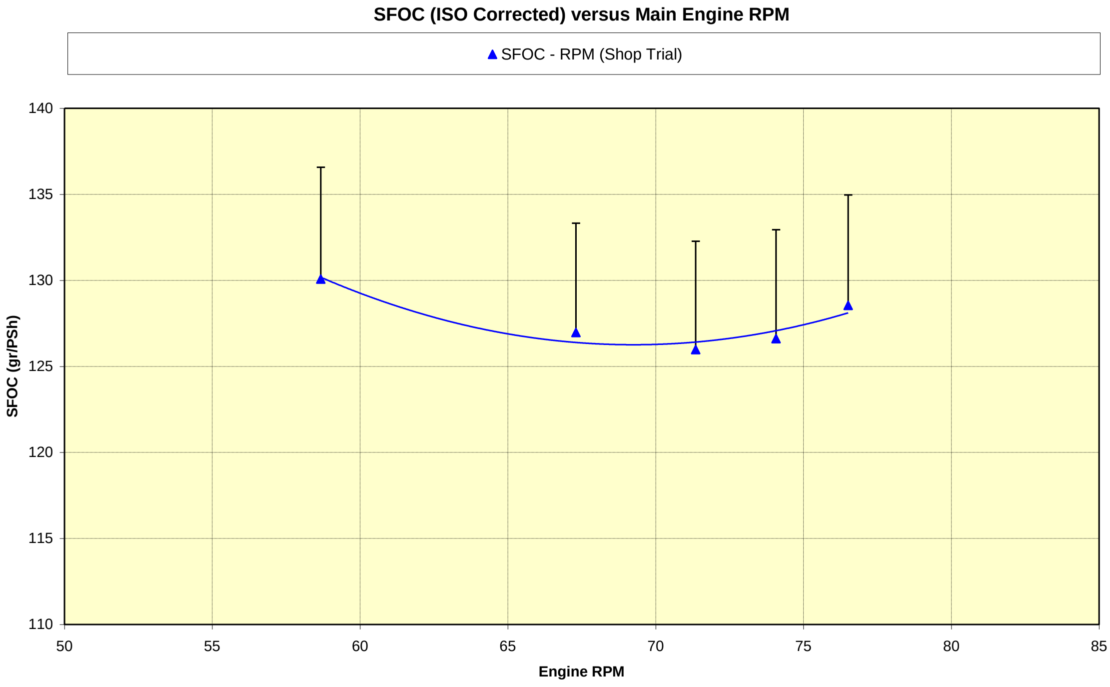
Table 5.6-Main Particulars of ship's Main Engine [1]

Maker
Model
Type
Reduction gear (Yes or No)
Reduction gear ratio (if one)
Number of cylinders
Bore, Stroke
Cylinder firing order
Rated Power (at 100% MCR)
Rated Speed (RPM at 100% MCR)
Propeller Speed (RPM)
Service Power (Sea Trial NCR)
Service Speed (RPM at Sea Trial NCR)
Propeller Speed (RPM at Sea Trial NCR)
SFOC (Sea Trial-ISO corrected)
FO characteristics: type, density, FLCV (Sea Trials)
SFOC (Shop Trial-ISO corrected) at 100% Load
DO characteristics: density, FLCV (Shop Trial)

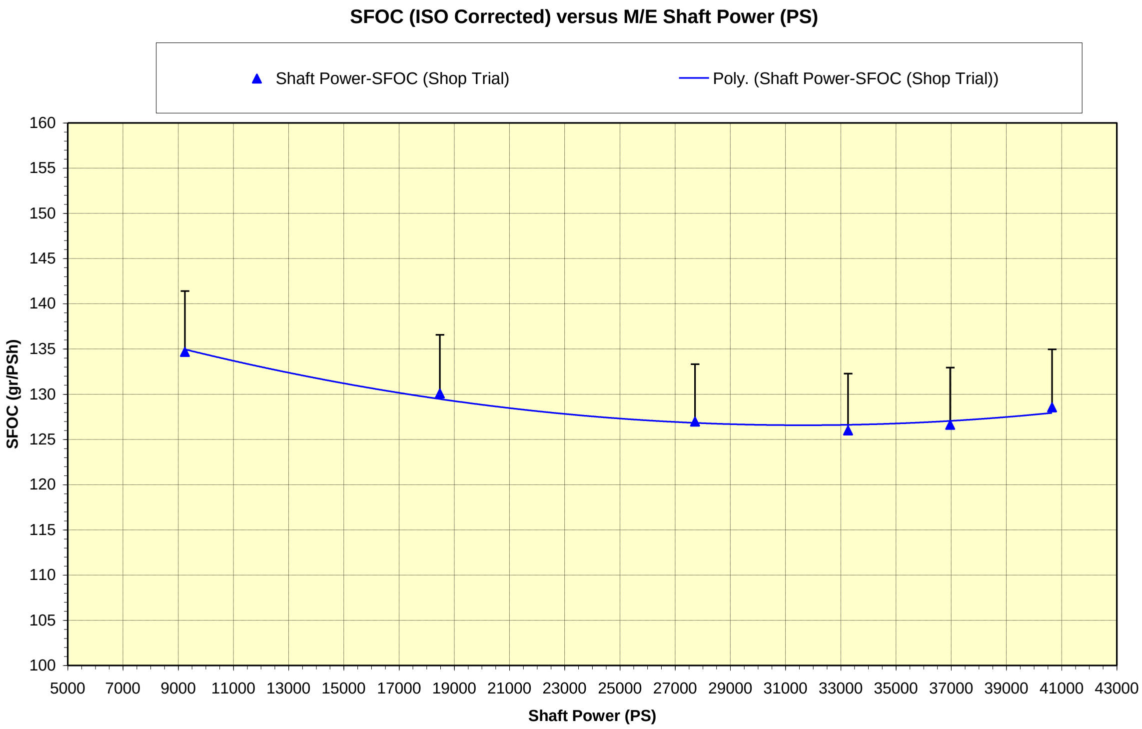
In addition, <u>the following two curves</u> are necessary, as obtained from the shop trial results:

- Main Engine SFOC versus Engine RPM
- Main Engine SFOC versus Main Engine BHP

Examples of these curves are shown in Figures 5.9 and 5.10, taken from an actual Energy Audit Report for a typical VLCC **[1].**



Picture 5.9-Example curve: M/E SFOC versus Engine RPM [1]



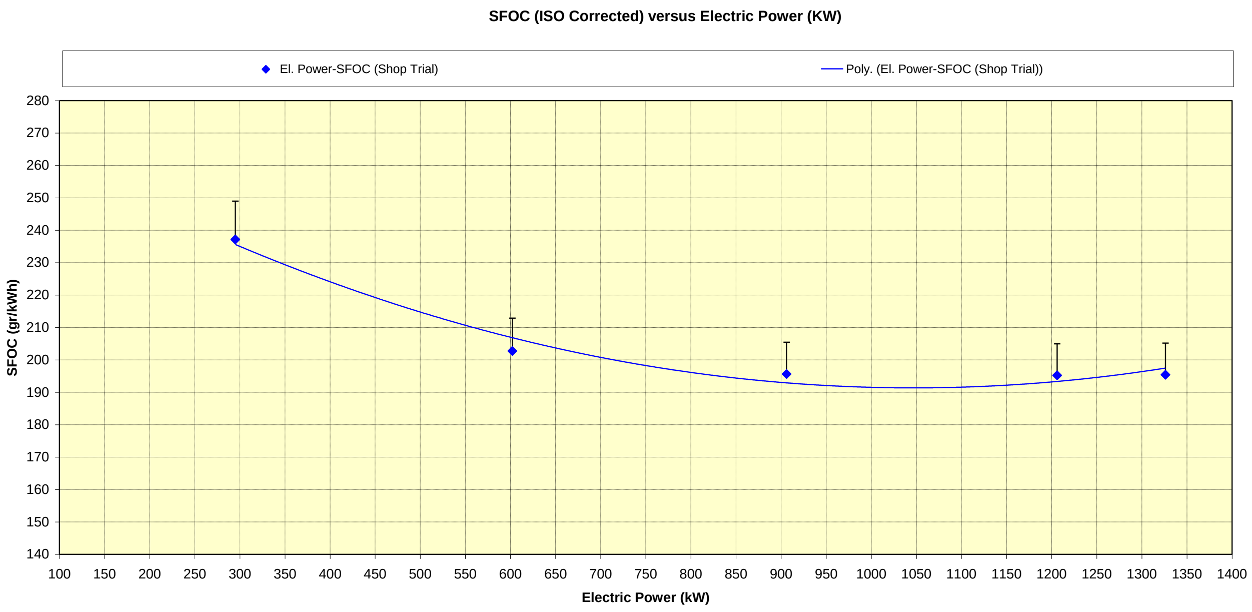
Picture 5.10-Example curve: M/E SFOC versus Main Engine BHP [1]

Regarding now the Diesel Generators, the details presented in Table 5.7 are necessary.

Table 5.7-Main Particulars of ship's Diesel Generators [1]

Maker
Model
Type
Number of cylinders
Engine Rated Power
Rated Speed
Bore, Stroke
Cylinder firing order
DO consumption (Shop Trial) at 100% Load
SFOC (Shop Trial-ISO corrected) at 100% Load
Generator Rated Power
Generator Power Factor

In addition, D/G's SFOC (ISO corrected) versus electric power curve is necessary, as obtained from the shop trial results. An example of that curve is shown in Figure 5.11, taken from an actual Energy Audit Report for a typical VLCC **[1].**



Picture 5.11-Example curve: D/G SFOC versus Electric Power [1]

5.4.4. Basic Electrical Balance data

In this paragraph of the Energy Audit Report, the electrical balance data are presented, taken from the manufacturer's respective electric load analysis. For this purpose, an electrical balance Table is constructed, which contains the continuous load, the intermittent load, the deck machinery load and the total load for different ship operation modes. For each operation mode, the Table also contains the number of generators used, the respective nominal power and the load factor. An example of electrical balance table is shown below, taken from an actual Energy Audit Report for a typical VLCC **[1].**

Table 5.8-Basic electrical balance data [1]

	Normal Sea Going	**Tank Cleaning**	**At Port In / Out**	**At Unloading**	**At Loading**	**At Harbor**
Continuous Load (kW)	870.1	1406.7	1180.9	1637.2	1059	544.9
Intermittent Load (kW)	445	438.2	429.6	442.6	384.5	391.4
Deck Machinery Load (kW)	0	0	393.2	25.3	25.3	0
Total Load (kW)	1048.1	1582	1745.9	1839.6	1238.1	701.4
No. of generators used	1	2	2	2	2	1
Nominal Power (kW)	1 x 1180	2 x 1180	2 x 1180	2 x 1180	2 x 1180	1 x 1180
Load Factor (%)	88.8	67	74	77.9	52.5	59.4

In addition, a table containing the basic ship electrical system characteristics is necessary. These characteristics are shown in the Table 5.9 .

Table 5.9-Basic ship electrical system characteristics [1]

Nominal voltage
Rated current
Frequency
Phases
Single phase circuitry nominal voltage

5.4.5. Description of the systems audited

At this point, a summary of the ship systems audited during an Energy Audit is presented in the Table 5.10.

Table 5.10-Ship systems audited during Energy Audit [1]

Auxiliary Boilers
Feed water and steam distribution and condensate return system
FO/DO service system
Cooling SW and FW system
Compressed air system
HVAC system
Lighting system

In an actual Energy Audit Report, there shall be detailed description, investigation and assessment of performance of each one of the above systems (e.g. auxiliary boilers particulars, lighting system electrical balance etc).

5.5. References

[1] Energy Audit Report written by Alpha Marine Services Ltd. for an existing VLCC (2010)

6. ENERGY AUDIT REPORT

The Energy Audit Report presented in this chapter, was written in co-operation with Alpha Marine Services Ltd., following the Energy Audit conducted on a vessel with the characteristics given in Section 6.4.

The Report is presented for educative purposes only. For confidentiality reasons, the details of the audited ship, such as her Name, Port of Registry, Flag and IMO number, as well as the details of the shipowner company, are deliberately omitted.

6.1. General

6.1.1. Purpose

The purpose of the energy audit is to assess the following:

- The vessel's trade, operational pattern, energy efficiency and consumption characteristics of the main energy consuming machinery onboard.
- The crew operational practices affecting the energy consumption onboard.

The basic goals of the energy audit are to:

- Establish energy consumption Key Performance Indicators (KPIs) in order to calculate the corresponding values and to compare against the reference values from the sea and the shop trials regarding the vessel's main energy consumers. These KPIs and calculated values may also be used for comparison with any future measurements, thus timely identifying any deteriorating trends that may require prompt corrective actions. Such KPIs may for example be the main engine Specific Fuel Oil Consumption (SFOC), the generators' and electric motors' load factor, utilization factor and power factor, as well as the vessel's fuel consumption per mile or per metric tonne of cargo transported.
- Identify a number of Energy Saving Potentials (ESPs). The latter are identified by comparing the vessel's energy performance as well as the crew energy practices with relevant industry standards and recommended best practices. The ESPs are identified by a feasibility ranking and financial evaluation (Cost Benefit Analysis – CBA). The purpose of the aforementioned estimations is to provide an idea of the involved costs and required labor work. Especially in cases where a considerable amount of capital investment is required, detailed investigation, calculations and application of relevant models are required before actually implementing the proposals.

6.1.2. Energy Audit Schedule

The energy audit was carried out in two phases and five stages, as follows:

Phase I

- Stage 1: Selection of the ship to be audited.
- Stage 2: Acquisition of ship' documentation and drawings. Review of the vessel's operational /voyage data within the last year. Identification of areas for further investigation and proposal of preliminary Energy Saving Potentials (ESPs).

Phase II

- Stage 3: Onboard Energy Audit: Data gathering from the various processes, machinery and systems audited for verification purposes. Verification of Phase I preliminary ESPs and identification of additional ESPs.
- Stage 4: Analysis of data collected during Stages 2 and 3, verification of the feasibility study and selection / categorization of ESPs. Preparation of economic feasibility study.
- Stage 5: Delivery of Energy Audit Report.

6.1.3. Abbreviations

The following abbreviations are used in this report:

Table 6.1- Abbreviations used [1]

Abbreviation	Meaning
A/B	Auxiliary Boiler
A/C	Air Conditioning
AHU	Air Handling Unit
BHP	Brake Horse Power
C/E	Chief Engineer
CFL	Compact Fluorescent Lamp
C/O	Chief Officer
COT	Cargo Oil Tank
D/G	Diesel Generator
DO	Diesel Oil
ECR	Engine Control Room
EGE	Exhaust Gas Economizer
EHP	Effective Horse Power
E/R	Engine Room
ESP	Energy Saving Potential
FAD	Free Air Delivery*
FL	Fluorescent Lamp
FLCV	Fuel Lower Calorific Value
FO	Fuel Oil (Residual fuel with a viscosity of 180cSt at 400°C)
FW	Fresh Water
GS	General Service
HVAC	Heating,Ventilation and Air Conditioning
IHP	Indicated Horse Power
INC	Incandescent Lamp
IR	Infrared
KPI	Key Performance Indicator
LO	Lubricating Oil
MCR	Maximum Continuous Rating
M/E	Main Engine
MT	Metric Tonne
PMS	Preventive Maintenance System
RH	Relative Humidity
R/G	Reduction Gear
RPM	Revolutions per minute
SFOC	Specific Fuel Oil Consumption
SHP	Shaft Horse Power
SW	Sea Water
T/C	Turbocharger
WG	Water Gauge

*Free Air Delivery= The net amount of air inserting into a space (including the losses due to leaks in pipes, etc.)

6.1.4. Conversion factors and prices

The following conversion factors, prices etc. were applied in this report:

Table 6.2- Conversion factors and prices [1]

Item	Value
1 PS	0.736 kW
1 kcal	4.1868 kJ
CO_2 conversion factor for DO grade DMB:	3.206 t_{CO_2}/t_{DO}
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RMG 380 price (380 cSt @ 40 ^{0}C):	670 USD/t (February 2012)
DMB price	1100 USD/t (February 2012)
FLCV for RMG 380 as per FO analysis (during shipboard audit):	40070 kJ/kg
Euro to US dollar conversion ratio (current):	1.00€ = 1.45 USD

6.1.5. List of measuring instruments used

Table 6.3- List of measuring instruments used [1]

Instrument	Maker/Type
3-phase power analyzer	FLUKE 1735
Single phase power analyzer	FLUKE 43B
Digital recording multi meter	FLUKE 189
IR camera	FLIR systems-ThermaCAM E45
IR thermometer	FLUKE IR 66
Flue Gas Analyzer	KANE 900 Plus
Air flow Meter	LT Lutron LM-8000
Humidity/Temperature Meter	LT Lutron HT-3006HA
Tachometer	Digitaker 9003.001
Pyranometer	Kipp & Zonen SP Lite 2

During measurements, all the safety precautions and constraints were taken into account, as per Company's SMS safety requirements.

All instruments are calibrated, either from the manufacturer or from approved Institutes with procedures according to relevant international standards.

6.1.6. Ship's hull and performance measuring tools used

The vessel currently uses engine makers' instruments and indicators at the engine control room for the performance monitoring such us RPM meter, fuel oil pump mark indicator (indicates the amount of fuel passing through the pump) etc.

6.2. Energy-related definitions and categorization of identified ESPs

Energy Saving Potential (ESP): The room for improvement (to procedures, processes and equipment) identified when measuring and analyzing an energy consuming / converting system, which can lead to increased energy efficiency and decreased energy wastage and consumption.

The implementation of an ESP requires changes to processes and procedures and replacement of equipment with more efficient and/or better sized units.

Energy Efficiency: A ratio between an output of performance, service, goods, energy and an input of energy. "Doing more with less"

Energy Savings: An amount of saved energy, determined by measuring before and after implementation of energy efficiency improvement measures.

Energy Conservation: Reduction in energy consumption associated with reduction of services and quantity of goods.

Energy Saving Potentials are categorized according to the following criteria:

- Cost
- Benefit (environmental and financial).
- Feasibility.

The **cost or the benefit** of an ESP is characterized as:

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Thus we can identify:

- **Low cost/Low benefit ESPs**: ESPs that can be easily and quickly applied with minimal costs incurred. Usually the energy efficiency impact of these ESPs is small. Feasibility of actual implementation is high.
- **Low or medium cost/ High benefit ESPs:** Normally these are ESPs, which are relatively easily applied by making a capital investment once or spending a small amount of money periodically and the benefit accumulates over a long operation period. Feasibility of actual implementation is medium to high.
- **High cost / Medium & High benefit ESPs:** These are ESPs involving replacement of significant machinery items or a large number of machinery items, in order to upgrade to a higher energy efficiency standard.
- **High cost / Low benefit ESPs:** ESPs that, although they are not economically feasible, produce a remarkable environmental benefit.
- **Operational ESPs:** ESPs that require operational procedure alterations, increase of crew awareness and use of environmentally-friendly practices.

As a rule of thumb, changes difficult or complicated (and costly) to implement, have a significant energy efficiency impact while easily implemented (and low cost) ones have a less significant energy efficiency impact.

6.3. Executive Summary

6.3.1. Summary of identified ESPs

Table 6.4 contains the Executive summary of identified ESPs. For each ESP, the corresponding values presented in this Table are produced by a detailed feasibility-cost calculation, shown in the following chapters.

Table 6.4- Summary of identified ESPs [1]

ESP	Description	Est. Fuel Savings (t/year)	Eqv. CO_2 Reduction (t/year)	Estimated Avoid. Cost (USD/year)	Est. Capital Investment (USD)	Cost / Benefit	Materiali-zation Feasibility
01	Critical SFOC reduction to benefit from M/E overhaul	37.6	116.94	25200	70000	High / High	High
02	Estimated benefit from D/G maintenance (improvement of SFOC)	11.07	34.4	12177	9720	Medium / Medium	Medium
03	Replacement of Cooling SW Pump & General Service Pump Motors with High Efficiency Motors	12.57 (Total)	40.22 (Total)	13831.7 (Total)	3400 (Total)	Medium / Medium	Medium
04	E/R fan efficient operation management	9.88	31.62	10868	-	Zero/ Medium	High
05	Use of auxiliary boilers for the incineration of sludge residues	0.28	0.896	308	-	Zero /Low	High
06	Installation of FUEL MILL MC Homogenizer	25.55	79.5	17118.5	45000	High / Medium	Low
07	Minimization of compressed air service system leakages	1.72	5.50	1892	300	Low / Low	High
08	Optimum adjustment of HVAC fresh/return air ratio	0.64	2.05	704	-	Zero / Low	High
09	Minimization of HVAC system operation during medium ambient temperature conditions	13	41.6	14300	-	Zero / Medium	High
10	Accommodation's lighting loads rational use	2.79	8.9	3069	-	Zero/ Medium	High
11	Cargo spaces lighting minimization	104.2	333.4	69814	-	Zero /High	High
12	Replacement of incandescent lamps by CFLs	4.1	13.12	4510	946	Low/ Medium	High
13	Minimization of voltage unbalanced in motors	3.33	10.6	3663	-	Low / Medium	Medium

6.3.2. Energy Audit conclusions

The energy audit was conducted as part of the EU-funded research project “Targeted Advanced Research for Global Efficiency of Transportation Shipping” (“TARGETS”), with a view to assess the Energy Saving Potentials onboard the ship.

Energy saving potentials, identified in this report, can thus in turn be assessed by the Company, with the aim to adopt some of them as “best practices”. They can be communicated and implemented within the fleet for improving the vessels’ energy efficiency as far as practicable. In such a process, and taking into account the European initiatives and international increasing awareness regarding the need for green house gas emissions reduction, the carbon dioxide emissions reduction accounting for energy saving potential is an equally important factor to take into account along with the techno-economical feasibility.

Regarding ESP-01 it is difficult to directly relate maintenance problems with energy wastage, unless these problems become prominent. By weighing the wastage estimate with the maintenance cost, it is obvious that maintenance should be carried out primarily for reliability reasons.

ESPs No. 03 and 07 indicate design stage inefficiencies present in the E/R machinery which provide an example of relatively simple and low cost / short payback time solutions that are worth considering at least for future new buildings.

An example of obtaining benefit with zero cost is the optimization E/R fan management (ESP-04), the use of A/B for incineration of the sludge generated in the engine room (ESP-05), the optimum adjustment of HVAC fresh / return air ratio and the minimization of HVAC operation (ESP-09).

As can be seen from Table 6.4, although certain ESPs do not yield considerable FO conservation amounts with corresponding CO_2 reduction and financial benefits, they only require operational practice modifications at zero cost. Such ESPs should obviously be priority candidates for implementation within a fleet energy conservation program.

ESPs-10, 11 and 12, related to simple lighting management, are also straightforward to implement onboard Company's ships, although the expected benefits are rather of low effect.

Regarding the replacement of incandescent lights by CFLs (ESP-11) and although the associated benefits are significantly low, this ESP is also related to an overall perception of environmental awareness and energy conservation campaigns, therefore its implementation is also considered as a priority candidate.

As may be seen by a comparison of the identified ESPs, some associated with a relatively greater energy saving potential and corresponding carbon dioxide emissions reduction are, also, attractive from the financial point of view. Other energy saving potentials not providing significant benefits on a single piece of machinery or even a single vessel basis (like the installation of energy efficient electric motors), could yield significant benefits within the context of the overall energy efficiency improvement, if implemented on the entire fleet.

6.4. Description of the audited ship and its systems

The following Sections provide significant information regarding the ship from the energy consumption point of view. Ship's particulars, characteristic curves for hull and diesel engines and basic technical information regarding energy consuming auxiliary machinery and systems are presented with the purpose to support the energy audit findings that follow.

6.4.1. Ship's particulars

Table 6.5- Ship's particulars [1]

Ship Type	Car Carrier
Gross Tonnage	48017
Net Tonnage	14919
Navigational Area	Worldwide
Service Speed	18.5 kn
L_{OA}	190.50m
L_{BP}	180.00m
B (moulded)	32.26m
D (moulded up to Freeboard Deck)	13.35m
D (moulded up to Upper Deck)	30.70m
Summer Load Draught (extreme)	8.922m
Summer Deadweight	16141 t

6.4.2. Ship's operational pattern

The vessel is a RO-RO oceangoing trader transferring cars. Voyage data from July 2011 till February 2012 were analyzed. For the purpose of this report the vessel's operation is divided into seven modes:

- Sea Passage (Ballast)
- Sea Passage (Laden)
- Manoeuvring
- Anchorage
- Port facilities
- Delays at port
- Shift at port
- Alongside

The average time distribution between the aforementioned modes is provided in Figure 6.1 [1]:

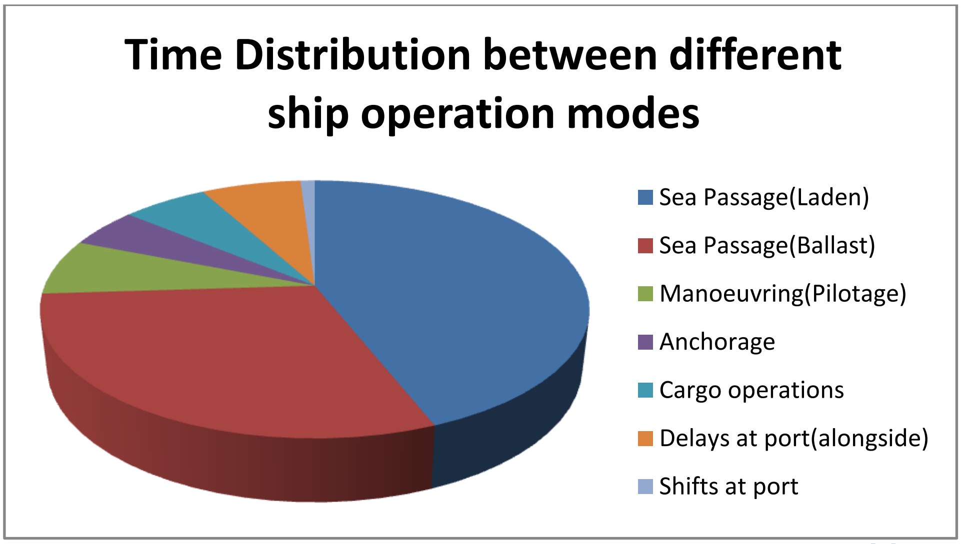

Figure 6.1- Time Distribution between different ship operation modes [1]

Sea Passage(Laden)	0.440
Sea Passage(Ballast)	0.300
Manoeuvring(Pilotage)	0.070
Anchorage	0.050
Cargo operations	0.060
Delays at port(alongside)	0.070
Shifts at port	0.010

The voyage duration in hours does not show any regular pattern, since the vessel is not following any standard trading route. Nevertheless the average voyage duration of the voyages analyzed is 252.7 hours or about 11 days. The sea passage time (in ballast and laden condition) corresponds to 74% or about 7.77 days while the cargo operations to 6 % or about 0.65 days, as can be seen in the Table on the left. About 5 % of the time is spent at the anchorage or drifting at waiting areas, which translates to about 0.5 days per voyage. This anchorage – drifting waiting time can be attributed to congestion at the loading / discharging ports, delays in vessel chartering or due to weather conditions.

Pilotage time corresponds to 7% of the voyage time or about 0.73 days and includes manoeuvring. Finally alongside time corresponds to 7% or about 0.75 days (in Figure 6.1 it is displayed as delays at port) of the voyage time only. This time includes ship preparation for loading / unloading, agreement with the port on the safety matters, cargo areas inspections and cargo calculations, pilot and tugs waiting time, unberthing manoeuvres etc.

6.4.3. Use and consumption/distribution of fuels

Two types of fuel are used onboard the vessel: Residual Fuel Oil RMG 380 (Viscosity 187.5 cSt at 50 °C) and Diesel Oil DMB. The main machinery onboard operating under the internal combustion principle is the M/E which is burning RMG 380 and the three D/Gs burning DMB. There is also an auxiliary boiler onboard burning RMG 380 and one incinerator burning DO. D/Gs and A/Bs in some occasions can be operated in DO too. Fuel used per type is given in Table 6.6.

Table 6.6- Machinery and the respective fuel used for different operations [1]

Machinery	Operation	Fuel Used
M/E	Maneuvering	FO grade RMG 380
	Navigation	FO grade RMG 380
D/G	Start / Stop	DO grade DMB
	Normal Operation	DO grade DMB
	Prolonged Shutdown	
A/Bs	Pilot Burner	DO grade DMB
	Main Burner	DO grade DMB
Incinerator	Garbage & Sludge incineration	DO grade DMB

The consumption distribution of fuels is shown in Figures 6.2-6.5 **[1].**

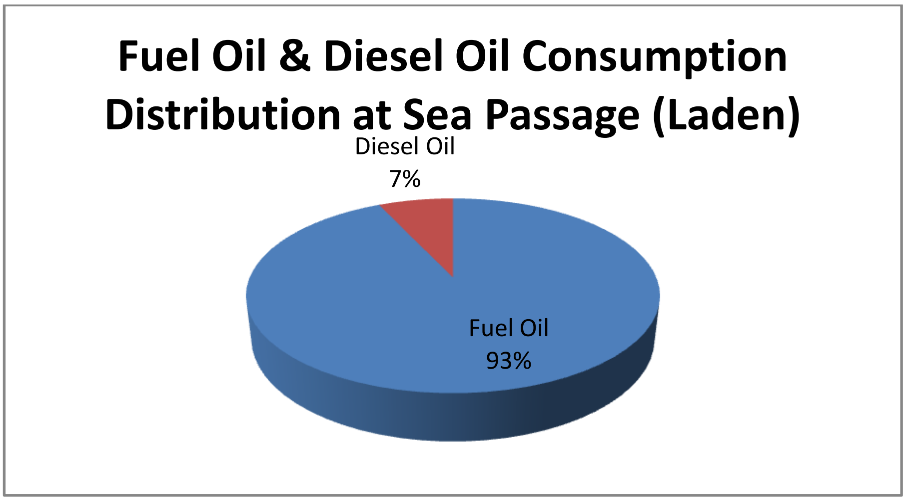

Figure 6.2- FO & DO Consumption Distribution at Sea Passage (Laden) [1]

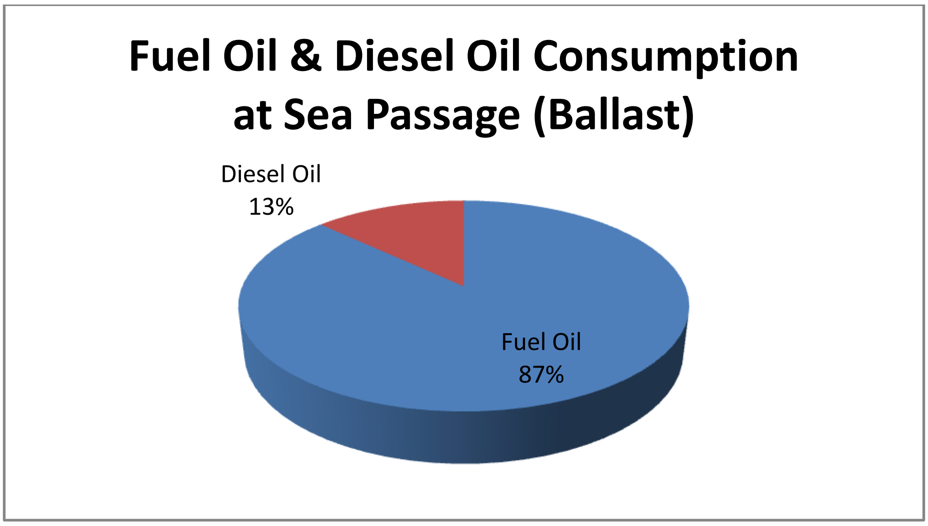

Figure 6.3- FO & DO Consumption Distribution at Sea Passage (Ballast) [1]

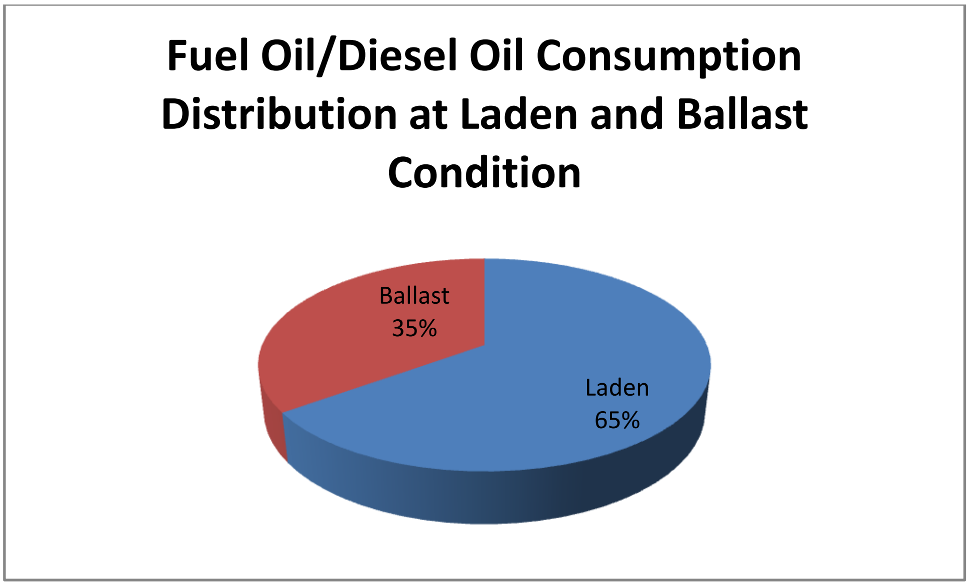

Figure 6.4- FO & DO Consumption Distribution [1]

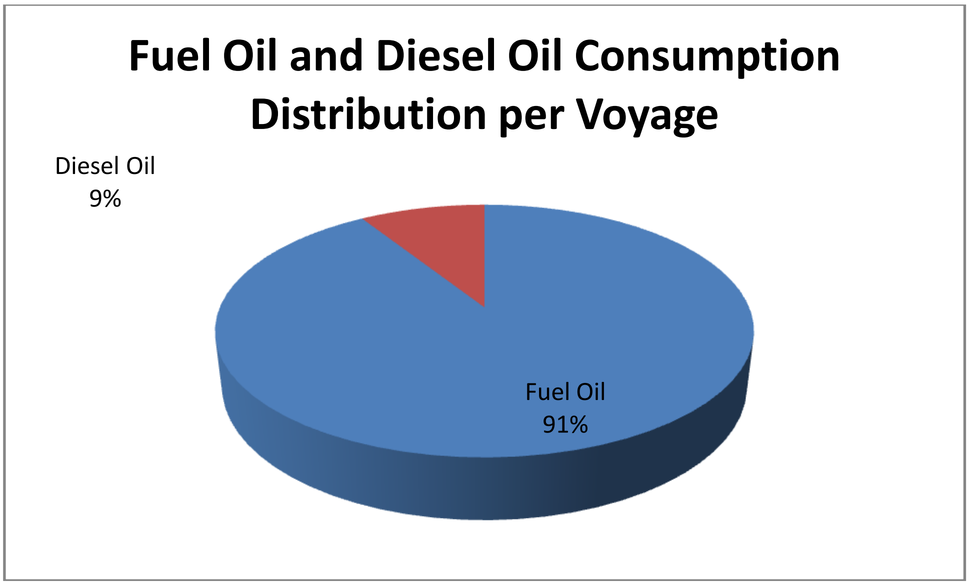

Figure 6.5- FO & DO Consumption Distribution per Voyage [1]

6.4.4. Main Engine particulars

Table 6.7- Main Engine Particulars [1]

Cycle	2-stroke Diesel Engine
Number of Cylinders	6
Bore	600mm
Stroke	1944mm
MCR	13150 kW
Speed (at MCR)	111 RPM
SFC at shop trials	124.9 gr/kWh
Firing order	1-5-3-4-2-6
Type	Hitachi B&W
Propeller Speed	111 rpm
Service Power(sea trial NCR:85% MCR)	9672 kW

6.4.5. Diesel Generator particulars

Three Diesel generators are installed onboard:

Table 6.8- Diesel Generator Particulars [1]

Type	4-cycle diesel engine
Number of cylinders	6
Engine rated power	1000 HP (735.5kW)
Firing Order	1-5-3-6-4-2
Bore	220mm
Stroke	300mm
DO Consumption at 100%Load(Shop Trial)	203.2 gr/kWh
SFOC at 100% Load(Shop Trial-ISO corrected)	203.2 gr/kWh +3%
Generator Rated Power	680 kW

6.4.6. Basic electrical balance data

The data in Table 6.9 was taken from the yard's electric load analysis **[1].**

Table 6.9- Basic Electrical Balance Data [1]

Load	**Input total of connected load (kW)**	**Power consumption in kW**					**Remark**
		At sea going	**At port in or out**	**Loading or unloading**	**At port**	**At emergency**	
Propulsion auxiliaries	467.5	128.6	189.3	19.6	19.6	-	
Machinery space/auxiliaries	456.1	52.8	98.2	75.7	45.4	-	
A/C and refrigerator	170.5	119.1	119.1	119.1	119.1	-	
Ventilation	1115.4	436.5	436.5	826.8	15.9	-	
Lighting	127.6	112	31.5	99.1	21	-	
Hotel	108	43.2	43.2	43.2	43.2	-	
Deck Machinery	673.6	-	400	16	-	-	
Emergency load	150.2	29.7	29.7	29.2	29.2	150.2	
Total load	3268.9	821.9	1349.5	128.7	293.4	150.2	
Generator in operation	Main generator (680 kW)	Two (2) 62.2%	Two (2) 99.1%	Two (2) 90.3%	One (1) 43.1%	-	% shows load factor of each generator
	Emergency generator (160 kW)	-	-	-	-	One (1) 93.9%	

The following table provides the basic ship electrical system characteristics:

Table 6.10- Ship Electrical System characteristics [1]

Nominal voltage	450 V
Rated current	962 A
Frequency	60 Hz
Phases	3
Single Phase Circuitry nominal voltage	110V

6.4.7. List of assessed consumers

The selection of consumers, of which the load pattern was assessed, was based on the following parameters:

- Unknown utilization factor.
- Unknown or variable load factor.
- Suspected inefficient operation or consumer is candidate to be the subject of a preliminary ESP.
- High power or extensive or continuous operation of consumer.

The electric consumers selected to be assessed regarding their load factor, utilization factor, power factor, load control and their operational pattern, appear in Table 6.11.

Table 6.11- List of assessed consumers [1]

Consumer	**Motor Power (kW)**	**Load Type**
No.1 Cooling SW Pump	30	Continuous load
Port Cooling FW Pump	7.5	Continuous load
Port lube oil Pump	75	Continuous load

6.4.8. Auxiliary Boilers

The particulars of Auxiliary Boilers are provided in Table 6.12.

Table 6.12- Auxiliary Boilers particulars & Burner Characteristics [1]

Number of units	1
Type	Composite Boiler
Evaporation:	
• Oil Burning Side	1300 kg/hr
• Exh. Gas Side, with M/E at 85%MCR	1300 kg/hr
Steam pressure:	
• Design:	7.0 kg/cm^2 (0.69 MPa)
• Normal:	6.0 kg/cm^2 (0.59 MPa)
Steam Temperature(or condition):	Saturated
Feed Water Temperature:	70°C
Flue Gas Temperature:	243°C

Burner characteristics:

Number:	1 per boiler
FO consumption min/max:	99 kg/hr
Fuel used during operation:	Diesel Oil

6.4.9. Feed Water/Steam distribution and condensate return system

The boiler feed water system comprises the feed water pumps, the circulating pumps, the auxiliary condenser and the feed water filter (cascade) tank. The feed pumps draw up the distilled water from the cascade tank and deliver it to the steam drum. The distilled water is evaporated and the produced steam is distributed to the steam consumers via the main steam line. The excessive steam is condensed via the auxiliary condenser and returns to the cascade tank.

The 6 kg/cm^2 steam distribution system is feeding the E/R pressure steam consumers which include:

- Fuel oil, bilge and sludge tanks in the E/R.
- Purifier heaters.
- HVAC heating element.
- M/E jacket water pre-heater.
- M/E, D/G and A/B FO pre-heaters.
- M/E, D/G and A/B FO steam tracing piping.
- Accommodation fresh water calorifier.
- Incinerator waste oil tank.

The majority of the steam heated loads is controlled manually for adjusting the system flow. A number of heating loads which does not require accurate temperature control, like the sludge and bunker tanks, are equipped with manually controlled valves. In general heated loads are maintained to temperatures normally required for the proper operation of the equipment involved.

6.4.10. FO/DO service system

The FO system is arranged with a separate FO supply piping, pumps, and FO pre-heaters, servicing the M/E, the D/G sets, and the A/B. However, there are common FO service and settling tanks for feeding the M/E, the D/G and the A/B. The service tank is heated at a temperature of about 90°C. The FO pre-heater is maintaining the temperature to the desired value, comprising a viscorator (modifies the viscosity of the fuel) and a viscosity controller before the engine inlet. Control of steam flow and therefore temperature at the M/E FO heater is affected by a pneumatically operated steam valve, regulated by the viscosity controller.

The temperature of the FO is maintained at about 135°C to ensure it is then fed to the engine injectors at the appropriate viscosity.

Separate flow meters are installed for measuring the consumption of the M/E and the three D/G sets.

On the contrary, the A/B is served directly from the service tank. The M/E and D/G flow meters are installed after the circulating pumps and before the FO heaters.

The consumption is possible to be double-checked from the level indicators of the settling and service tanks. The FO piping is insulated to minimize heat losses to the E/R.

The DO service system comprises the DO service tank, the suction piping from the DO service tank (which is also connected to FO supply pumps) and the piping system of the M/E, D/Gs and A/B. The incinerator is equipped with a separate DO service tank fed from the DO service tank via the DO transfer pump.

6.4.11. Cooling SW and FW system

The cooling water system comprises two interconnected cooling systems; the cooling SW system and the cooling FW system. The cooling SW system is fed by the three cooling SW pumps (i.e. two main and one for port use).

The cooling SW system provides the necessary cooling load to the central FW / SW coolers, the M/E air cooler, the auxiliary condenser, the air compressor, the FW generator, the D/G FW coolers, the D/G air coolers and the LO coolers.

The cooling FW system is served by the two central jacket cooling FW pumps and comprises two M/E jacket cooling FW pumps and one jacket FW cooler. The main central cooling FW system is serving the M/E jacket, the two main air compressors, the D/G FW coolers, the D/G air coolers and the FW generator.

6.4.12. Compressed air system

The compressed air system supply side comprises two main reciprocating two-stage air compressors (capacity: 230 m^3 /hr FAD at 30 kg/cm^2 each), one topping up air compressor (capacity: 140 m^3 /hr FAD at 30 kg/cm^2), two main air reservoirs (capacity: 7 m^3 each).The main air compressors provide air at 30 kg/cm^2 to the main air reservoirs.

The M/E and the D/G are considered as high pressure air consumers for starting. They are served by the main air compressors through the main air reservoirs.

More numerous are the low pressure air consumers which comprise a number of control loads, e.g. pneumatic temperature and level control valves, auto back flush filters, purifiers etc. and a number of compressed air outlets distributed in the E/R, outside the accommodation and on the main deck. The latter are used for connecting portable air tools and diaphragm pumps according to maintenance and operation needs. The above loads are served by the service air compressor. The control loads are served through the control air dryer(s), which is a very good design practice. The combination of lube oil filter integrated to the control compressor package unit and the dryers enhances feeding air of improved quality to the control pneumatic loads, thus extending their life and minimizing maintenance and replacements.

6.4.13. HVAC system

The vessel is equipped with a marine type packaged air conditioning unit with the following characteristics:

Number of units:	1
Type:	Multi cylinder high speed type
RPM:	1415 RPM
Power Consumption:	65 kW
AHU Fan Motor	
Air Volume	185 m^3 /h
Static pressure	160mmAq
Motor output	11 kW
Number of sets	2
AHU Air Cooler	
Type	Cross fin tube
Capacity	225900 kcal/h
Inlet air temperature	25.3°C
Number of sets	1
AHU Air Heater	
Type	Cross fin tube
Capacity	250000 kcal/h
Inlet air temperature	-2.5°C
Steam consumption	496 kg/h
Number of sets	1
AHU Humidifier	
Steam consumption	125 kg/h

Number of sets	1 set

Heating & cooling unit

Capacity	225900 kcal/h (896440 BTU/h)
Condensing Temperature	40.5°C
Evaporating Temperature	6.6°C
Compressor speed	1415 RPM
Number of sets	1

Condenser

Effective surface	44.3 m^2
Water flow	68.3 m^3/h
Number of sets	1

The HVAC system is sized for the following temperature and humidity conditions:

Space	**Summer**	**Winter**
Open Air	37°C, 70% RH	-18°C
Room	27°C, 50% RH	21°C, 50% RH
Cooling Water	32°C	-
Fresh Air	50% RH	50% RH

According to the air duct drawings and the in situ inspection, the conditioned air from the AHU is fed through the fan and insulated ducts to the cabins, mess rooms, the bridge and to the ballast control room. Air is provided to the conditioned spaces through ceiling diffusers.

After the cooling of the spaces, the air is drawn from door louvers into the alleyways. A grillage installed in the accommodation alleyways, which is serving as suction of the main return air duct, is leading back into the AHU. At the AHU inlet, there is a damper section from where the ratio of outside air and return air fed into the AHU can be adjusted.

The air temperature is controlled by a thermostat, whose sensor is installed at the superheater. The air relative humidity is adjusted manually by a valve. The air temperature, during heating, is controlled by an automatic steam regulating valve, which keeps the temperature after the heating coil at a constant level.

6.4.14. Lighting system

The vessel's lighting system is divided into the normal and emergency operation groups. For the purpose of the energy audit, the normal operation group is primarily of interest. Normal lighting is operating at 110V. The system is powered from the three transformers. The first transformer located in the engine room is of 450/105 V - 30 kVA, the second transformer located in the forecastle is of 450/105 V - 15 kVA and the third one located in Emergency Generator room is of 450/105 V - 7.5 kVA.

The majority of general lighting fixtures installed onboard are of fluorescent tube type 18W T8 coolwhite. Lighting fixtures with three fluorescent tubes are installed in public spaces, alleyways, as general lighting fixtures in cabins and in the engine room, galley, etc.

A significant number of lighting fixtures with incandescent light bulbs are installed onboard the vessel. The following table shows their number and power. Some of them are expected to have high average utilization factor, e.g. in the E/R, while other low utilization factor, e.g. lockers.

Table 6.13- Lighting system power consumption analysis [1]

Space	Quantity	Power(W)	Type
Car Deck	1118	80	FL
Car Deck	71	80	FL
Car Deck	46	40	FL
Car Deck	70	80	FL
Car Deck	3	80	FL
Car Deck	54	40	FL
Car Deck	3	40	FL
Car Deck	7	60	INC
Car Deck	35	60	INC
Crew's Mess Room	2	80	FL
Ballast Control Room	2	80	FL
Officer’s Mess Room	2	60	FL
Officer’s Smoking Room	2	60	FL
Captain's Office	2	60	FL
C/ENG Office	2	60	FL
All Cabins (exc.captain's class)	10	40	FL
Crew's Smoking Room	2	40	FL
W/H & Chart Space	2	40	FL
Treatment Room	1	40	FL
Gymnasium Radio Room	1	40	FL
Galley	2	80	FL
Sub Switch board room	2	80	FL
Serving passage	2	80	FL
AC Unit & Ref.Mach.Room	2	40	FL
Sub Switch board room	1	40	FL
Fire Station	1	40	FL
Car Deck	1	40	FL
Car Deck	1	80	FL
Car Deck	1	40	FL
Electric Equipment Room	1	40	FL
Inner passage in accommodation	2	40	FL
Radio Toil (accommodation spaces)	1	20	FL
Toil of each cabin(ceiling)	20	20	FL
W/H cabin(ceiling)	1	20	FL
Cabins bed light	13	15	FL
Cabins desk light	13	15	FL
Toil mirror light	22	8	FL
Captain Bed Mirror light	1	8	FL
C/Eng. Bed Mirror light	1	8	FL
Owner Mirror light	1	8	FL
C/Eng. Mirror light	1	8	FL
1/Mate Mirror light	1	8	FL
Pilot Mirror light	1	8	FL
2/Mate Mirror light	1	8	FL
3/Mate mirror light	1	8	FL
Spare office mirror light	1	8	FL
2 &3 Engineer Room Mirror light	1	8	FL
Radio operator mirror light	1	8	FL
Telephone booth	1	8	FL
Captain Day room table light	1	100	INC
C/Engineer Day room table light	1	100	INC
Officer’s smoking room table light	1	100	INC
Treatment room,outer pass.,E/R, steer.gear room	12	5	INC

Outer passage	1	5	INC
Engine room	1	5	INC
Steer engine room	1	5	INC
Emergency fire pump	1	10	INC
Emergency generator room	1	10	INC
Wheel house	1	5	INC
Chart space	1	5	INC
Inner passage	1	5	INC
Engine control room	1	10	INC
Outside	20	60	INC
Engine Room	4	80	FL
Engine Room	4	40	FL
Engine Room	77	80	FL
Engine Room	64	40	FL
Tally office	1	40	FL
TOTAL POWER (W)	**121122**		

6.5. Analysis of measurements and Audit findings

This Section serves the following main purposes:

- To present the data gathered before and during the shipboard energy audit in a concise manner, thereby depicting the vessel's energy characteristics at its present state.
- To identify areas, where potential exists for improved energy efficiency and conservation, i.e. identify ESPs.
- To carry out a preliminary estimation of the amounts of energy that may be saved if alternative processes, procedures and equipment are applied.
- To carry out a preliminary estimation of the financial aspects of ESPs, where sufficient financial data acquisition was possible.

Collection of data and / or measurements and corresponding analysis was carried out for the following:

- Vessel's operational pattern.
- Vessel hydrodynamic / propulsion performance.
- M/E performance.
- D/G performance.
- Electrical load management.
- Major auxiliary machinery operation and control.
- A/B performance and operational pattern.
- Cooling system.
- Compressed air system.
- HVAC system.
- Lighting system.

6.5.1. Ship's operational pattern

The main reason to study the vessel's operational pattern is to find how the operation modes mentioned in Section 6.4.2 are distributed within the voyage time and to assess whether the energy distribution is efficient.

The vessel's operational pattern affects the FO and DO consumptions and the load factor mainly of the M/E and secondarily of the D/G sets so, not only the machinery is affected, but also their SFOC which is directly related to energy efficiency.

The KPIs of interest in this context are the following:

- M/E FO Consumption per hour (kg/hr).
- M/E FO Consumption per navigated mile (kg/mile)

- M/E SFOC in gr/kWh.
- Vessel actual speed and ordered speed.
- The navigation time with speed overrun. In this report speed overrun is assumed to be the condition, where the actual speed exceeds the ordered speed by more than 0.5 knot.
- D/G FO consumption in kg/hr.
- D/G SFOC in gr/kWh (electric).

The following parameters are of interest in the vessel operational pattern analysis:

- Time distribution of the seven operating modes.
- The vessel's speed overrun time
- Load factor of the M/E.
- Calculation of KPIs in the form of FO and DO consumptions per hour, per mile and SFOC of M/E and D/G.

A) Time Distribution between different ship operation modes

The operation mode duration, for each voyage, was calculated as a percentage of the total voyage duration. The average values from all voyages were derived and is shown in Figure 6.6.

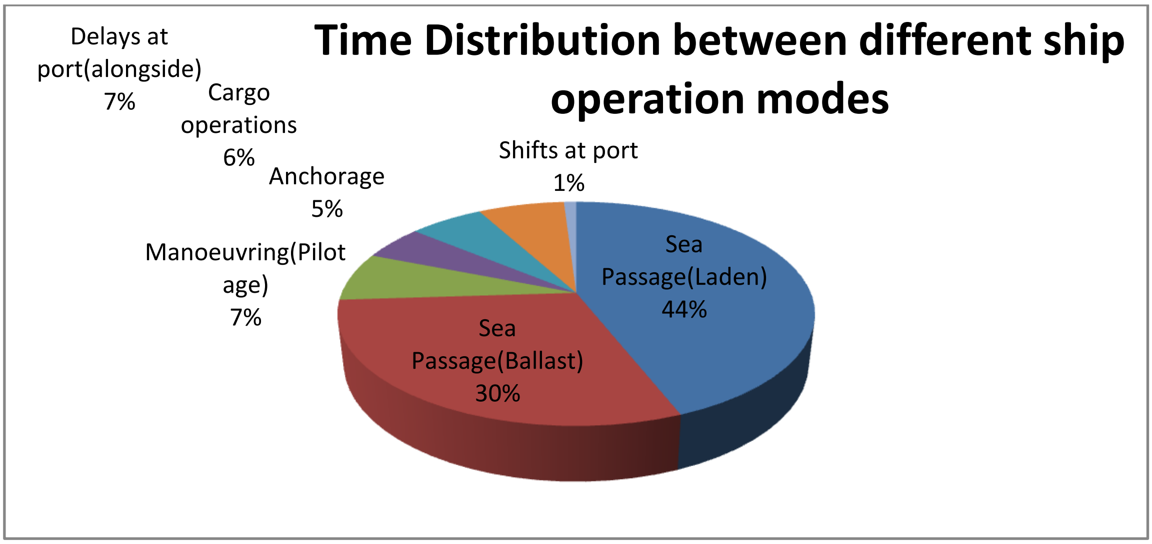

Figure 6.6- Time Distribution between different ship operation modes [1]

Sea Passage(Laden)	0.440
Sea Passage(Ballast)	0.300
Manoeuvring(Pilotage)	0.070
Anchorage	0.050
Cargo operations	0.060
Delays at port(alongside)	0.070
Shifts at port	0.010

The important observation to be made regarding this chart is that the vessel is sailing in laden condition at 44%, while the vessel is sailing in ballast condition at 30%, as can be seen in Table on the left. From the above figures, the ratio of the vessel's time sailing ballast against the time sailing in laden condition is calculated $\frac{0.3}{0.44} = 0.682$. This is an indication of a well managed vessel.

Another figure which is remarkable is the anchored/drifting time spent (5%) per voyage. This parameter is directly related to ***"Just in time" arrival*** and shows that the company has eliminated this time by minimizing the vessel's speed overrun, The investigation shows that the Master is in direct communication with the charterers and adjusts the vessel's speed and the fuel consumption in order to be on time in his destination without delays or early arrivals.

B) Speed Overrun Time

According to the voyage data analysis, the vessel's speed does not exceed by more than 0.5 knots the ordered speed by the charterers, due to the fact that the charterers are in direct contact with Master and the Vessel follows the just in time arrival program by adjusting her speed according to the berthing prospects and the planned loading/unloading operation. The average speed of the vessels is 15.72 knots.

In the face of this operation, it is recognized that the vessel is not running faster than ordered, which is very important for energy conservation.

C) Calculation of KPIs related to FO and DO consumption

The average values of M/E, D/G and A/B FO consumptions are calculated from the available voyage data, and are presented in Tables 6.14 and 6.15.

Table 6.14- Fuel Oil and Diesel Oil Consumptions during Sea Passage Ballast [1]

Voyage	F/O & D/O Consumptions during Sea Passage Ballast			
	Average M/E FO Consumption			Average D/G DO Consumption
	kg/hr	kg/mile	SFOC(gr/kWh)	kg/hr
Voyage 1	1030,39	77,13	147,843	127,84
Voyage 2	1117,07	79,66	141,581	86,48
Voyage 3	977,17	64,85	128,12	74,18
Voyage 4	86,96	40	-	88,71
Voyage 5	867,75	73,16	109,981	179,35
Average	815,87	66,96	131,881	111,31
Standard Deviation	291,56	11,63	12,831	33,83

Table 6.15- Fuel Oil and Diesel Oil Consumptions during Sea Passage Laden [1]

Voyage	F/O & D/O Consumptions during Sea Passage Laden			
	Average M/E FO Consumption			Average D/G DO Consumption
	kg/hr	kg/mile	SFOC(gr/kWh)	kg/hr
Voyage 1	1295,24	85,84	140,711	127,84
Voyage 2	843,33	114,54	149,157	68,29
Voyage 3	1455,54	89	147,591	81,09
Voyage 4	629,14	60,32	58,35	90,76
Voyage 5	1267,69	82,31	178,522	243,2
Voyage 6	1400,41	91,88	143,912	94,03
Voyage 7	972,41	71,57	105,651	74,76
Voyage 8	1355,73	85,61	137,47	81,14
Voyage 9	98,86	43,48	-	153,24
Voyage 10	1514,16	88,55	137,077	99,49
Voyage 11	1532,69	77,96	155,413	107,72
Voyage 12	1395,1	85,2	136,015	74,18
Average	1146,69	81,35	135,44	107,98
Standard Deviation	340,5	12,02	17,81	33,39

According to the voyage data available the average load of the M/E is 70.91% of MCR in laden condition and 57.75% of MCR in ballast condition. The average load factor of the M/E is lower than the NCR (90% MCR) due to the fact that the vessel is operating in an economical and environmental friendly mode.

The average SFOC in non-ISO conditions (131.81 gr/PSh at 57.75% load) in ballast condition is compared with the SFOC in non-ISO conditions at shop tests (128 gr/PSh at 57.75% load) and with the SFOC (126.8 at 57.75% load) based on the sea trial data. Taking into account the corrections of the manufacturer for fuel with lower calorific value (FLCV) and the difference in fuel density, the values seem to be slightly higher than the +3% SFOC warrantee.

The average D/G SFOC was measured during the audit and is equal to 212 gr/KWh at 60% load.In comparison with the shop trial data (196.2 kg/KWh at 60% load), the value seems to be significant higher. It must be noted that the indicated values of the D/G SFOC from the voyage data are average values calculated on the basis of an average electric load during sea passage and are not corrected to ISO conditions, since the ambient and coolant pressure and the temperature conditions are unknown. Nevertheless, the increased SFOC indication justifies further investigation based on actual SFOC measurements taken during the shipboard audit.

6.5.2. M/E and ship performance

Measurements onboard were taken by using the shipboard equipment (pressure gauges, thermometers, FO flow meters and Makers instruments for the performance analysis. The printouts of pressure indicator diagrams from the engine's cylinders and calculation of the corresponding indicated horsepower were taken by the Makers performance measurement tool and analyzed with the planimeter. The pressure readings were taken by installing the portable pressure transducer at the indicator cock of each cylinder.

A) M/E performance measurements

Table 6.16 summarizes the three performance measurements taken during the shipboard Energy Audit.

Table 6.16- Summary of M/E performance measurements [1]

Parameters measured	**Units**	**Audit Data**		
Engine speed	RPM	103.8	101.5	106.3
Mean Exhaust Gas Temp. of Cylinders	°C	357.7	354	365.8
Scavenger Air Pressure in Receiver - P_{scav}	bar	1.60	1.20	2.00
Compression Pressure - P_{comp}	bar	90.3	82.3	93.5
Mean Max. Combustion Press. - P_{max}	bar	117.5	106.0	122.7
Mean Pump Index		88.3	80.0	89.7
T/C Inlet Exhaust Gas Temperature	°C	438.0	431.0	448.0
T/C Outlet Exhaust Gas Temperature	°C	323.0	329.0	324.0
T/C Speed	rpm	11500	11000	11800
Air Cooler FW Inlet Temperature	°C	32.0	32.0	29.0
Air Cooler FW Outlet Temperature	°C	36.0	37.0	36.0
Air Temperature before Air Cooler	°C	158.0	147.0	167.0
Air Temperature after Air Cooler	°C	56.0	49.0	55.0
Blower Inlet Temperature	°C	33.0	32.0	41.0
Blower Inlet Pressure	mbar	1024.8	1024.7	1016
Scavenging Receiver Air Temperature	°C	56.0	49.0	55.0
E/R Temperature	°C	33.0	40.0	42.0
Sea Water Temperature	°C	28.0	28.0	28.0

Main LO Inlet Pressure	bar	3.53	2.55	2.15
Main LO Inlet Temperature	˚C	46.0	46.0	46.0
Cooling FW Inlet Pressure	bar	2.11	2.11	2.13
Cooling FW Inlet Temperature	˚C	64.0	65.0	63.0
Cooling FW Jacket Outlet Temperature	˚C	79.5	79.5	79.5
Piston CO Outlet Temperature	˚C	51.3	50.7	51.3
FO Booster Engine Inlet Pressure	bar	7.06	7.26	7.06

The data are plotted against the relevant available sea and shop trial curves, in order to assess the vessel's hydrodynamic and machinery performance. The correction of the measured values was made according to Energy Management Standard ISO 5001.

Table 6.17- ISO corrected parameters [1]

ISO corrected Parameters	**Units**	**Audit Data**		
Engine speed	RPM	103.8	101.5	106.3
Mean Exhaust Gas Temp. of Cylinders	˚C	342.7	340.7	339.3
Scav. Air Pressure in Receiver - P_{scav}	bar	1.62	1.21	2.11
Compression Pressure - P_{comp}	bar	91.5	83.2	97.4
Combustion Pressure - P_{max}	bar	118.9	107.0	126.6
Pmax-Pcomp	bar	27.4	23.8	29.2
$P_{compabs}$ / $P_{scavabs}$		35.0	37.7	31.5
Expected P_{comp}	bar	95.7	80.1	113.9
(Expected – Corrected) P_{comp}	bar	4.2	-3.1	16.5
Mean Indicated Pressure	bar	14.66	13.78	15.85
Indicated Engine Power	PS	11368.9	10447.0	12585.3
Effective Engine Power	PS	10593	9689	11791
Mechanical Efficiency		0.9300	0.9250	0.9320
Shaft Power	PS	10573	9664	11730
Load	%	80%	73%	89%
Start Time		8:55	10:25	13:35
End Time		9:55	11:25	14:35
Duration	hrs	1	1	1
FO Density @ 15 C	kg/lt	0.9868	0.9868	0.9868
FO Temperature at Flowmeter	˚C	85.0	84.0	80.0
Corrected FO Density @ Engine Inlet	kg/lt	0.9408	0.9145	0.9965
Measured FO Mass Consumption	kg	1590.8	1412.9	1813.7
FO Mass Consumption Rate	kg/hr	1590.8	1412.9	1813.7
FLCV	kJ/kg	40560	40560	40560
SFOC	gr/PSh	150.46	146.21	154.63
SFOC (ISO Corrected)	gr/PSh	142.89	138.86	146.85
SFOC (ISO Corrected)	gr/kWh	194.15	188.67	199.53
Fuel Energy Consumption	PS	24352	21629	27764
M/E total energy efficiency		0,45	0,46	0,46
T/C Performance				
Pressure Drop Air Filter	mmWG	30	29	28
Pressure Drop Air Cooler	mmWG	160	155	165
Air Cooler Performance				
DT air out-water in	˚C	24	17	26
DT water out-in	˚C	4	5	7

For a standard main engine, the engine layout is based on the ambient reference conditions of the International Standard Organization (ISO), given in Table 6.18.

Table 6.18- ISO ambient reference conditions [4]

ISO 3046-1:2002(E) and ISO 15550:2002(E): ISO ambient reference conditions	
Barometric pressure:	1,000 mbar
Turbocharger air intake temperature:	25°C
Charge air coolant temperature:	25°C
Relative air humidity:	30%

With this layout basis, the engine must be able to operate in unrestricted service, i.e. up to 100% Specified Maximum Continuous Rating (SMCR), within the typical ambient temperature range that the ship is exposed to, operating from tropical to low winter ambient conditions.

When applying the central cooling water system which, today, is more commonly used than the seawater system, the corresponding central cooling water/scavenge air coolant temperature is 4°C higher than the seawater temperature, i.e. equal to 36°C.

The winter ambient reference conditions used as standard for MAN B&W two-stroke engines are given in Table 6.19.

Table 6.19- Winter ambient reference conditions [4]

Winter ambient reference conditions	
Barometric pressure:	1000 mbar
Turbocharger air intake temperature:	10°C
Cooling water temperature:(minimum for lub. oil cooler)	10°C
Relative air humidity:	60%

The above ISO, tropical and winter ambient reference conditions are used by MAN Diesel & Turbo for ships, and MAN B&W two-stroke engines comply with the above rules. MAN B&W engines matched according to the above rules are able to operate continuously up to 100% SMCR in the air temperature range between about -10 and 45°C.

Often the engine room temperature is mistaken for being equal to the turbocharger air intake temperature. However, since the air ventilation duct outlets for a normal air intake system are placed near the turbochargers, the air inlet temperature to the turbochargers will be very close to the ambient outside air temperature.

Under normal air temperature conditions, the air inlet temperature to the turbocharger is only 1-3°C higher than the ambient outside air temperature.

An increase of the seawater temperature and, thereby, the scavenge air temperature has a negative impact on the heat load conditions in the combustion chamber. Therefore, all MAN B&W two-stroke engines for marine applications have an alarm set point of 55°C for the scavenge air temperature for protection of the engine, as described later.

For a standard ambient temperature matched engine operating at an increased seawater temperature existing in some inland, gulf, bay and harbor areas, the maximum power output of the engine should be reduced to an engine load resulting in a scavenge air temperature below the level of the scavenge air temperature alarm.

The data are plotted against the relevant available sea and shop trial curves, in order to assess the vessel's hydrodynamic and machinery performance.

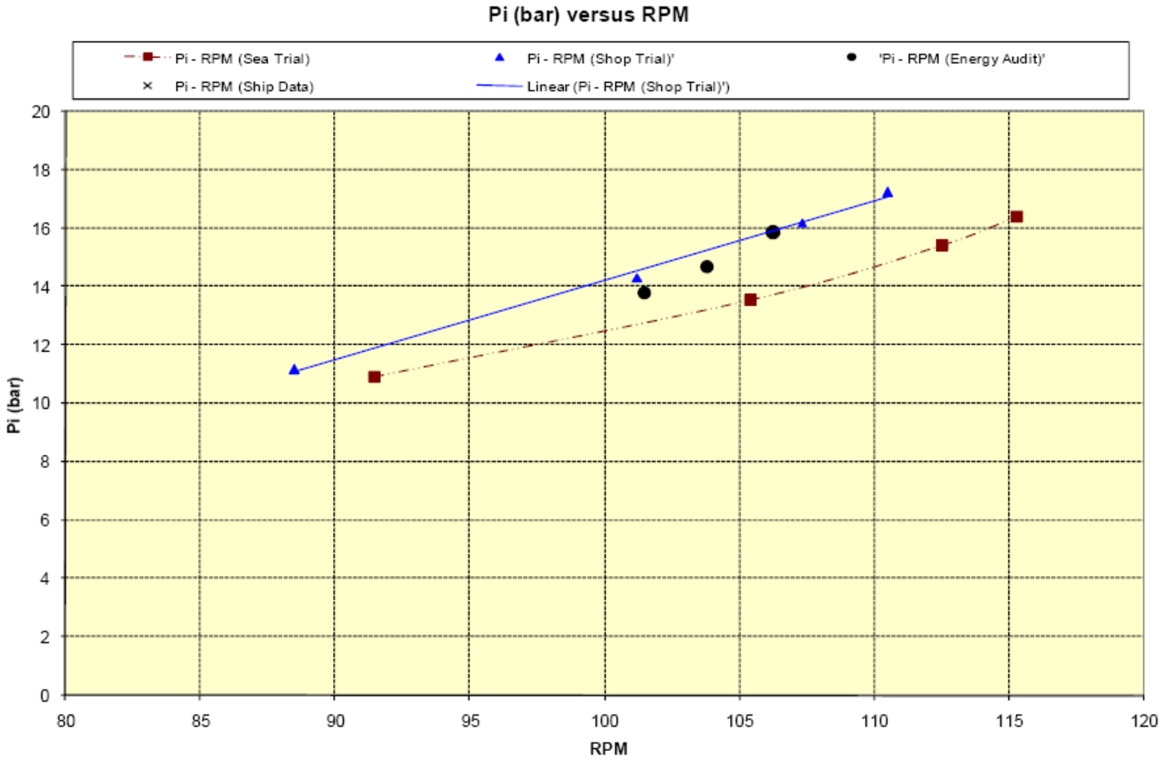

Figure 6.7- Indicated Pressure (P_i) vs. Engine RPM

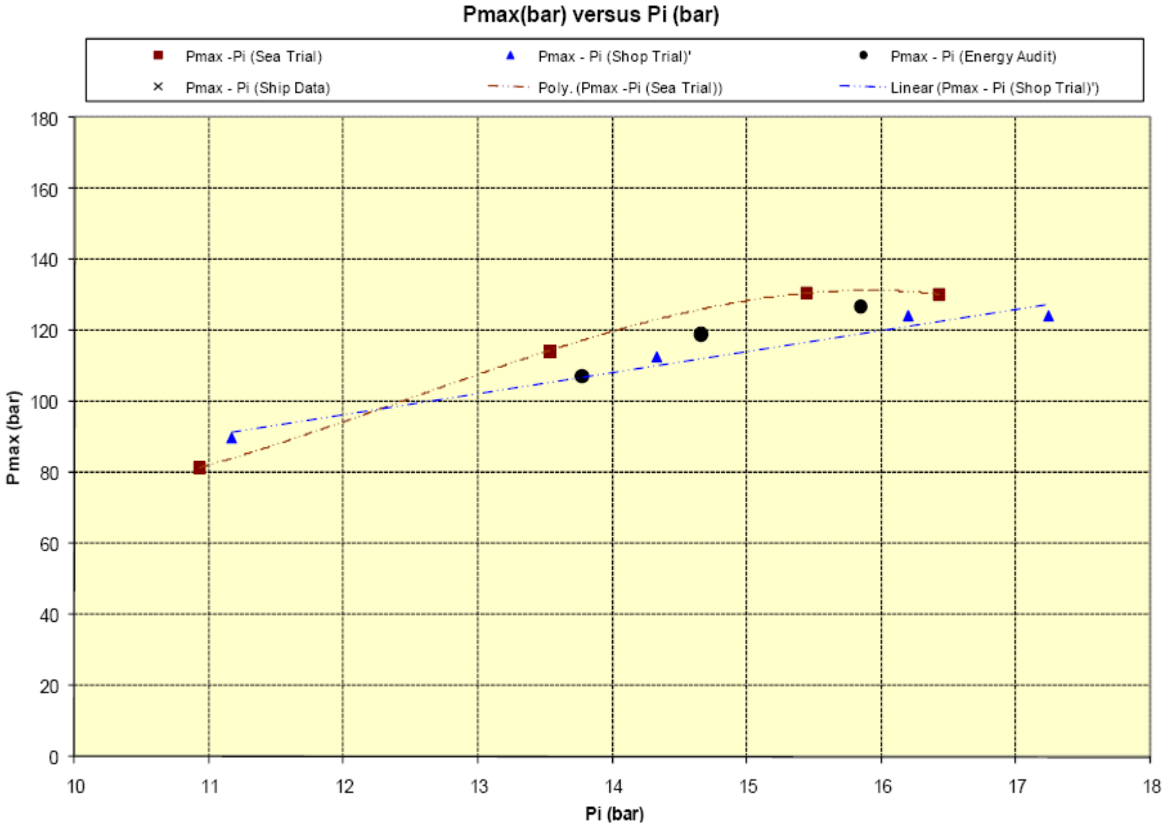

Figure 6.8- Maximum combustion pressure (P_{max}) vs. Indicated Pressure (P_i)

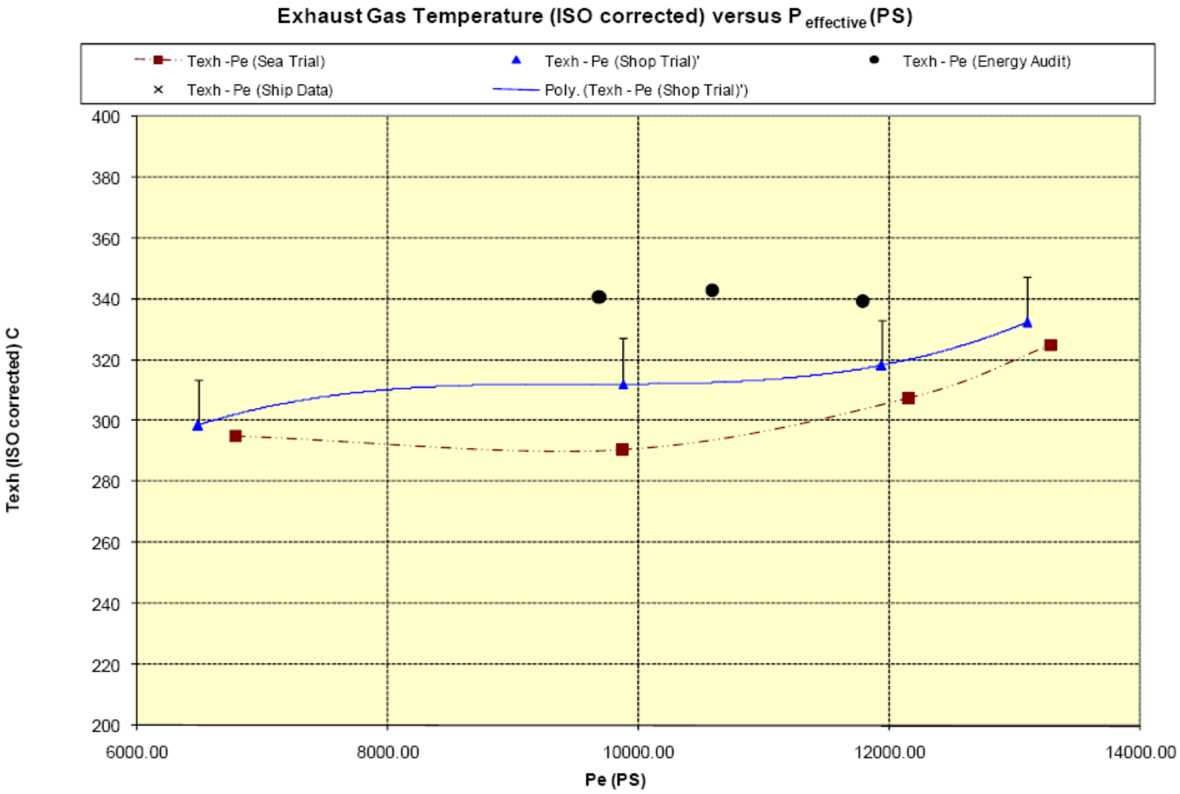

Figure 6.9- Exhaust Gas Temperature (T_{exh}) vs. Effective Power ($P_{effective}$)

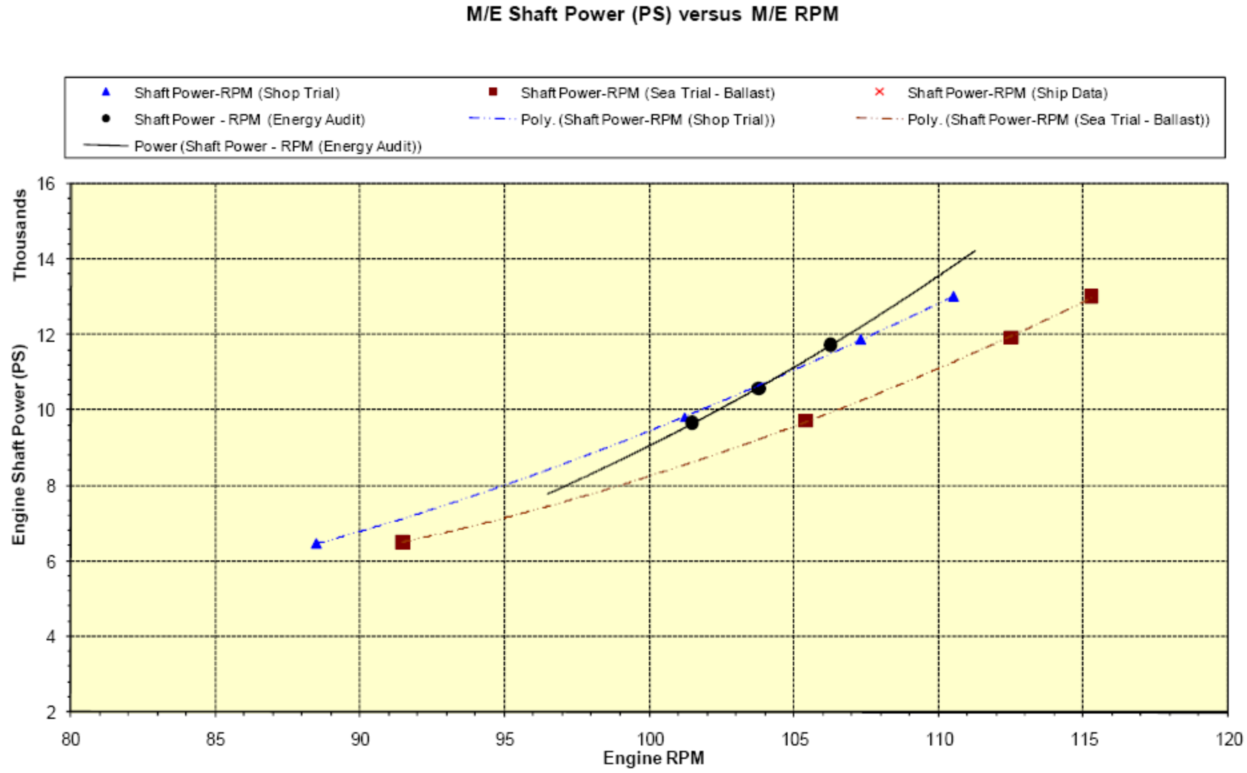

Figure 6.10- M/E shaft power vs. M/E rpm

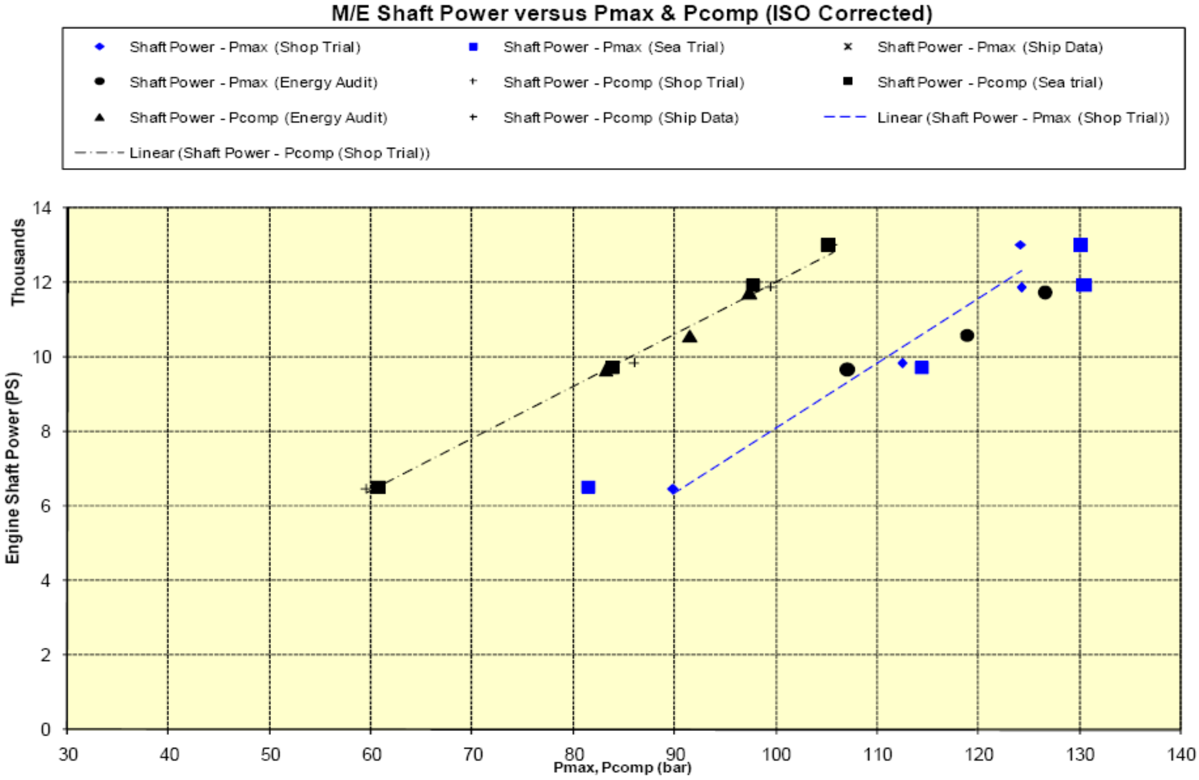

Figure 6.11- M/E Shaft Horse Power vs. P_{max} & P_{comp}

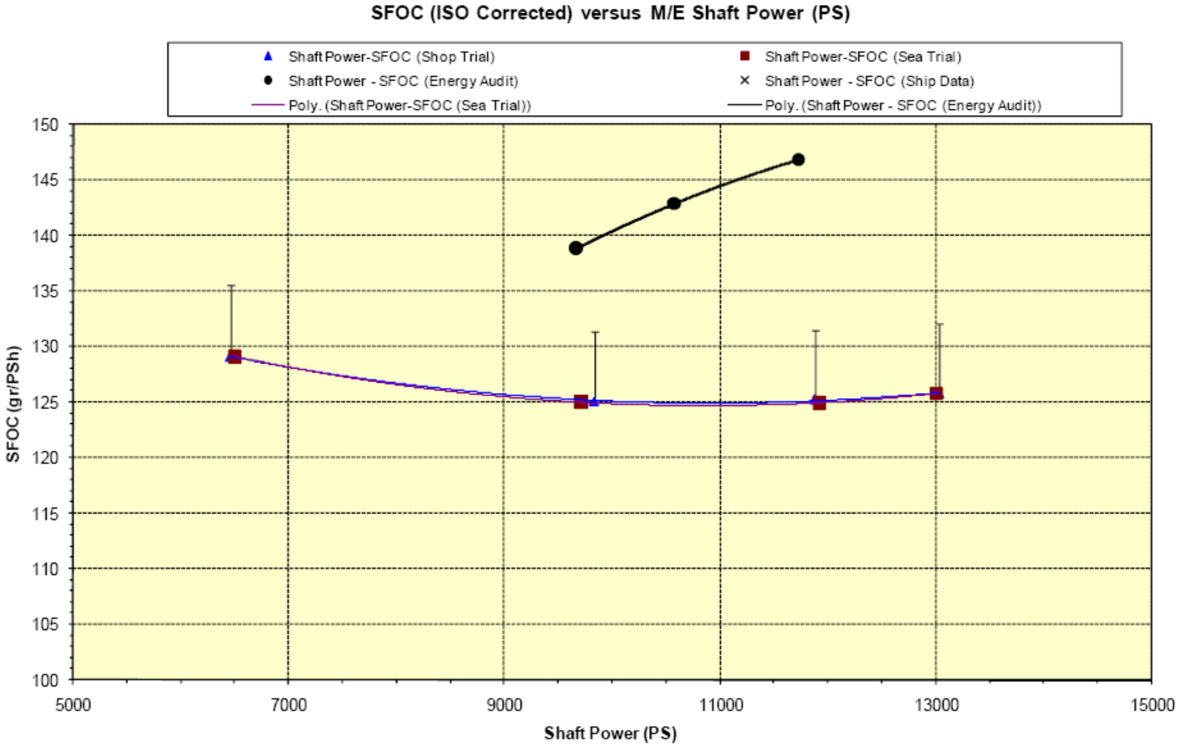

Figure 6.12- SFOC (ISO corrected) vs. M/E Shaft Power (PS)

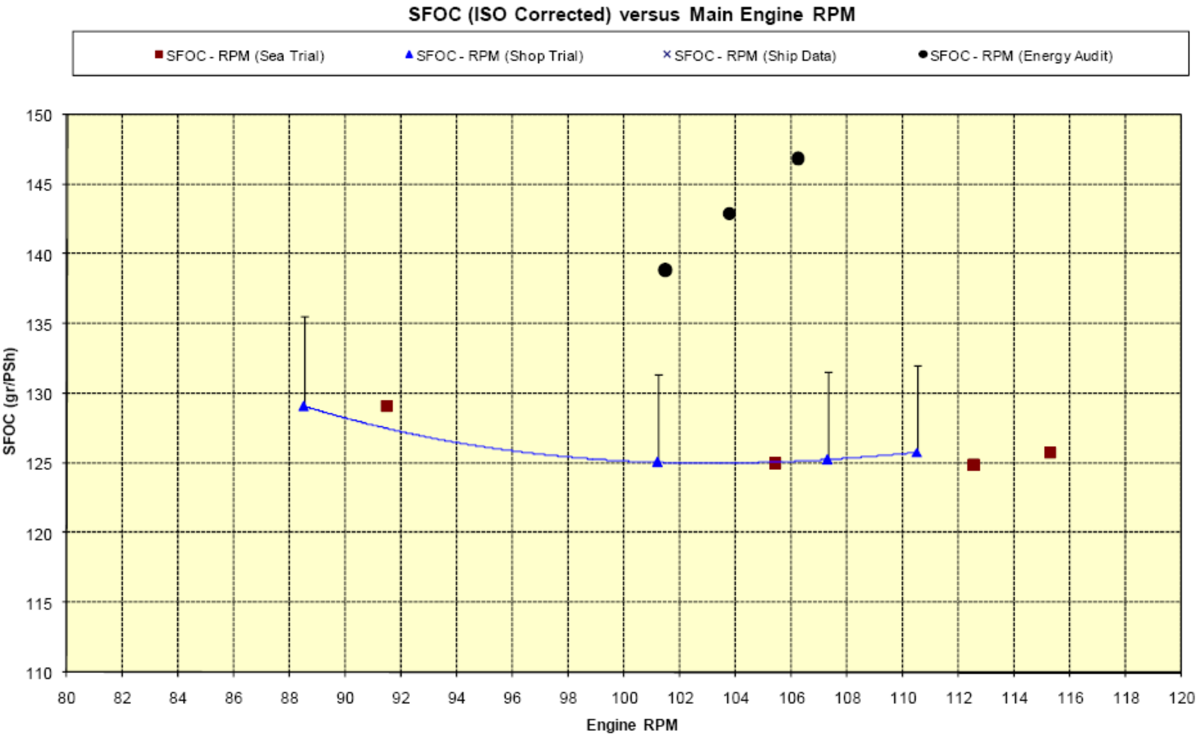

Figure 6.13- SFOC (ISO corrected) vs. M/E RPM

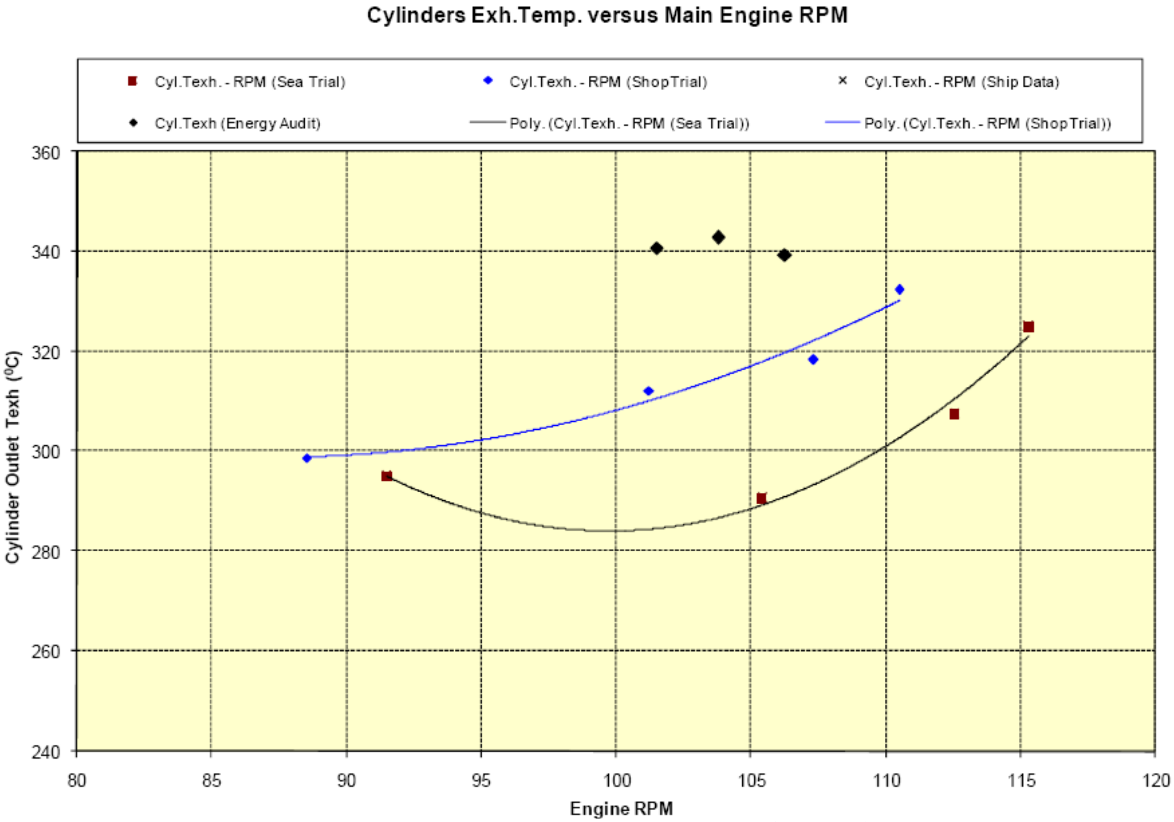

Figure 6.14- Cylinders Exhaust Temperature (Cyl. T_{exh}) vs. M/E RPM

B) Results and identification of ESPs

A list of detailed comments and derived indications of main engine performance is provided below:

- At air cooler the temperature difference between air outlet and cooling water inlet shows a decrease about by 50% of the shop trial values. The deviation from the shop trial curve is an indication of air cooler fouling from air or from water side.
- The water temperature difference across the air cooler is 50% lower than the shop trial value.

Furthermore, there is a possible indication of an inadequate heat transfer from the air to the water related to fouling of the water side.

- The P_{max} value of cylinder No.2 (122 bar) deviates more than the recommended value of 3 bars, from the average P_{max} (117.5 bar at 103.78 RPM).
- The P_{max} value of cylinder No.4 (114 bar) deviates more than the recommended value of 3 bars, from the average P_{max} (117.5 bar at 103.78 RPM).
- The P_{max} value of cylinder No.1 (119 bar) deviates more than the recommended value of 3 bars, from the average P_{max} (122.6 bar at 106.25 RPM).
- The P_i value of the cylinder No 3 (15.7 bar) deviates more than the recommended value of the 0.5 bars from the average P_i (14.6 bar at 103.7 RPM).
- The P_i value of the cylinder No 4 (13.7 bar) deviates more than the recommended value of the 0.5 bars from the average P_i (14.6 bar at 103.7 RPM).
- The P_i value of the cylinder No 3 (15.4 bar) deviates more than the recommended value of the 0.5 bars from the average P_i (14.6 bar at 103.7 RPM).
- The M/E SFOC at 80.65 % load was found equal to 142.45 gr/PSh (corrected according to ISO 3046-1:2002(E)), or approximately 10% higher than the shop test curve. The increase is above the manufacturer 5% tolerance. The higher SFOC could be partly attributed to the ideal conditions when performing the shop test, to the different fuel quality and the higher FLCV which was used during the test. Nonetheless, the air cooler fouling indications noted above or the low pressures observed in the cylinders' combustion chambers are attributive parameters that lead to SFOC increase.

The SFOC and the fuel energy consumption were slightly higher than those at the sea trial and shop test. This is correlated with the above observations and probably with fuel oil quality.

It is rather difficult to absolutely correlate a certain amount of SFOC reduction to particular maintenance actions, like the fouled air cooler cleaning. Nevertheless, to demonstrate potential benefits the minimum achieved SFOC reduction will be inserted to the Return on Investment (ROI) calculations. The cost of repairs will be considered once during this 3 year period. The SFOC improvement corresponds to an equal percentage reduction for the M/E average FO hourly consumption. The following ESP is presented, along with the relevant equations:

ESP-01	**Critical SFOC reduction to benefit from M/E overhaul(dismantling the cylinders, repair and reconnection)**
Type:	High cost/high benefit
Feasibility:	High

Estimated cost for overhauling=70000 USD (6.1a)

Required Payback Time=3 years (6.1b)

Interest Rate=4%=0.04

Required financial annual benefit for maintenance cost equalization in 3 years =

$$= 70000\times\left[\frac{r\times(1+r)^{N}}{(1+r)^{N}-1}\right] = 70000\times\left[\frac{0.04\times1.04^{3}}{1.04^{3}-1}\right] = 70000\times0.36=25200 \text{ USD } \textbf{[2]} \quad (6.1c)$$

$$\text{Fuel Price} = 670\,\frac{\text{USD}}{\text{MT}} \quad (6.1d)$$

$$\text{Corresponding conservation estimate} = \frac{25200\,\text{USD}/\text{year}}{670\,\text{USD}/\text{MT}} = 37.6\,\frac{\text{MT}}{\text{year}} \quad (6.1e)$$

$$\text{Equivalent CO}_2 \text{ reduction} = 3.11\,\frac{MT_{CO_2}}{MT_{Fuel}}\cdot37.6\,\frac{MT_{Fuel}}{year} = 116.94\,\frac{MT_{CO_2}}{year} \quad (6.1f)$$

(reference: Table 2.3)

$$\text{Average yearly sea passage time} = 74\%\cdot356 \text{ days}\cdot24 \text{ h}=6482.4 \text{ h} \quad (6.1g)$$

$$\text{Present FO Consumption} = 131.81\,\frac{gr}{PSh}\cdot11178PS = 1473\,\frac{kg}{h} \quad (6.1h)$$

Critical FO consumption for maintenance cost payback in 3 years=

$$=1473\frac{kg}{h}-37.6\frac{MT}{year}=1473\frac{kg}{h}-37.6\frac{1000kg}{6482.4h}=1473\frac{kg}{h}-5.8\frac{kg}{h}=1467.2\frac{kg}{h} \quad (6.1i)$$

$$\text{Critical FO Consumption reduction} = 5.8\,\frac{kg}{h} \quad (6.1j)$$

$$\text{Critical FO Consumption reduction percentage} = \frac{5.8\,\frac{kg}{h}}{1473\,\frac{kg}{h}} = 0.39\% \quad (6.1k)$$

Suggestions:

1. In order to be able to determine the exact quantity of the consumed FO in the M/E, it is suggested the installation of an additional flow meter in the M/E FO return line.
2. The vessel carries out daily measurements at M/E. The data are recorded in Daily Performance reports, which are forwarded to the company. A review of the subject reports revealed that although the basic operating parameters of the M/E were reported to the company, the comparison on a daily or on a monthly basis, was not possible, because the results could not be normalized for the same ambient conditions. So as to correct and compare the engine temperatures, pressures and the daily measured SFOC, it is very important to record the actual E/R ambient conditions during the performance tests, which are:

- The actual E/R temperature at M/E blower inlet, and
- The actual air pressure near the blower inlet (the pressure at blower inlet is slightly higher than the atmospheric pressure read on the bridge barometer due to the static pressure imposed by the E/R fans).

C) Hull Performance Measurements

The hull performance measurements, i.e. the ship speed, the relative wind speed and direction, the relative current speed and direction and the wave estimated characteristics and direction, were carried out concurrently with the M/E performance measurements. During the tests, the vessel was in laden condition and good weather conditions were prevailing.

Table 6.20- Hull Performance Measurements [1]

Measurement		**Audit Data**		
		103.78 rpm	**101.48 rpm**	**106.25 rpm**
Ship's speed over ground(VGk)	knots	18.69	18.28	19.14
Ship's speed over ground(VG)	m/sec	9.614	9.403	9.846
Engine revolutions	rpm	103.8	101.5	106.3
Propeller revolutions	rpm	103.8	101.5	106.3
Power measured	PS	10606	9673	11742
Relative wind velocity (V_{WR})	knots	28.1	26.9	20.3
Relative wind velocity (V_{WR})	m/sec	14.5	13.8	10.4
Relative wind direction (D_{WR}) (bow=0)	degrees	57	63	27
Relative wind direction (D_{WR})	rad	0.99	1.09	0.47
Wave height (H)	m	1	1	2.5
Wave period (Tm)	sec	3	3	3
Incident wave angle (bow=0)	degrees	63	63	67
Sea Water Temperature (TW)	°C	25.0	27.0	28.0
Sea Water Density (ρw)	kg/m^3	1.025	1.025	1.025

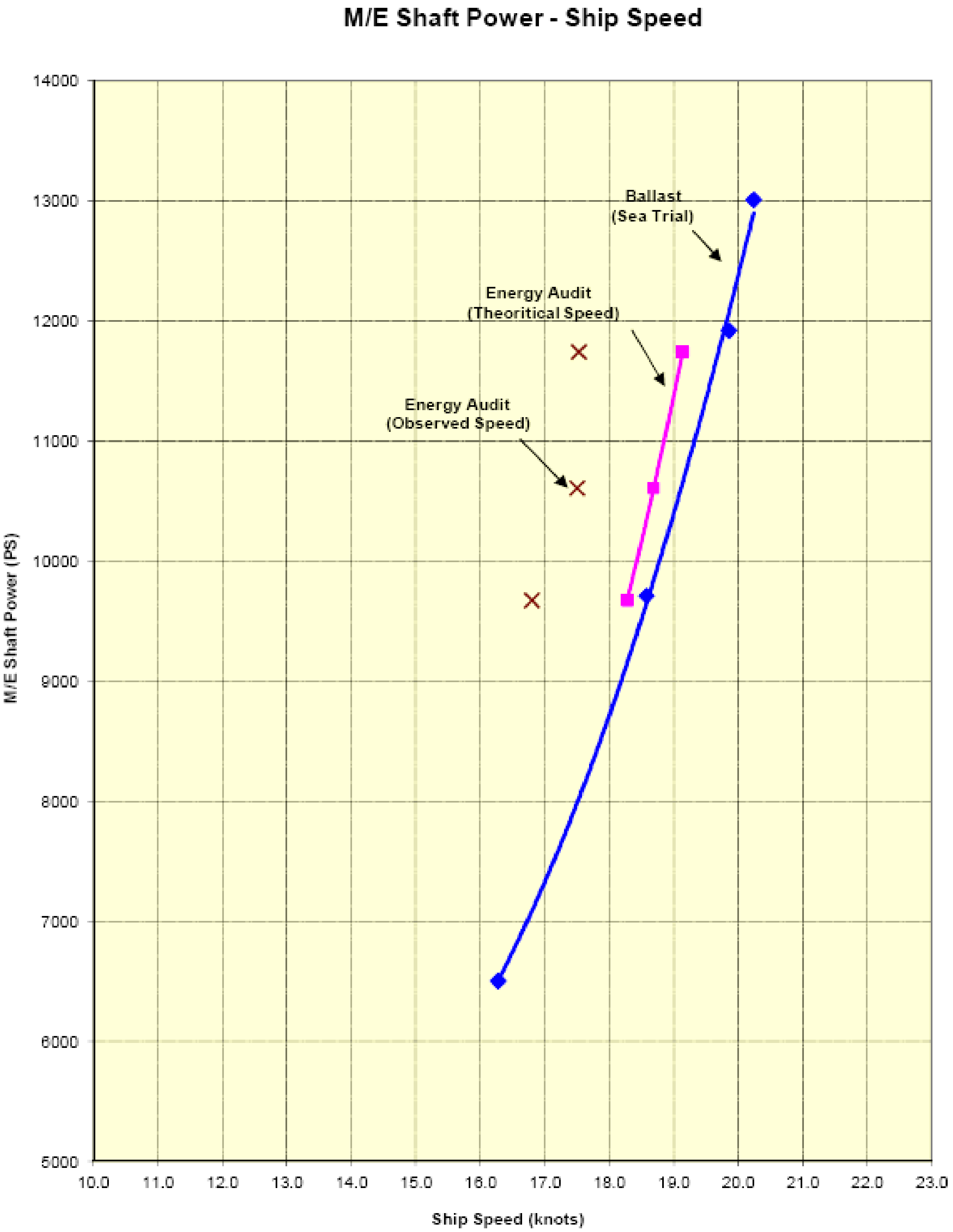

Figure 6.15- M/E SHP (PS) vs. Ship's Speed (knots) [1]

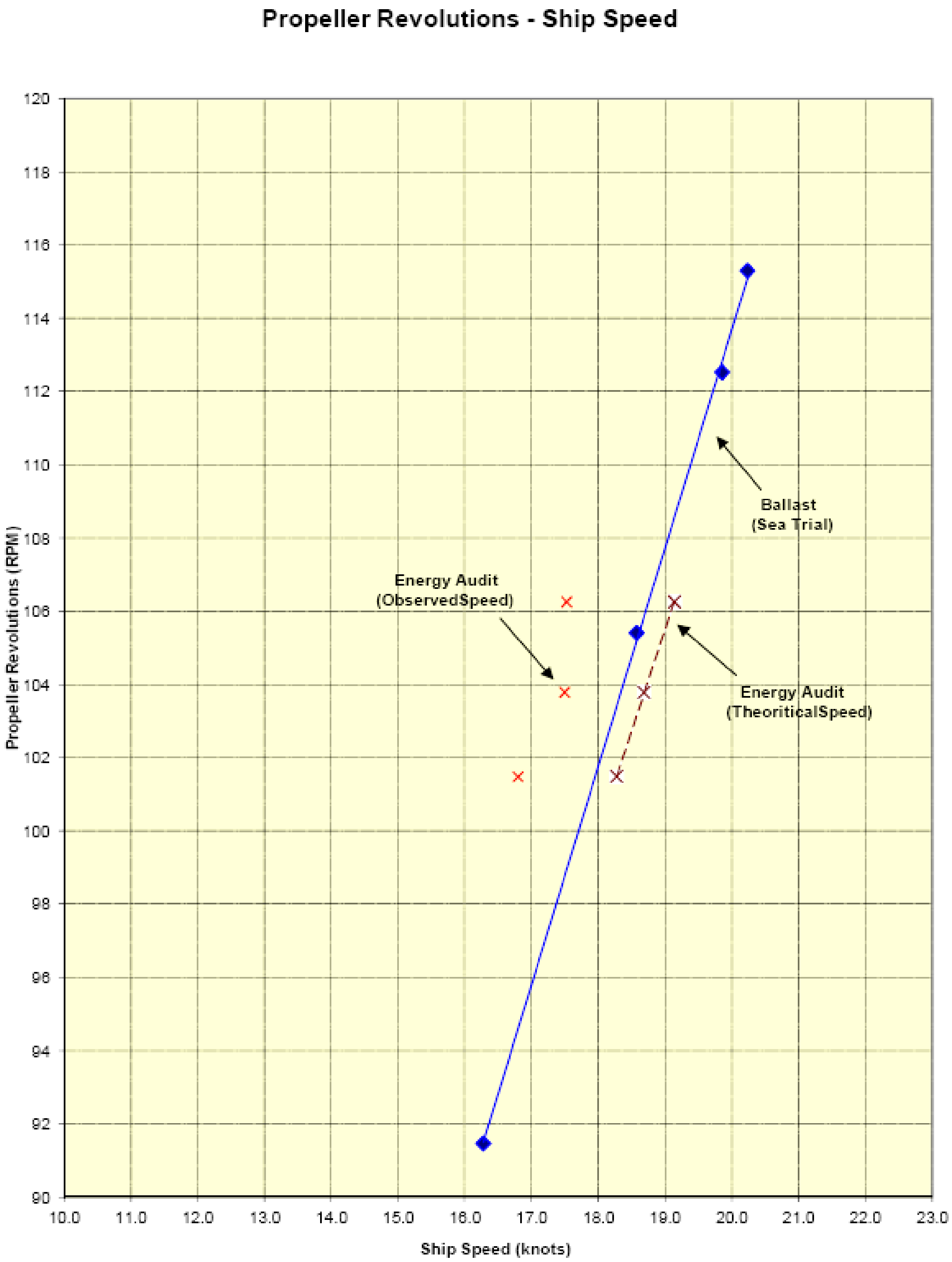

Figure 6.16- Propeller Revolutions (RPM) vs. Ship's Speed (knots) [1]

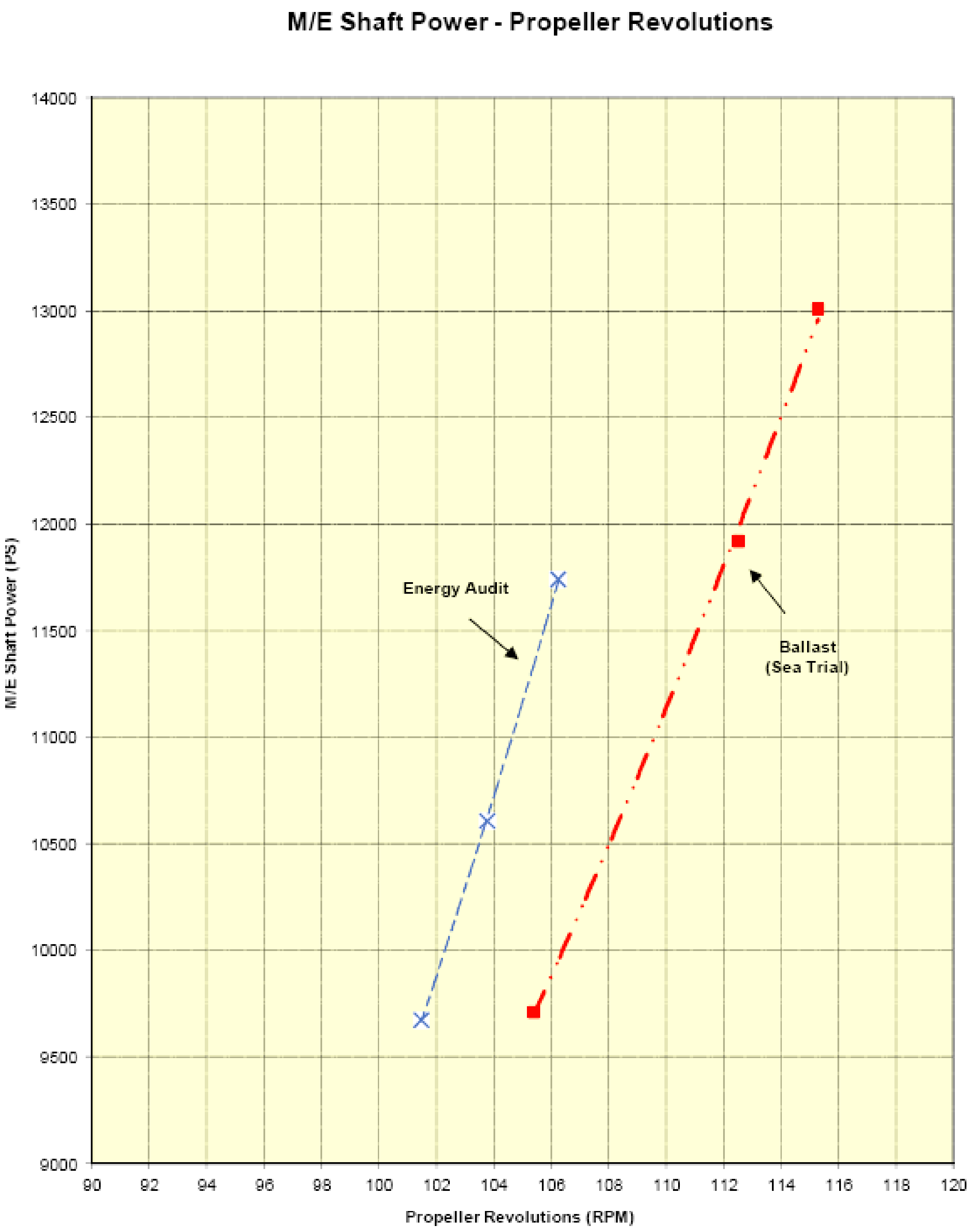

Figure 6.17- M/E SHP (PS) vs. Propeller Revolutions (RPM) [1]

From Figures 6.15-6.17, we can observe that, for the same propeller speed, the ship achieves lower speed in comparison with Sea Trial speed. Equivalently, for the same Shaft Power, there is lower propeller speed, and, consequently lower speed of the vessel in comparison with Sea Trial data. That condition was expected, due to hull and propeller fouling, which are associated with ship's operation.

6.5.3. Assessment of D/G performance and investigation of electrical balance

Measurements onboard were obtained using the shipboard equipment (pressure gauges, thermometers, FO flow-meters, etc.). D/G performance was assessed by analyzing the audit performance parameters and then by comparing them with the shop and sea trial reports.

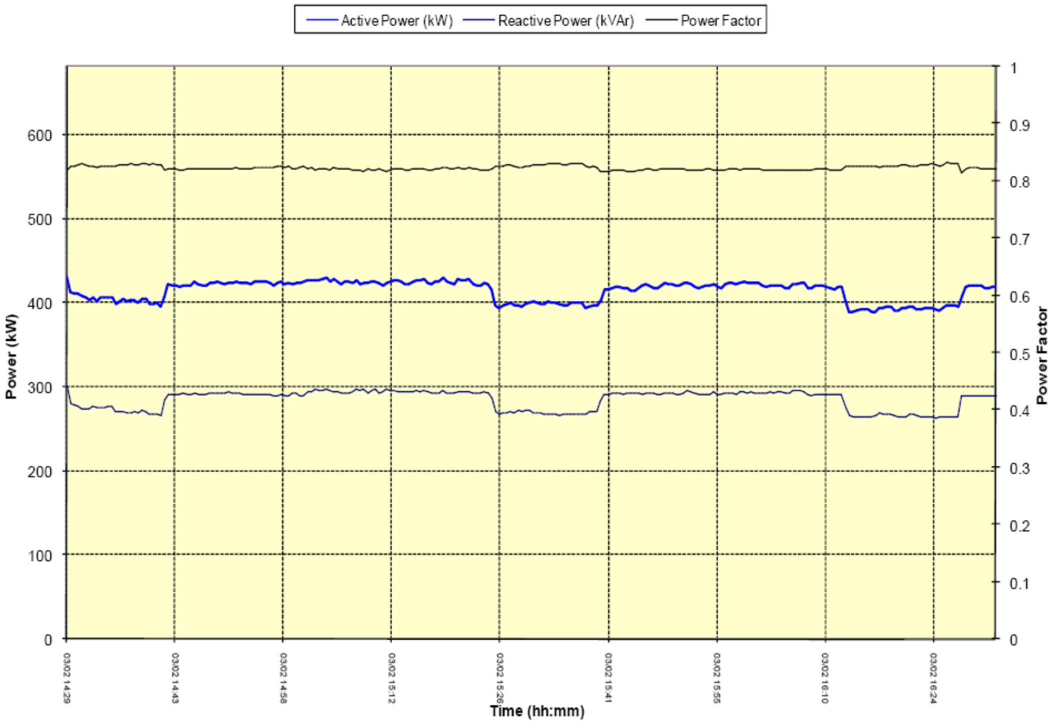

Figure 6.18- Active Power (kW), Reactive Power (kVAr) and Power Factor vs. Time for D/G set

Table 6.21- Sea Trial & Energy Audit Data for Diesel Generators [1]

Parameters measured	**Units**	**Sea Trial D/G**	**Audit**
Load	**%**	**100%**	**60%**
Speed	RPM	720	720
Mean max. Combustion Pressure	kg/cm^2		103.2
Mean Exhaust Gas Temp. of Cylinders	°C	345	352.5
Mean Pump Index (indicates the amount of fuel passing through the generator)	mm		18.8
Fuel Oil Pressure at Engine Inlet	kg/cm^2	8.0	1.0
Air Cooler FW Inlet Temperature	°C	67	31
Air Cooler FW Outlet Temperature	°C	64	35
Charge Air Pressure after A/C	kg/cm^2	0.63	0.78
Charge Air Temperature before Air Cooler	°C		113.0
Charge Air Temperature after Air Cooler	°C	31.0	43.0
T/C Revolutions	rpm	12550	
T/C Outlet Exhaust Gas Temperature	°C	305	
Blower Inlet Temperature	°C		38.6
Blower Inlet Pressure	mbar		1022
Jacket Water Inlet Pressure	kg/cm^2	2.30	
Jacket Water Inlet Temperature	°C		66.6
Jacket Water Outlet Temperature	°C		68.0
Lub Oil Pressure before Filter	bar	5.2	5
Lub Oil Pressure before Cooler	bar	66.5	
Lub Oil Temp. after Cooler	°C	56.5	
Engine Room Ambient Temperature	°C	35.0	40.0
Sea Water Temperature	°C	27.0	27.0

Elements missing from ''Sea Trial'' column were not available. Elements missing from ''Audit'' column were not measured due to possible technical reasons.

Table 6.22- Shop Trial Data for Diesel Generators [1]

Parameters measured	**Units**	**Shop Trial D/G**				
Load	%	**25%**	**50%**	**75%**	**100%**	**110%**
Speed	RPM	720	720	720	720	720
Mean max. Combustion Pressure	bar	66.83	93.8	113.8	133.7	140.8
Mean Exhaust Gas Temp. of Cylinders	°C	219.2	256.6	295.8	384.0	350.8
Mean Pump Index	mm	9.0	13.0	17.0	21.0	23.0
Fuel Oil Pressure at Engine Inlet	kg/cm^2					
Air Cooler FW Inlet Temperature	°C					
Air Cooler FW Outlet Temperature	°C					
Charge Air Pressure after A/C	bar	0.27	0.65	1.14	1.64	1,84
Charge Air Temperature after Air Cooler	°C	21.0	25.0	33.0	40.0	42.0
T/C Revolutions	rpm	13800	20000	25200	29200	30700
T/C Inlet Exhaust Gas Temperature	°C					
T/C Outlet Exhaust Gas Temperature	°C	205.0	245.0	265.0	285.0	300.0
Blower Inlet Temperature	°C					
Blower Inlet Pressure	mbar					
Jacket Water Inlet Pressure	bar	1.28	1.18	1.18	1.18	1.18
Jacket Water Inlet Temperature	°C	45.0	63.0	69.0	68.5	66.0
Jacket Water Outlet Temperature	°C	49.7	66.7	87.2	74.7	73.7
Lub Oil Pressure before filter	bar	5.19	5.10	5.00	4.90	4.80
Lub Oil Pressure after Filter	bar	1.37	1.23	1.18	1.15	1.08
Lub Oil Temp. before Cooler	°C	40.0	55.0	62.0	60.5	65.0
Lub Oil Temp. after Cooler	°C	39.0	53.0	55.0	54.0	54.0
Engine Room Ambient Temperature	°C	14.0	16.0	17.0	16.5	19.0
Sea Water Temperature	°C	15.0	15.0	15.0	15.0	15.0
ISO corrected Parameters	**Units**					
Electric Power	kW	170	340	510	680	748
Generator Efficiency		0.956	0.956	0.956	0.956	0.956
Engine Power	kW	178	356	533	711	782
Electric Load	%	25%	50%	75%	100%	110%
FLCV	kJ/kg	42500	42500	42500	42500	42500
Fuel Oil Temperature at Engine Inlet	°C					
Fuel Density @ 15°C	kg/lt	0.8602	0.8602	0.8602	0.8602	0.8602
Test Duration	min	20	20	20	20	20
Fuel Temperature @ flowmeter	°C	15.0	15.0	15.0	15.0	15.0
Fuel Density @ flowmeter	kg/lt	0.9	0.9	0.9	0.86	0.9
Consumption rate (weight)	kg/hr	44.6	72.1	105.1	138.2	152.6
SFOC (ISO corrected)	gr/kWh	262.7	213.2	206.0	203.20	204.0
Fuel Power	kW	526.5	851.2	1240.8	1631.5	1801.5
Total Engine Efficiency		0.3377	0.4178	0.43	0.44	0.4343

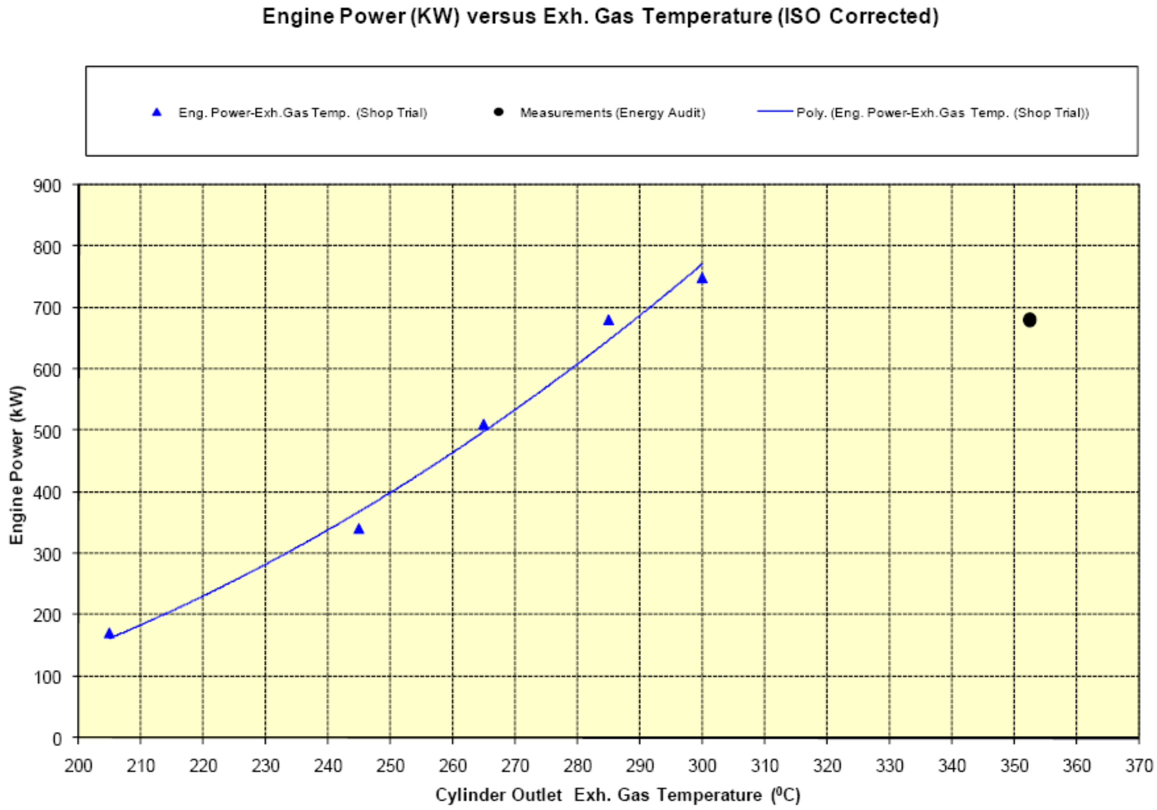

Figure 6.19- Engine Power vs. ISO corrected Exhaust Gas Temperature [1]

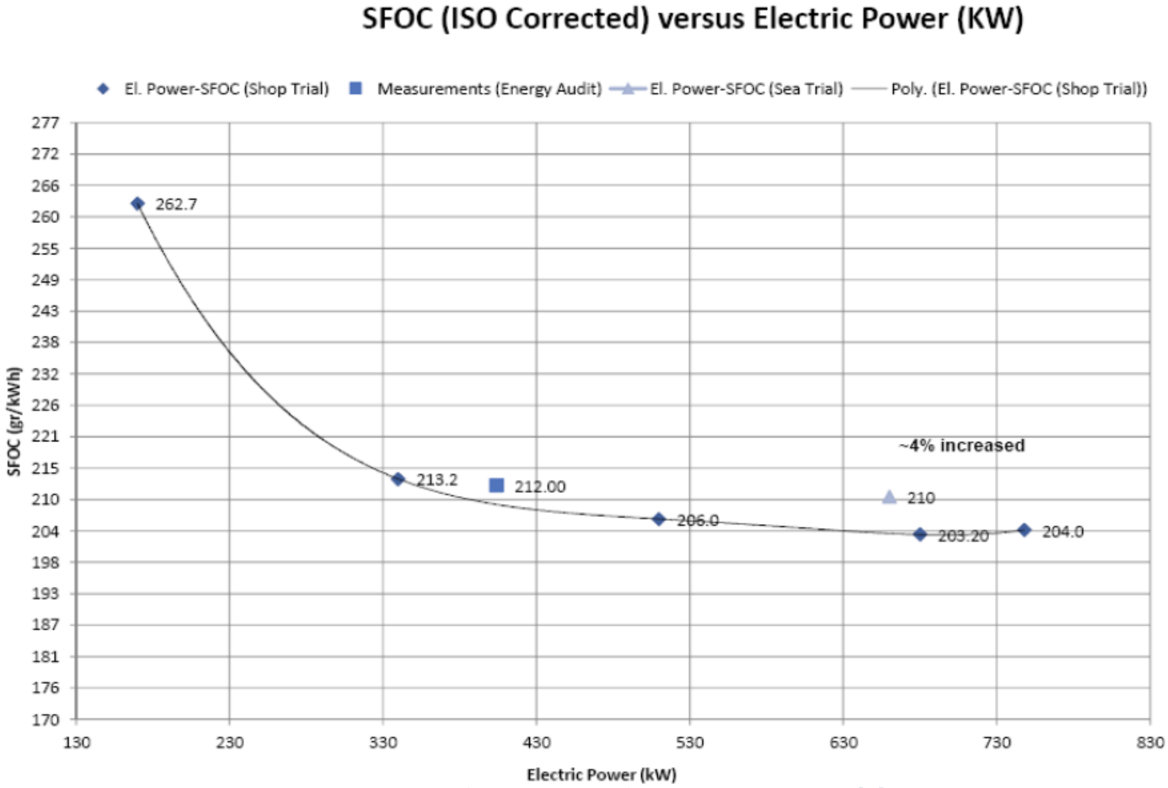

Figure 6.20- SFOC (ISO corrected) vs. Electric Power [1]

A) Results and identification of ESPs

A review of the D/G performance data reports reveals the following:

– The exhaust gas temperature is about 20% higher than the shop trial values. This may be attributed to the use of DO during shop trial on the one hand and to an indication of T/C fouling.

– The SFOC (corrected according to ISO 3046-1:2002(E)) of the D/G (212.5 gr/KWh, 60.0% load) appears to be approximately 3% higher than the shop trial report (208 gr/KWh, for the same load).
It is rather difficult to correlate the excessive SFOC with particular maintenance needs. Nevertheless, it is assumed that ISO corrected SFOC would marginally decrease by 3%.

Thus the following ESP is identified, described by the relevant equations:

ESP-02	**Estimated benefit from D/G maintenance(improvement of SFOC)**
Type:	Medium cost/medium benefit
Feasibility:	Medium

$$\text{D/G current DO Consumption (at 60\% Load)} = 212.5\ \frac{gr}{kWh} \quad (6.2a)$$

Assumed SFOC improvement after overhaul= 3% (6.2b)

Sea Passage & Pilotage Time= 74% +7%= 81% (6.2c)

$$\text{Average yearly sea passage \& pilotage time} = 81\% \cdot 356\ \text{days} \cdot 24\ \text{h} = 7096\ \text{h} \quad (6.2d)$$

$$\text{Yearly average of one (1) D/G operation time} = 60\% \cdot 7096\ \text{h} = 4257\ \text{h} \quad (6.2e)$$

Yearly average DO consumption for one (1) D/G estimation =

$$=212.5\frac{gr}{kWh}\cdot 0.6\cdot 680kW\cdot 4257\frac{h}{year}=369.1\frac{MT}{year} \quad (6.2f)$$

$$\text{DO conservation estimate} = 3\%\cdot 369.1\frac{MT}{year} = 11.07\frac{MT}{year} \quad (6.2g)$$

$$\text{Equivalent } CO_2 \text{ reduction} = 3.20\frac{MT_{CO_2}}{MT_{Fuel}}\cdot 11.07\frac{MT_{Fuel}}{year} = 34.4\frac{MT_{CO_2}}{year} \quad (6.2h)$$

$$\text{DO price} = 1100\frac{USD}{MT} \quad (6.2i)$$

Spares cost per engine (assumption)= 15000 USD (6.2j)

Labour cost per engine (assumption*) = 12000 USD (6.2k)

Invested annual amount (assuming overhaul every 3 years)=

$$=(12000+15000)\cdot\left[\frac{r\cdot(1+r)^N}{(1+r)^N-1}\right]=27000\cdot\left[\frac{0.04\cdot 1.04^3}{1.04^3-1}\right]=9720\frac{USD}{year} \quad (6.2l)$$

$$\text{Avoided operational cost per year} = 1100\ \frac{USD}{MT}\cdot 11.07\frac{MT}{year}=12177\frac{USD}{year} \quad (6.2m)$$

$$\text{Payback Time} = \frac{9720\ USD}{12177\frac{USD}{year}} = 0.8\ \text{year} = 9.6\ \text{months} \quad (6.2n)$$

*assuming 4 persons for 5 days, 10h/day, USD 60/hour

6.5.4. Investigation of Load Management and power characteristics

An investigation of the load management and power characteristics was carried out by recording the generators' loading pattern and by correlating this with the electrical behavior of selected electric loads capable of significantly affecting the power characteristics.

Electric parameters of loads with high nominal power are capable of significantly affecting the electric parameters of the grid and generator(s). On the other hand, the loads with unknown utilization factor and load factor are of significant interest for the proper sizing of motors and for the transient phenomena caused to the grid when starting.

To obtain a representative view of the vessel's electric system, the following tasks were carried out:

- Monitoring of No.1 & 2 generators' electric parameters during sea passage, manoeuvring and loading.
- Monitoring of control and service air compressor which are the main intermittent loads in operation during sea passage.
- Analysis and review of the data collected above. Correlation of the generator load and power factor with the operating intervals, load and power factor of the selected loads.

A) Results and Identification of ESPs

The active, reactive power and power factor diagrams during anchorage, loading, manoeuvring / pilotage and sea passage are presented in Figures 6.21-6.23. The active, reactive power and power factor show a different behavior, depending on the generators and loads that are connected, stopped or started. In the respective diagrams, various phases are identified and described. Furthermore, the electric generators load factor was monitored during various vessel operation modes.

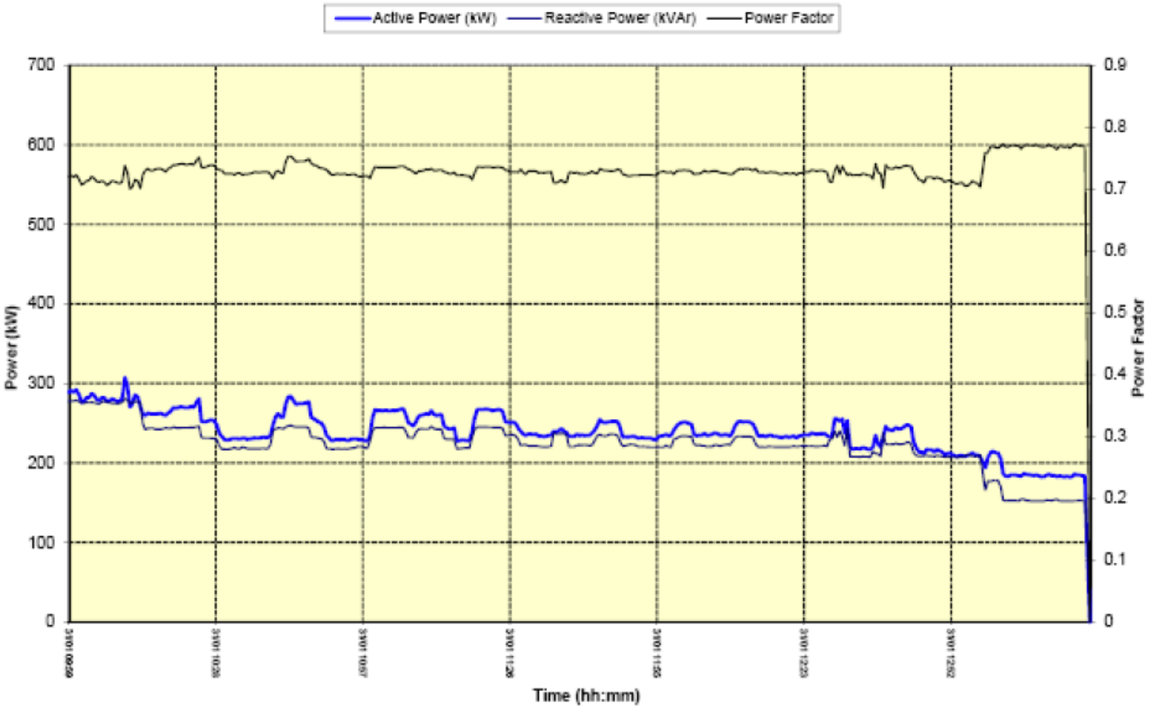

Figure 6.21- Central D/G (working in parallel with starboard D/G) Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time at Canal Passage [1]

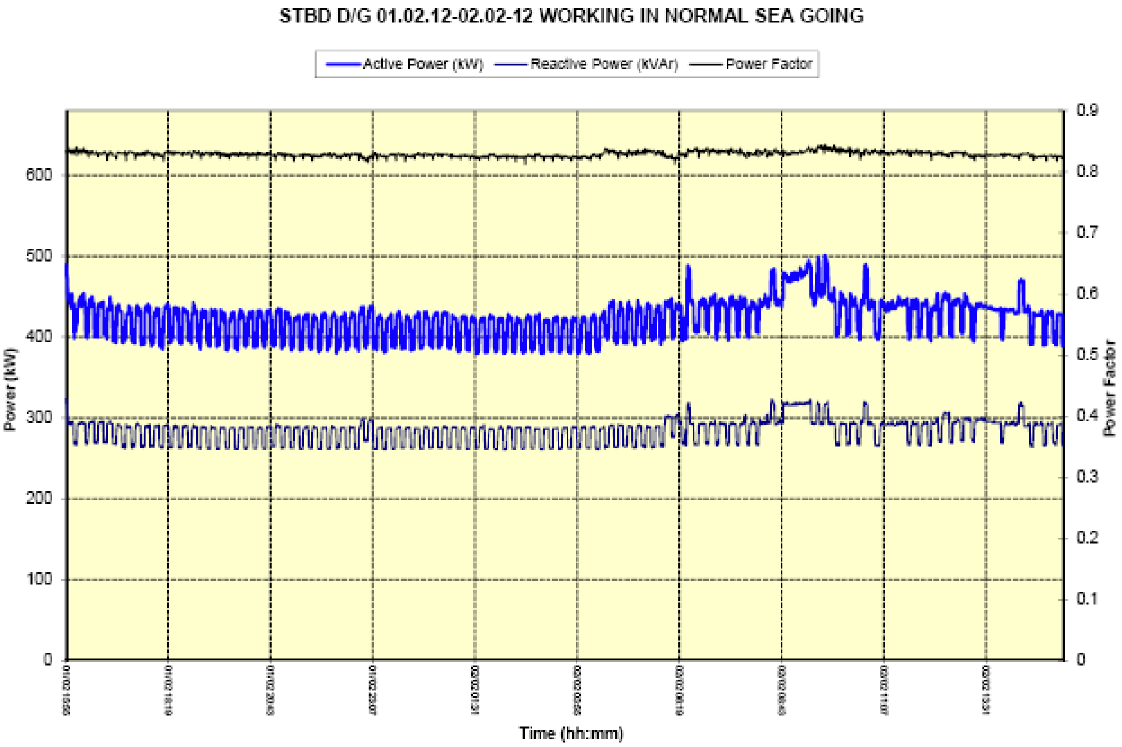

Figure 6.22- Starboard D/G Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time at Sea Passage [1]

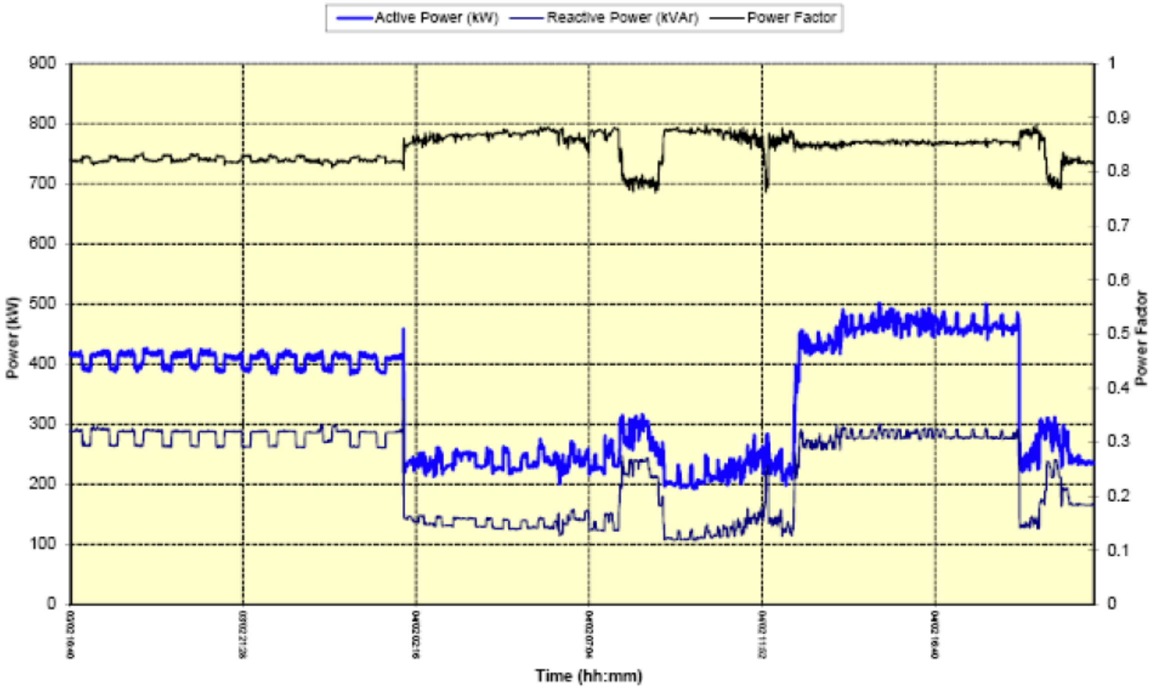

Figure 6.23- Starboard D/G (working in parallel with Central D/G) Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time at Port operations [1]

Figures 6.21-6.23 show that during sea passage only one generator was in operation, and two diesel generators were kept in operation only during standby, discharging and loading at port which considered a very good operational practice.

6.5.5. Performance and operation for selected E/R pumps and fans

The performance of major pumps was investigated. The following pumps were selected for audit:

- No.1 Cooling SW Pump.
- Port Cooling FW Pump.
- Port Lube Oil Pump.

A) Pumps Operation Investigation

The pumps listed above, either operate continuously or have loads of significant rated power, which was the reason for their selection for investigation. Measurements of the electric parameters (active power, voltage, cosφ, starting current) and hydraulic parameters of the pumps were carried out to facilitate their energy efficiency assessment. Table 6.23 presents the collected and calculated data.

Table 6.23- Electric Motors (measured values compared to the respective design values) [1]

Inspection Item	Unit	No.1 Cooling SW Pump		Port Cooling FW Pump		Port Lube Oil Pump	
		Measured	Design	Measured	Design	Measured	Design
Type		Induction		Induction		Induction	
Electric Power	kW	14.6	30	7	7.5	61.05	75
Voltage	V	440	440	440	440	440	440
Speed	rpm	1770	1760	1800	1760	1795	1760
Number of Poles		4	4	4	4	4	4
Slip	%	-0,57	-	-2,27	-	-1,99	-
Stator Phase Current	A	21.56	49	10.45	12.5	95.7	120
Power Factor		0.85	0.803	0.7	0.787	0.84	0.82
Shaft Power	kW	12	29.91	5	7.53	53	62.08
Load Factor	%	47	-	93	-	84	-
Motor Efficiency	%	85	-	71.4	-	83.5	-
Motor Efficiency Class		-	EFF2	-	EFF2	-	EFF2
Is the starting current normal?		Yes		-		Yes	
Is the starting time normal?		Yes		Yes		Yes	
Are all phase currents equal?		Yes		Yes		Yes	
Are there harmonics present?		No		No		No	
Is there excessive vibration?		No		No		No	

Table 6.24- Pumps (measured values) [1]

Inspection Item	Unit	No.1 Cooling SW Pump	Port Cooling FW Pump	Port Lube Oil Pump
Type		Centrifugal	Centrifugal	Centrifugal
Liquid		SW	FW	SW
Liquid Temperature	°C	29	70	55
Pump Delivery Press	kg/cm^2	2.3	3.0	-
Pump Suction Press	kg/cm^2	0.3	1.0	-

Figures 6.24-6.29 contain the measurements onboard for the Power Factor and the Load Factor, for each one of the three aforementioned pumps:

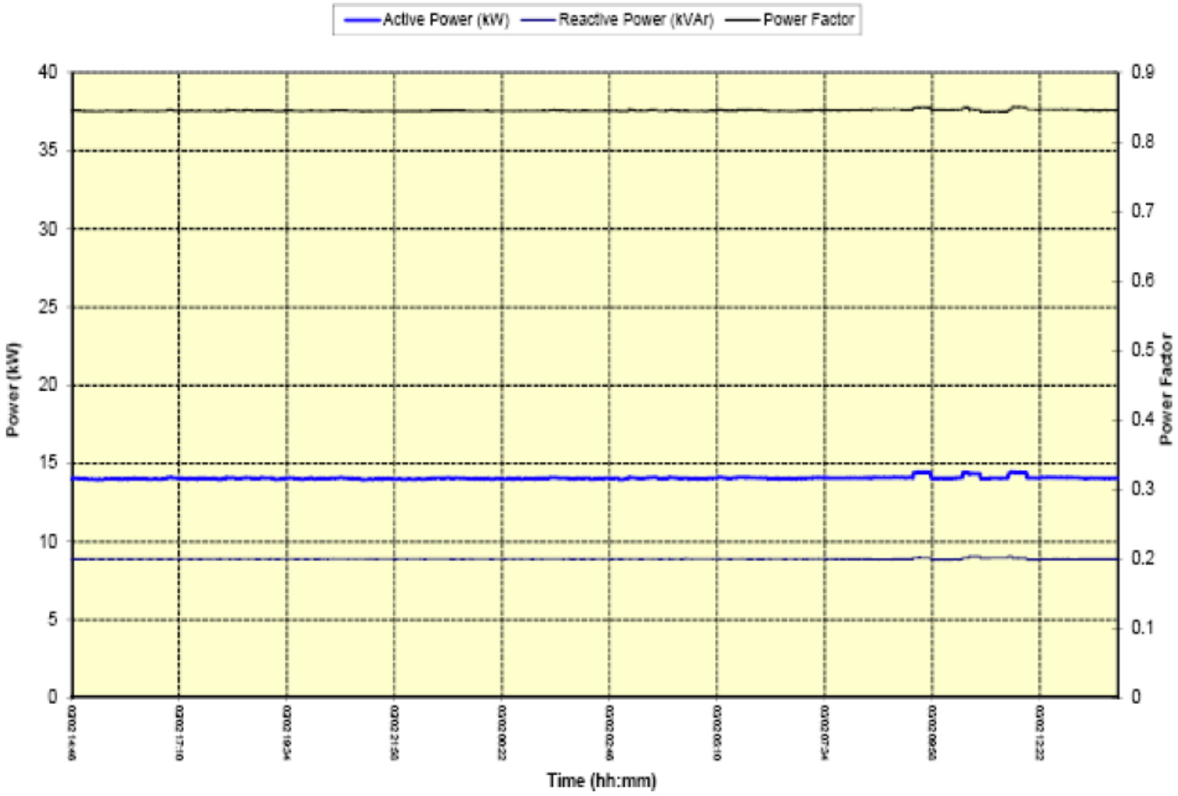

Figure 6.24- Cooling SW Pump Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time [1]

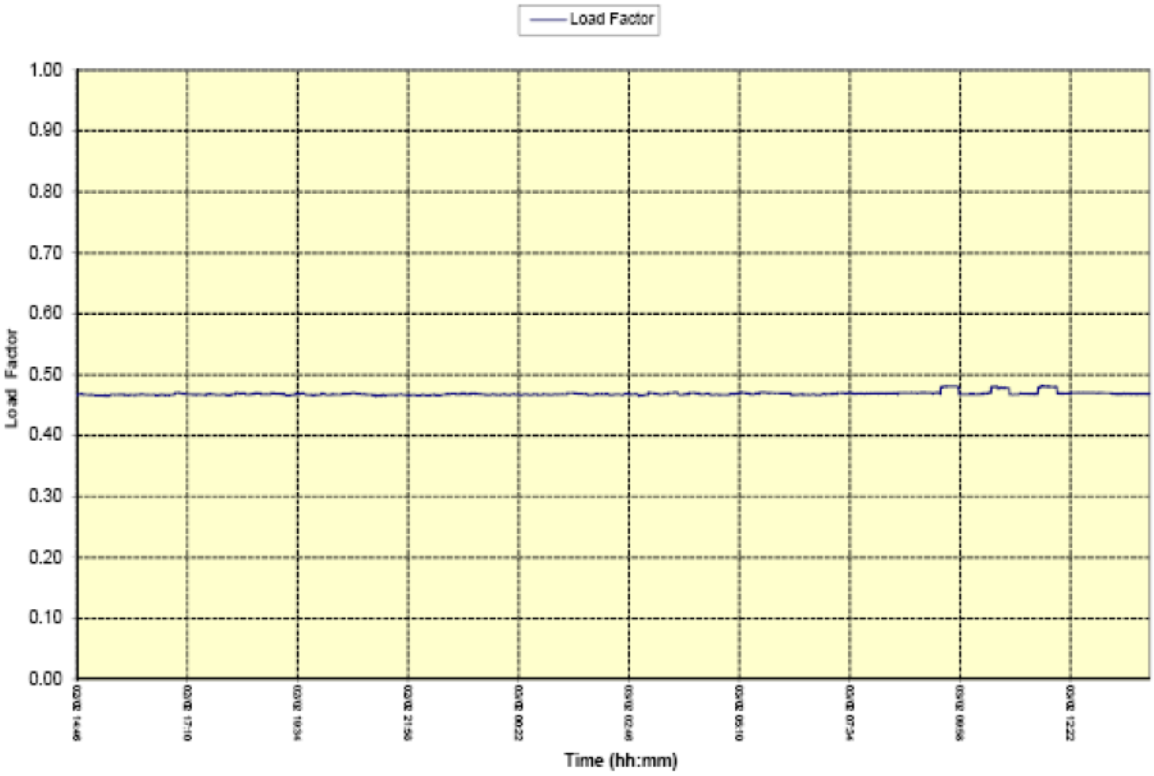

Figure 6.25- Cooling SW Pump Load Factor vs. Time [1]

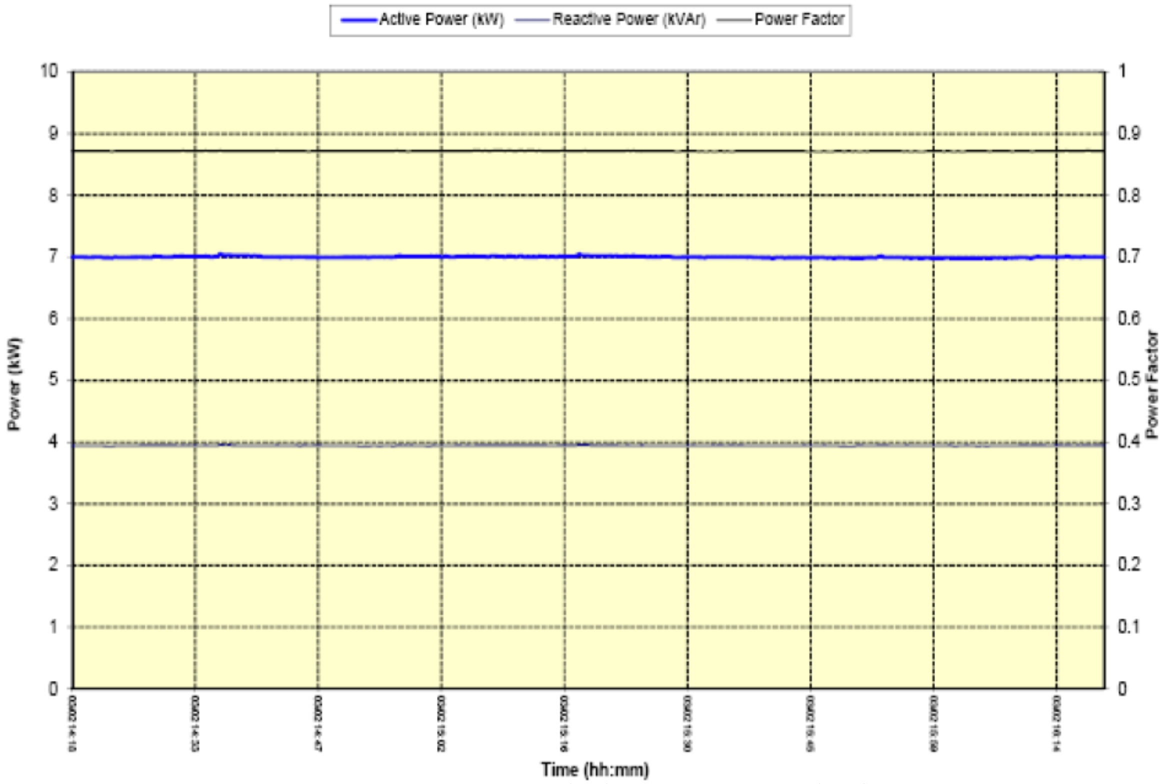

Figure 6.26- Port Cooling FW Pump Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time [1]

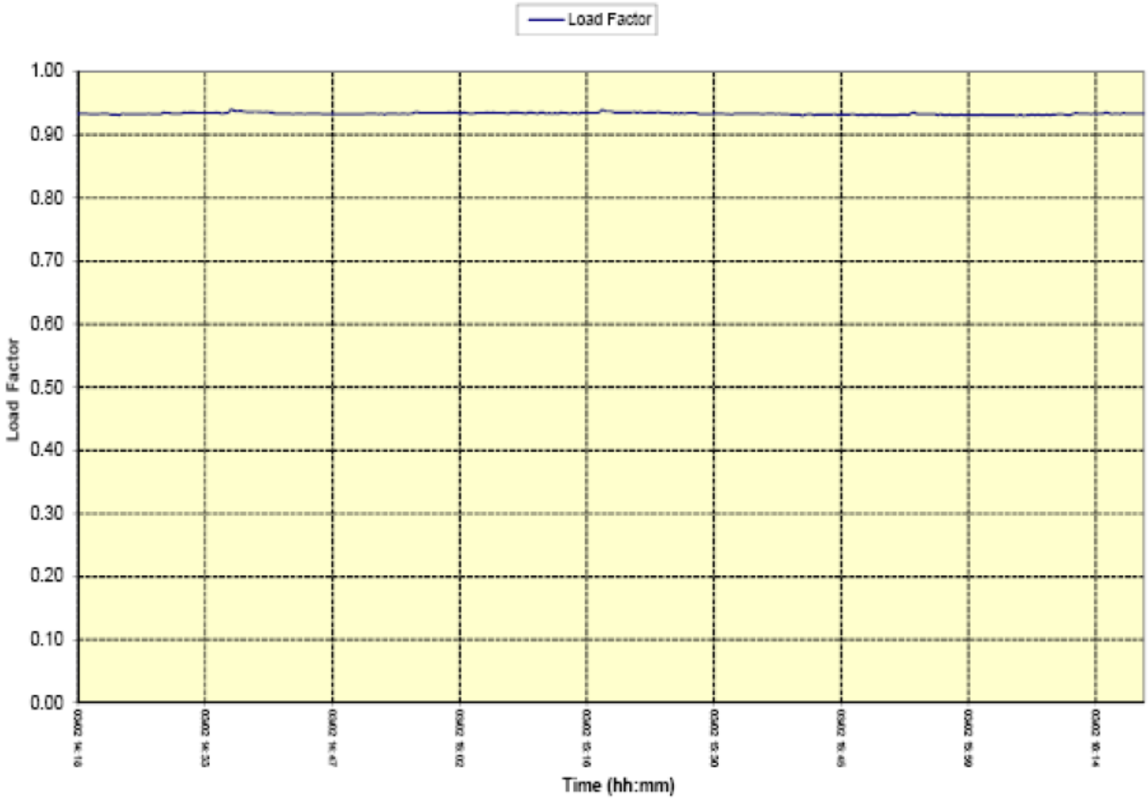

Figure 6.27- Port Cooling FW Pump Load Factor vs. Time [1]

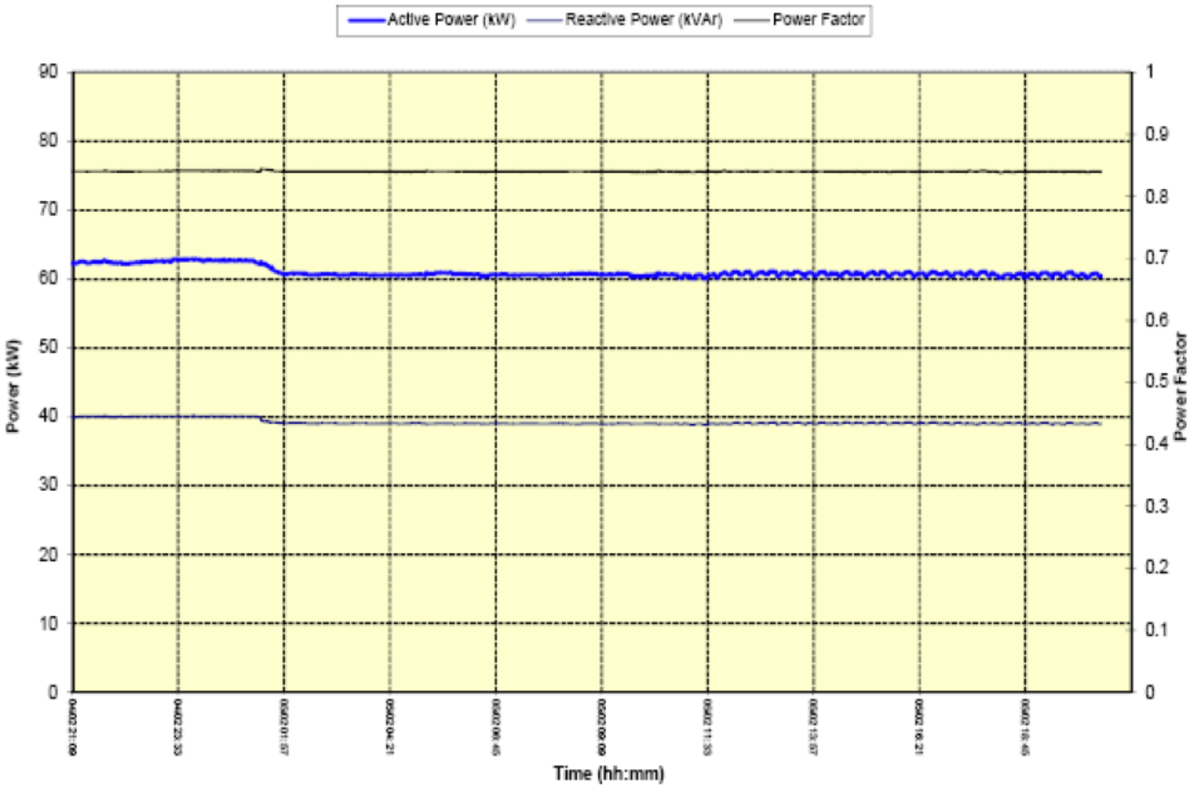

Figure 6.28- Port Lube Oil Pump Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time [1]

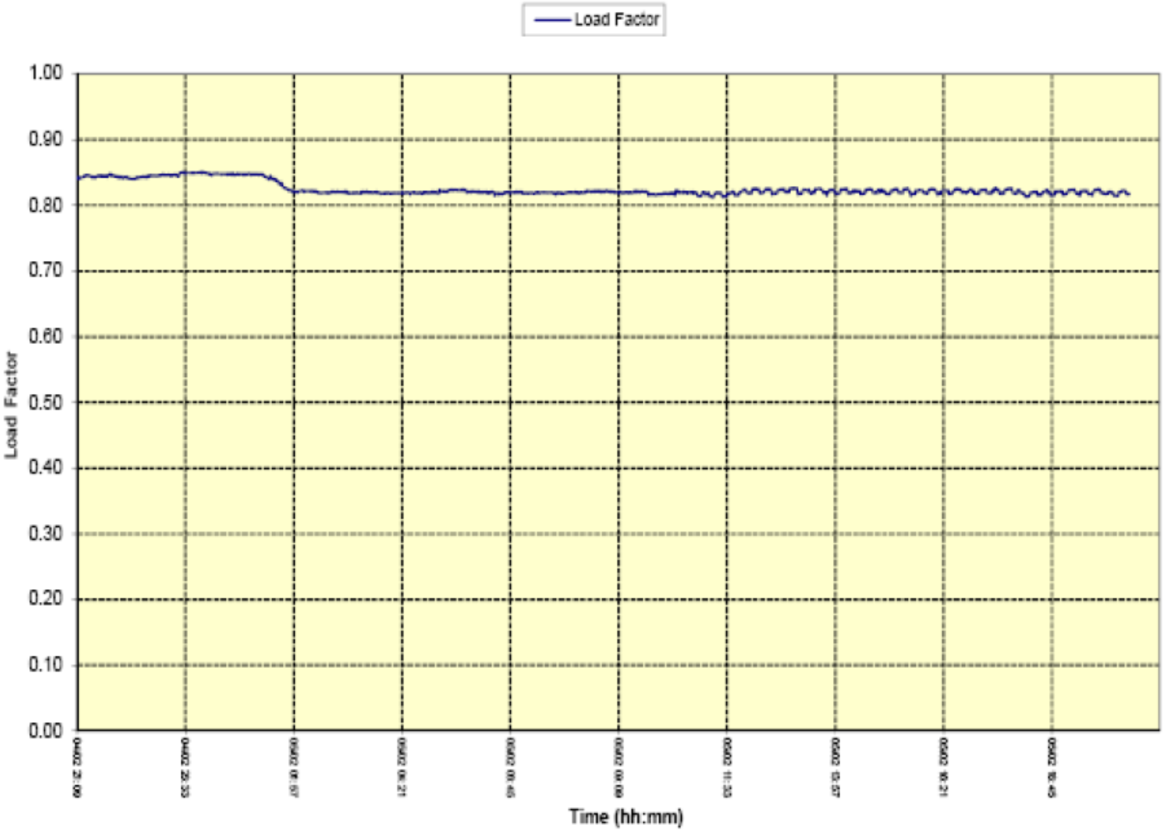

Figure 6.29- Port Lube Oil Pump Load Factor vs. Time [1]

Efficiency of motors is estimated to be classified as EFF2 and it is reported in the electrical load analysis. It is feasible to replace the examined motors in the future (whenever extensive repairs or replacement may be required) by EFF1 class, to obtain energy savings.

B) Results and Identification of ESPs

ESP-03	**Installation of High Efficiency Motors** **(Assessment for motors of Port Lube Oil Pump, Port Cooling FW Pump and Main Cooling SW Pump, with current efficiency EFF2)**
Type:	Medium cost/medium benefit
Feasibility:	Medium

Relevant parameters for Port Lube Oil Pump Motor:

$$\text{Operation Interval Duration} = 74\% \cdot 24\text{h} \cdot 365\text{ days} = 6482\text{ h} \tag{6.3a}$$

Calculated Shaft Power= 51 kW

Present motor efficiency= 84%

$$\text{Electric energy consumed by present motor} = \frac{1}{0.84} \cdot 6482\frac{\text{h}}{\text{year}} \cdot 51\text{ kW} = 393550\text{ kW} \tag{6.3b}$$

EFF1 motor efficiency= 94%

$$\text{Electric energy consumed by EFF1 class motor} = \frac{1}{0.94} \cdot 6482\frac{\text{h}}{\text{year}} \cdot 51\text{kW} = 351682\frac{\text{kWh}}{\text{year}} \tag{6.3c}$$

$$\text{Electric energy saving} = 393550 - 351682 = 41868\frac{\text{kWh}}{\text{year}} \tag{6.3d}$$

$$\text{Average actual DO consumption} = 212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{DO conservation estimate} = 41868\frac{\text{kWh}}{\text{year}} \cdot 212.5\frac{\text{gr}}{\text{kWh}} = 8.897\frac{\text{MT}}{\text{year}} \tag{6.3e}$$

$$\text{Equivalent CO}_2\text{ reduction} = 8.897\frac{\text{MT}_{Fuel}}{\text{year}} \cdot 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}} = 28.47\frac{\text{MT}}{\text{year}} \tag{6.3f}$$

$$\text{Fuel Price} = 1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs} = 1100\frac{\text{USD}}{\text{MT}} \cdot 8.897\frac{MT}{year} = 9787\frac{\text{USD}}{\text{year}} \tag{6.3g}$$

Investment amount = 3991 USD [3]

$$\text{Payback Time} = \frac{3991\text{ USD}}{9787\frac{\text{USD}}{\text{year}}} = 0.41\text{ year} = 4.92\text{ months} \tag{6.3h}$$

Relevant parameters for Main Cooling SW Pump Motor:

$$\text{Operation Interval Duration} = 74\% \cdot 24\text{h} \cdot 365\text{ days} = 6482\text{ h} \tag{6.4a}$$

Calculated Shaft Power= 12kW

Present motor efficiency= 85%

$$\text{Electric energy consumed by present motor}= \frac{1}{0.85}\cdot 6482\frac{\text{h}}{\text{year}}\cdot 12\text{kW}= 91510\text{ kW} \quad (6.4b)$$

EFF1 motor efficiency= 93%

$$\text{Electric energy consumed by EFF1 class motor}= \frac{1}{0.93}\cdot 6482\frac{\text{h}}{\text{year}}\cdot 12\text{kW}= 83638.7\frac{\text{kWh}}{\text{year}} \quad (6.4c)$$

$$\text{Electric energy saving}= 91510-83638.7=7871.3\frac{\text{kWh}}{\text{year}} \quad (6.4d)$$

$$\text{Average actual DO consumption}= 212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{DO conservation estimate}= 7871.3\frac{\text{kWh}}{\text{year}}\cdot 212.5\frac{\text{gr}}{\text{kWh}}=1.672\frac{\text{MT}}{\text{year}} \quad (6.4e)$$

$$\text{Equivalent } CO_2 \text{ reduction}= 1.672\frac{\text{MT}_{Fuel}}{\text{year}}\cdot 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}=5.35\frac{\text{MT}}{\text{year}} \quad (6.4f)$$

$$\text{Fuel Price}= 1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs}= 1100\frac{\text{USD}}{\text{MT}}\cdot 1.672\frac{MT}{year}=1839.2\frac{\text{USD}}{\text{year}} \quad (6.4g)$$

Investment amount = 1012.1 USD [3]

$$\text{Payback Time}= \frac{1012.1\text{ USD}}{1839.2\frac{\text{USD}}{\text{year}}}=0.55\text{ year}=6.6\text{ months} \quad (6.4h)$$

Relevant parameters for Port Cooling FW Pump Motor:

$$\text{Operation Interval Duration}= 74\%\cdot 24\text{ h}\cdot 365\text{ days}=6482\text{ h} \quad (6.5a)$$

Calculated Shaft Power= 5kW
Present motor efficiency= 71%

$$\text{Electric energy consumed by present motor}= \frac{1}{0.71}\cdot 6482\frac{\text{h}}{\text{year}}\cdot 5\text{kW}= 45647.8\text{ kW} \quad (6.5b)$$

EFF1 motor efficiency= 89.5%

$$\text{Electric energy consumed by EFF1 class motor}= \frac{1}{0.895}\cdot 6482\frac{\text{h}}{\text{year}}\cdot 5\text{kW}= 36212\frac{\text{kWh}}{\text{year}} \quad (6.5c)$$

$$\text{Electric energy saving}= 45647.8-36212=9435.8\frac{\text{kWh}}{\text{year}} \quad (6.5d)$$

$$\text{Average actual Fuel consumption(DMB)}= 212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{DMB conservation estimate}= 9435.8\frac{\text{kWh}}{\text{year}}\cdot 212.5\frac{\text{gr}}{\text{kWh}}=2.005\frac{\text{MT}}{\text{year}} \quad (6.5e)$$

$$\text{Equivalent } CO_2 \text{ reduction}= 2.005\frac{\text{MT}_{Fuel}}{\text{year}}\cdot 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}=6.4\frac{\text{MT}}{\text{year}} \quad (6.5f)$$

$$\text{Fuel Price}= 1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs}= 1100\frac{\text{USD}}{\text{MT}}\cdot 2.005\frac{MT}{year}=2205.5\frac{\text{USD}}{\text{year}} \tag{6.5g}$$

Investment amount = 445 USD **[3]**

$$\text{Payback Time}=\frac{445\ \text{USD}}{2205.5\frac{\text{USD}}{\text{year}}}=0.2\ \text{year}=2.4\ \text{months} \tag{6.5h}$$

Price estimates are taken from the European Commission Database for Energy Efficient Motors (EuroDEEM) and it is assumed that the efficient electric motor is about 30% more expensive than the standard motor.

The classification of electric motors, according to their power and number of poles featured can be seen in Figure 6.30 **[3]**.

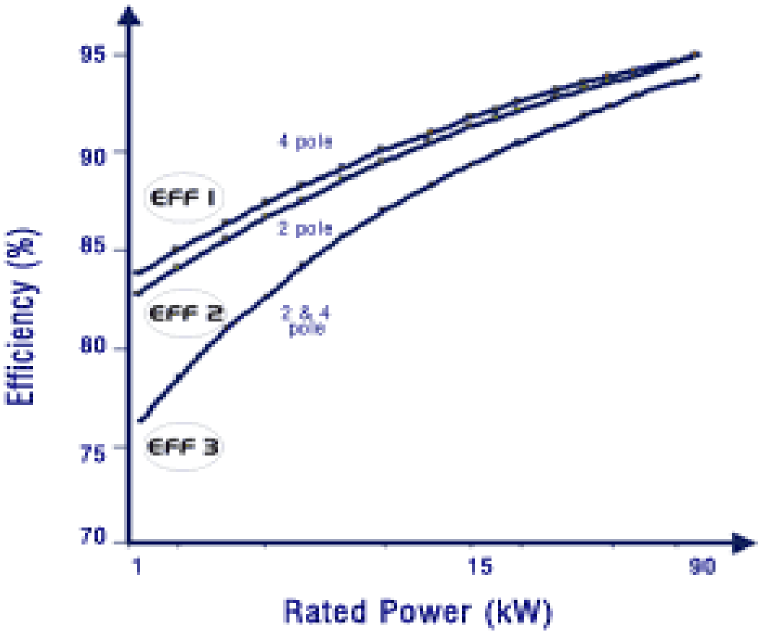

Figure 6.30- Classification of Electric Motors according to EuroDEEM [3]

C) E/R Vent Fan motor Operation

The values in Table 6.25 were measured during the shipboard Energy Audit of the No.3 E/R fan motor.

Table 6.25- E/R vent fan motor (measured values compared to the respective design values) [1]

Inspection Item	Unit	E/R No.3 Fan Motor	
		Measured	Design
Electric Power	kW	7.3	7.5
Voltage	V	440	440
Speed	rpm	1161	1150
Slip	%	-0,09	-
Stator Phase Current	A	-	14
Load Factor	%	0,79	-
Is the starting current normal?		Yes	
Is the starting time normal?		Yes	
Are all phase currents equal?		Yes	
Are there harmonics present?		No	
Is there excessive vibration?		No	

Figure 6.31 shows the E/R Fan Motor measurements during Sea Passage.

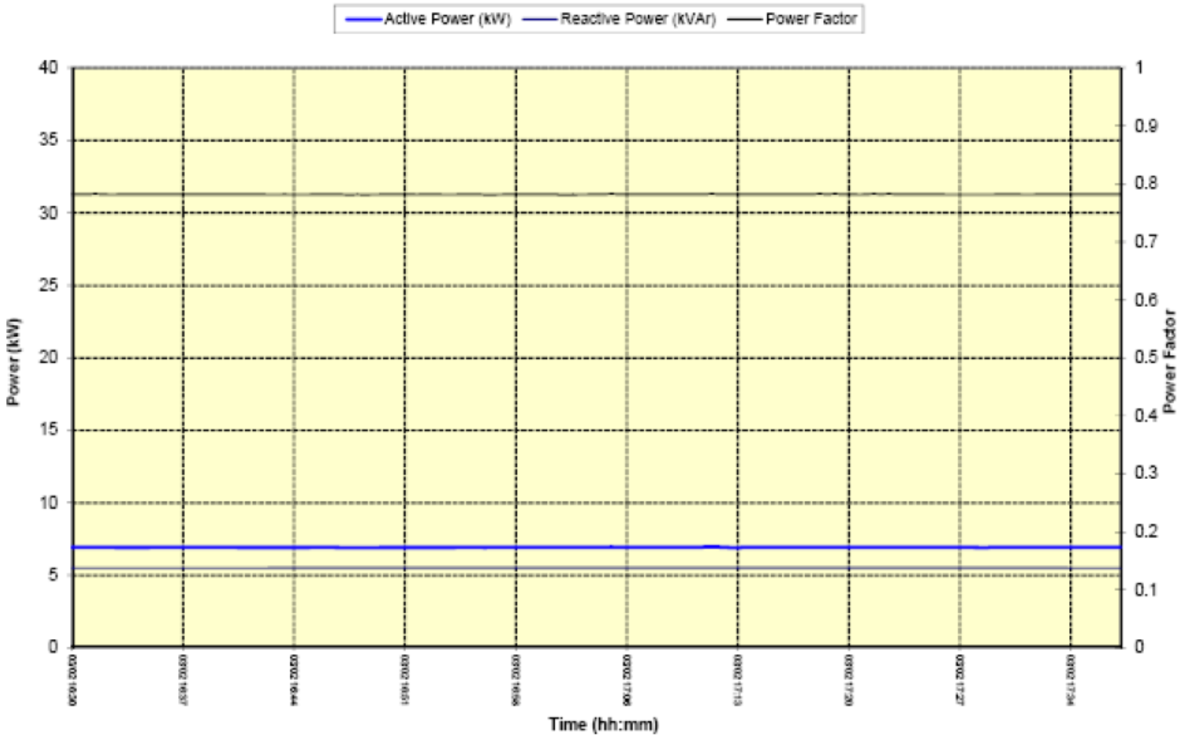

Figure 6.31- E/R fan motor Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time [1]

The role of E/R vent fans is to provide to the engines the required air for combustion and to ensure that the E/R space ventilation is enough to remove the radiated heat from the engines and the other equipment.

The investigation of the E/R vent fans was carried out taking into consideration the comparison of the fans utilization and load factor with the estimated E/R air flow needs. Based on air balance calculations according to ISO 8861:1998 (E), an estimation of E/R air flow needs are provided **[1]**:

Condition	**E/R air flow requirement**
Sea Passage- M/E and 1 D/G running	1525.44 m^3/min
Manoeuvring, Pilotage-M/E and 2 D/G running	1627.29 m^3/min
Cargo operations- 2 D/G and A/B running	389.52 m^3/min
Anchored Alongside- 1 A/B and 1 D/G running	254.5 m^3/min

The above values are calculated based on an ambient temperature of 35°C, 70% Relative Humidity. Since each E/R ventilation fan has a capacity of 550 m^3/min, the following operational pattern is proposed:

Condition	**Average Duration (hours per year)**	**Number of operating fans**	
		Present condition	Proposal
Sea Passage	6482	4	3
Manoeuvring,Pilotage	613.2	3	3
Cargo operations	525	2	1
Anchored, Alongside	1051.2	2	1

The proposed operations involves the reduction of the number or running fans compared to the present practice during anchored, alongside and cargo operations.

D) Results and Identification of ESPs

ESP-04	**E/R fan efficient operation management**
Type:	Zero cost/medium benefit
Feasibility:	High

Relevant Parameters:

Electric Power=7.3 kW

Load Factor=79%

$$\text{Sea Passage time}=0.74\cdot 365\text{ days}\cdot 24\frac{\text{h}}{\text{day}}=6482\text{ h}$$

$$\text{Pilotage time}=0.07\cdot 365\text{ days}\cdot 24\frac{\text{h}}{\text{day}}=613.2\text{ h}$$

$$\text{Cargo operations time}=0.06\cdot 365\text{ days}\cdot 24\frac{\text{h}}{\text{day}}=525.6\text{ h}$$

$$\text{Anchorage \& alongside time}=0.12\cdot 365\text{ days}\cdot 24\frac{\text{h}}{\text{day}}=1051.2\text{ h}$$

$$\text{Electric energy conservation (estimation)}=0.79\cdot 7.3\text{kW}\cdot(1\cdot 6482+1\cdot 525.6+1\cdot 1051.2)\frac{\text{h}}{\text{year}}=$$

$$=46475.1\frac{\text{kWh}}{\text{year}} \tag{6.6a}$$

$$\text{Average DO Consumption}=212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{DO Conservation estimation}=212.5\frac{\text{gr}}{\text{kWh}}\cdot 46475.1\frac{\text{kWh}}{\text{year}}=9.88\frac{\text{MT}}{\text{year}} \tag{6.6b}$$

$$\text{Equivalent CO}_2\text{ reduction}=3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}\cdot 9.88\frac{\text{MT}_{\text{Fuel}}}{\text{year}}=31.62\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.6c}$$

$$\text{Fuel price}=1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs}=1100\frac{\text{USD}}{\text{MT}}\cdot 9.88\frac{\text{MT}}{\text{year}}=10868\frac{\text{USD}}{\text{year}} \tag{6.6d}$$

The savings in this particular case are considerable and there is no investment of money or operational costs.

6.5.6. FO/DO piping system operation

The investigation of the FO and DO piping system included the following tasks:

- Identification of possible significant leakages in the system.
- Calculation of sludge quantities produced by the purifiers.
- Investigation of the FO piping and tank insulation condition and FO maintained temperatures. From the investigation carried out no leakages were identified. The IR thermographs taken at various piping positions show a satisfactory insulation installation.

The vessel’s volumes of sludge were measured and found to be 400 liters per day. It must be noted that the sludge tank quantities contain water, which is a product of the purification of the LO and FO. Based on the observations, the sludge tank contains about 50% water which is evaporated in the incinerator waste oil tank. Based on this observation and assuming that only a 50% of the sludge quantity is oil, a total sludge quantity of about 0.400 MT / day is derived.

In order to provide an idea of the energy content of this sludge quantity, the following calculation estimates are presented:

Sludge & Water Volume	300 liters/days
Sludge Volume	200 liters/day
Assumed Density	0.99 kg/liter
Sludge Mass	190 kg/day
Estimated calorific value (based on the respective Fuel Calorific Value)	35500 kJ/kg
Energy Wastage	1847.2 kWh/day

The FO overflow tank is connected directly to drainage lines from the M/E, D/G, FO heaters and pumps etc. and contains oil without any water mixture. This oil can be re-used and is not considered as sludge.

According to MARPOL Annex I, Reg. 12.1 and the Unified Interpretation 15 (old reg. 17.1), it is assumed that the daily sludge production is 0.015·C, where C is the daily fuel oil consumption in m^3. For this vessel:

Fuel density during audit	0.9862 MT/m^3
Average daily F.O. consumption (sea passage)	38.2 MT/day
Estimated sludge production (sea passage)	0.573 MT/day

From the above, it is derived that the vessel’s sludge production per day (0.3 MT/day) is lower than the MARPOL assumption (0.573 MT/day).

An energy efficiency practice is to incinerate the sludge produced onboard at the auxiliary boilers or to discharge it to appropriate shore facilities, which results in energy and DO conservation. The subject vessel is equipped with suitable auxiliary boilers for burning oil residues (sludge) and based on this, an investigation for the DO and energy conservation resulting from the minimization of the incinerator's use was conducted.

A) Results and Identification of ESPs

ESP-05	**Use of auxiliary boilers for the incineration of sludge residues**
Type:	Zero cost/low benefit
Feasibility:	High

Relevant Parameters:

$$\text{Daily sludge production(no water)}= 200\frac{\text{lt}}{\text{day}}$$

$$\text{Incinerator burning capacity}= 50\frac{\text{lt}}{\text{h}}$$

$$\text{Incinerator operation duration}= \frac{200\frac{\text{lt}}{\text{day}}}{50\frac{\text{lt}}{\text{h}}}=4\frac{\text{h}}{\text{day}} \tag{6.7a}$$

$$\text{Incinerator DO consumption}= 0.3\frac{\text{lt}}{\text{h}}$$

$$\text{DO density}=0.88\frac{\text{kg}}{\text{lt}}$$

$$\text{DO conservation estimate}= 0.88\frac{\text{kg}}{\text{lt}}\cdot 0.3\frac{\text{lt}}{\text{h}}\cdot 4\frac{\text{h}}{\text{day}}\cdot 270\frac{\text{days}}{\text{year}}=285.1\frac{\text{kg}}{\text{year}}=0.28\frac{\text{MT}}{\text{year}} \tag{6.7b}$$

$$\text{Equivalent CO}_2\text{ reduction}=3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}\cdot 0.28\frac{\text{MT}_{\text{Fuel}}}{\text{year}}=0.896\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.7c}$$

$$\text{DO price}=1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs}=1100\frac{\text{USD}}{\text{MT}}\cdot 0.28\frac{\text{MT}}{\text{year}}=308\frac{\text{USD}}{\text{year}} \tag{6.7d}$$

The potential for energy conservation justifies an investigation of sludge homogenizer technologies and the equipment available in the market. An attempt will be made to calculate the benefits of installing a fuel homogenizer. The homogenizers improve the physical quality and the combustibility of the heavy fuel oil (improved combustion), and reduce the need to remove difficult-to-burn asphaltenes as waste disposal. They turn asphaltenes into combustible fuel (fuel cost savings) and reduce the volume of sludge and also they reduce or eliminate the waste disposal cost. Apart from these, they reduce smoke and exhaust emissions as well.

ESP-06	**Installation of FUEL MILL MC Homogenizer**
Type:	High cost/medium benefit
Feasibility:	Low

Relevant Parameters:

$$\text{Daily sludge production(no water)}= 200\frac{\text{lt}}{\text{day}}$$

$$\text{Sludge reduction due to Fuel Mill installation}=0.5\%\cdot 200\frac{\text{lt}}{\text{day}}=100\frac{\text{lt}}{\text{day}} \tag{6.8a}$$

$$\text{FO conservation estimated due to Fuel Mill installation (according to maker's details)}=25.55\frac{\text{MT}}{\text{year}} \tag{6.8b}$$

$$\text{FO price}= 670\frac{\text{USD}}{\text{MT}}$$

$$\text{Equivalent CO}_2\text{ reduction}=3.11\frac{MT_{CO_2}}{MT_{Fuel}}\cdot 25.55\frac{\text{MT}}{\text{year}}=79.5\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.8c}$$

$$\text{Avoided costs}=670\frac{\text{USD}}{\text{MT}}\cdot 25.55\frac{\text{MT}}{\text{year}}=17118.5\frac{\text{USD}}{\text{year}} \tag{6.8d}$$

$$\text{Fuel Mill Homogenizer installation cost}=45000\text{ USD}$$

$$\text{Payback Time}=\frac{45000\text{USD}}{17118.5\,\text{USD}/\text{year}}=2.63\text{years} \tag{6.8e}$$

Note: For the calculation of Payback Time, the operational costs are not included, as they are considered slight, compared to installation cost.

6.5.7. Investigation of the compressed air piping system

The compressed air system navigation comprised an inspection of the piping, the air receivers, compressors and various loads.

No.	Compressed air system	Yes/No
1	Are there any leakages at the piping connections of the HP system?	Yes
2	Are there any leakages at the piping connections of the low pressure system?	Yes
3	Are there any leakages at compressed air connections in E/R, on deck?	Yes
4	Are there any leakages at the emergency shut down supply air bottle?	No
5	Are there any open blowing or unregulated blow guns?	Yes
6	Is the M/E and D/G air starting system in good condition?	Yes

The topping up air compressor motor operation cycle was recorded for a period of half a day. The load factor recording during night time is shown in Figure 6.32.

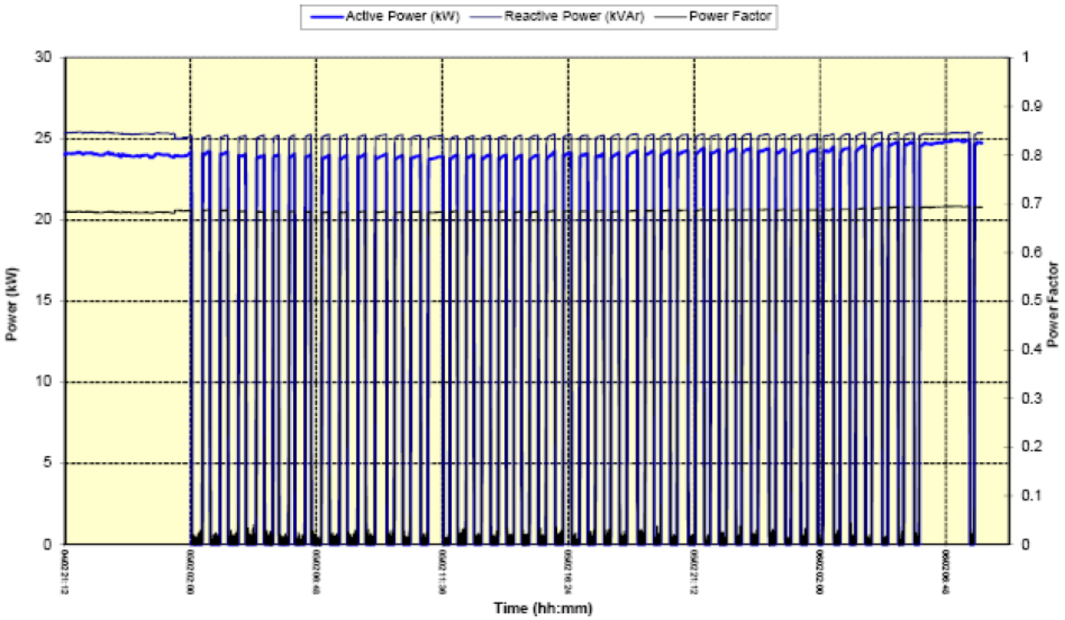

Figure 6.32- Topping Up Air Compressor Active Power (kW), Reactive Power (kVA) and Power Factor vs. Time [1]

A capacity test was performed in order to determine the FAD of the topping up air compressor. The time needed to raise the pressure of the air reservoir from 26 kg/cm^2 to 28 kg/cm^2 was 18 minute and the FAD was calculated to be 140 m^3 /h.

A) Results and Identification of ESPs

ESP-07	**Minimization of compressed air service system leakages**
Type:	Low cost/low benefit
Feasibility:	High

Relevant Parameters:

$$\text{Compressor operation}=8\frac{\text{h}}{\text{day}} \tag{6.9a}$$

$$\text{Compressor nominal power}=30\text{kW}$$

$$\text{Daily power loss due to leakages}=0.125\cdot 30\ \text{kW}=3.75\ \text{kW} \tag{6.9b}$$

$$\text{Daily energy loss due to leakages}=3.75\text{kW}\cdot 8\frac{\text{h}}{\text{day}}=30\frac{\text{kWh}}{\text{day}}$$

$$\text{Maximum possible annual energy savings}=30\frac{\text{kWh}}{\text{day}}\cdot 0.74\cdot 365\frac{\text{days}}{\text{year}}=8100\frac{\text{kWh}}{\text{year}} \tag{6.9c}$$

$$\text{Average DO consumption}=\ 212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{DO conservation estimation}=212.5\frac{\text{gr}}{\text{kWh}}\cdot 8100\frac{\text{kWh}}{\text{year}}=1.72\frac{\text{MT}}{\text{year}} \tag{6.9d}$$

$$\text{Equivalent CO}_2\ \text{reduction}=3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}\cdot 1.72\frac{\text{MT}_{\text{Fuel}}}{\text{year}}=5.504\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.9e}$$

$$\text{DO price}=1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs}=1100\frac{\text{USD}}{\text{MT}}\cdot 1.72\frac{\text{MT}}{year}=1892\frac{\text{USD}}{\text{year}} \tag{6.9f}$$

Repairs amount estimation= 300 USD

$$\text{Payback Time}=\frac{300\text{USD}}{1892\,\text{USD}/\text{year}}=0.16\text{ years}=2\text{ months} \qquad (6.9g)$$

Note: For the calculation of daily power loss, it is assumed, according to audit measures that it equals to 12.5% of the compressor nominal power.

6.5.8. Investigation of the HVAC system

The investigation of the HVAC system operating was performed during the following ambient conditions:

- Air Temperature 23 °C,
- Relative Humidity 75.5%

The HVAC compressor electric power demand was measured, together with air temperature and humidity in various spaces and at the AHU.

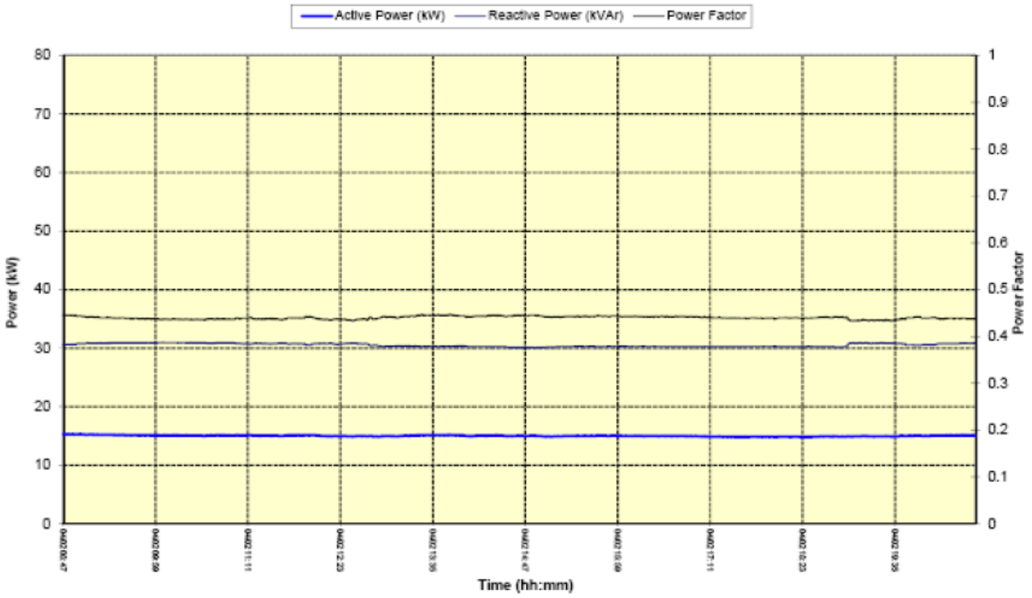

Figure 6.33- HVAC compressor Active Power, Reactive Power and Power Factor vs. Time [1]

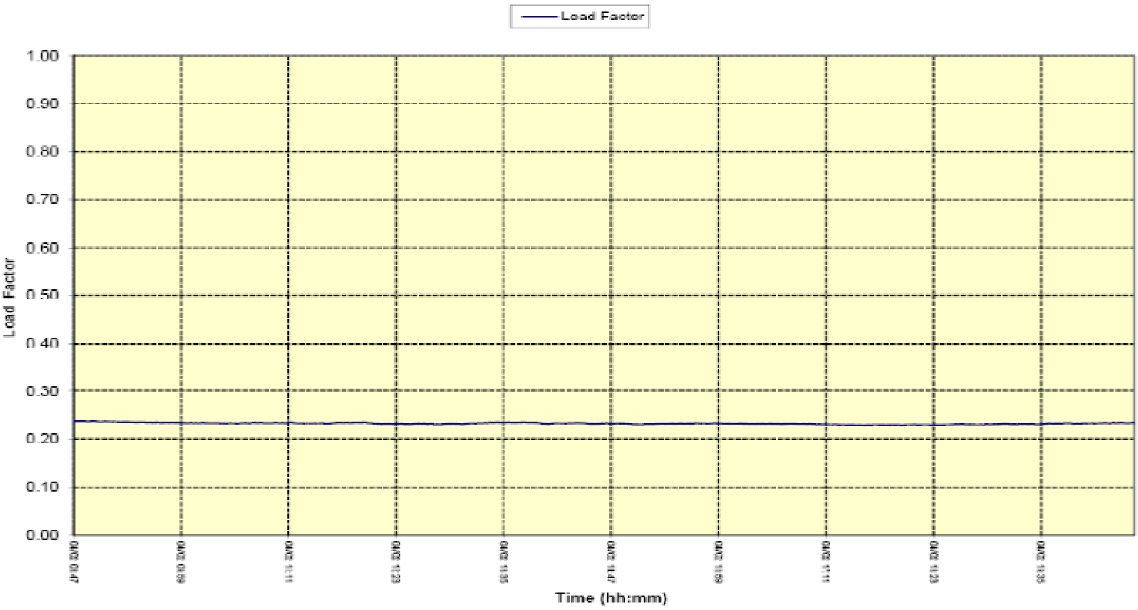

Figure 6.34- HVAC compressor Load Factor vs. Time

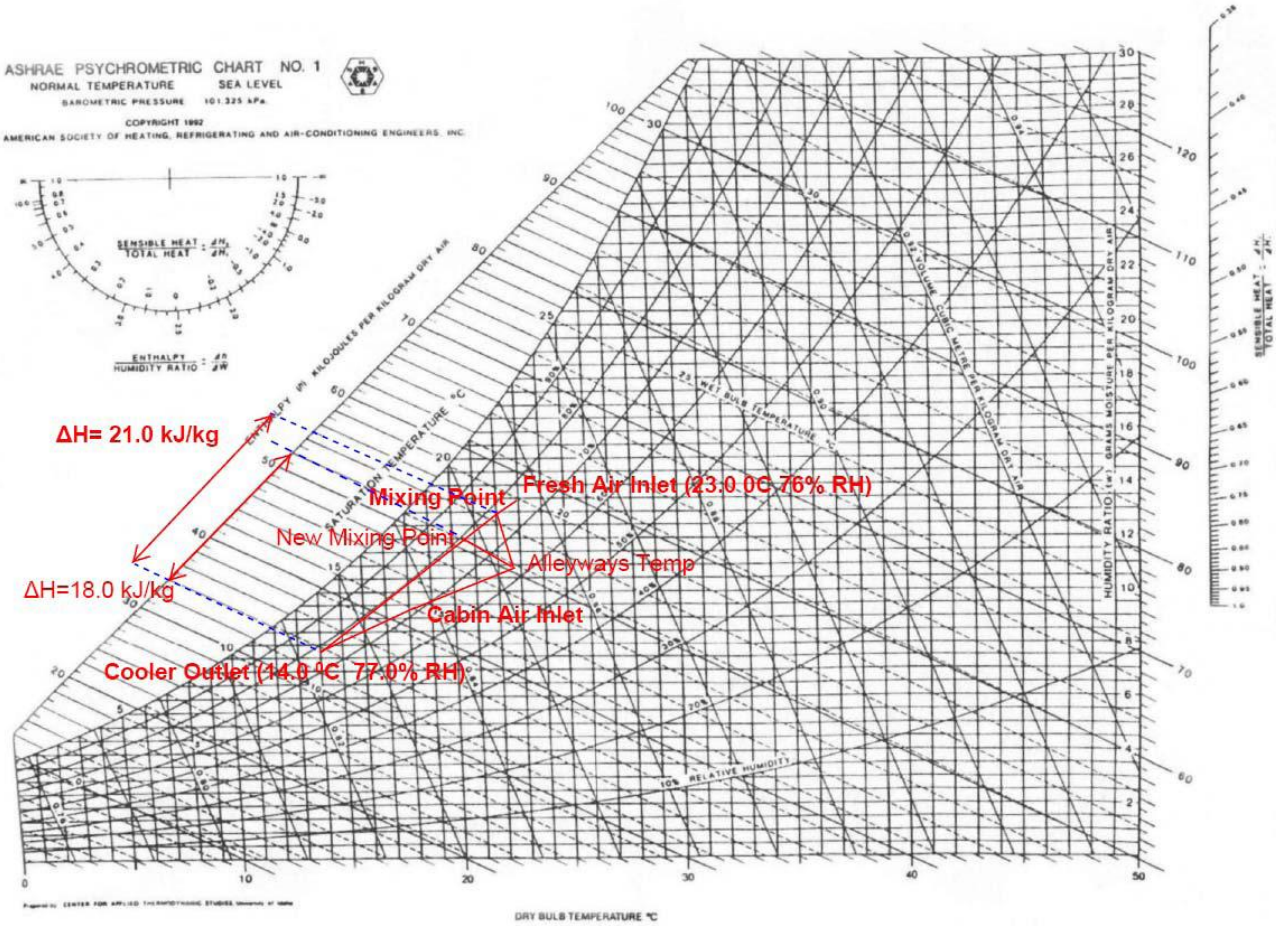

Figure 6.35- Psychrometric chart with AHU characteristic curves [1]

The air inlet and outlet temperature and the relative humidity were measured at the AHU cooling element in order to estimate the cooling load of the installation. Table 6.24 provides the measured and calculated data.

Table 6.26- AHU measurements

Fresh Air Temperature & RH	23°C	76% RH
AHU Return Air Temperature & RH	22.5°C	63% RH
AHU Air Temperature & RH after mixing	14°C	77% RH
Corresponding Enthalpy	55 kJ/kg	
Dry Air Inlet Density (after mixing)	1.1640 kg/m^3	
Return Air percentage	66.67%	
Fresh Air percentage	33.33%	
AHU Air Outlet Temperature & RH	14°C	80% RH
Corresponding Enthalpy	34 kJ/kg	
AHU fan flow rate	3.1 m^3/sec	
Total Enthalpy Difference for cooling the air	21 kJ/kg	
Cooling Load	75.4 kW	
Compressor electrical load	17 kW	

Regarding the above results the following comments are made:
– The cooling demand (26.1%) is low compared to the available compressor's cooling capacity.
– The compressor can operate in five capacity stages.
– The ratio of fresh air is at 33 %. Compared to the design value of 76% it is concluded that the dampers were not properly adjusted.

The values of enthalpy in Tables 6.26 and 6.27 were taken from the Psychrometric Chart, in Figure 6.35.

Table 6.25 provides the calculated data based on the alternative proposal.

Table 6.27- Data based on alternative proposal

Fresh Air Temperature & RH	23°C	76% RH
AHU Return Air Temperature & RH	22.5°C	63% RH
AHU Air Temperature & RH after mixing	21.4°C	62% RH
Corresponding Enthalpy	52 kJ/kg	
Dry Air Inlet Density (after mixing)	1.1640 kg/m^3	
Return Air percentage	75%	
Fresh Air percentage	25%	
AHU Air Outlet Temperature & RH	22°C	75% RH
Corresponding Enthalpy	34 kJ/kg	
AHU fan flow rate	3.1 m^3/sec	
Air mass flow rate	12920.4 kg/hr	
Total Enthalpy Difference for cooling the air	18 kJ/kg	
Cooling Load	32.3 kW	
Compressor electrical load	16.25 kW	

Note: SOLAS regulations specify a minimum percentage of fresh air in all working enclosed spaces. The proposal made above, refers only to accommodation spaces, so it does not go against SOLAS regulations.
The calculated compressor's electrical load required to maintain the same temperature inside the accommodation after the adjustment of the fresh air/return air is decreased

only by 0.7 kW due to the fact that the minimum load of the motor is 25%. An ESP is identified:

ESP-08	**Optimum adjustment of HVAC fresh/return air ratio**
Type:	Zero cost/low benefit
Feasibility:	High

Relevant Parameters:

$$\text{HVAC operation duration}=180\frac{\text{days}}{\text{year}}\cdot 24\frac{\text{h}}{\text{day}}=4320\frac{\text{h}}{\text{year}} \qquad (6.10a)$$

HVAC compressor current configuration=17 kW

HVAC compressor proposed configuration=16.25 kW

$$\text{Energy conservation estimate}=(17-16.25)\text{kW}\cdot 4320\frac{\text{h}}{\text{year}}=3240\frac{\text{kWh}}{\text{year}} \qquad (6.10b)$$

$$\text{Average DO consumption}=212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{Fuel conservation estimate}=212.5\frac{\text{gr}}{\text{kWh}}\cdot 3240\frac{\text{kWh}}{\text{year}}=0.69\frac{\text{MT}}{\text{year}} \qquad (6.10c)$$

$$\text{Equivalent CO}_2\text{ reduction}=0.69\frac{\text{MT}_{\text{Fuel}}}{\text{year}}\cdot 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}=2.21\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \qquad (6.10d)$$

$$\text{DO price}=1100\ \frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs}=1100\ \frac{\text{USD}}{\text{MT}}\cdot 0.69\frac{\text{MT}}{\text{year}}=759\frac{\text{USD}}{\text{year}} \qquad (6.10e)$$

Based on the relatively low average space temperature of 22.0°C, there appears to be some room for energy conservation at medium ambient temperatures (e.g. between 20 - 25°C). When such temperatures prevail, the Chief Engineer could try to shut down the air conditioning unit. Temperatures in the accommodation spaces may be maintained solely by operating the AHU fan and allowing fresh air to the AHU inlet.

Thus the following ESP is identified:

ESP-09	**Minimization of HVAC system operation during medium ambient temperature conditions**
Type:	Zero cost/medium benefit
Feasibility:	Medium

Relevant Parameters:

$$\text{HVAC shut down interval duration estimation}=\ 150\frac{\text{days}}{\text{year}}\cdot 24\frac{\text{h}}{\text{day}}=3600\frac{\text{h}}{\text{year}} \qquad (6.11a)$$

HVAC compressor power demand= 17kW

$$\text{Energy conservation estimation}=\ 17\text{ kW}\cdot 3600\frac{\text{h}}{\text{year}}=61200\frac{\text{kWh}}{\text{year}} \qquad (6.11b)$$

$$\text{Average DO Consumption}=\ 212.5\ \frac{\text{gr}}{\text{kWh}}$$

$$\text{DO Conservation estimation} = 212.5\,\frac{\text{gr}}{\text{kWh}}\cdot 61200\,\frac{\text{kWh}}{\text{year}} = 13\,\frac{\text{MT}}{\text{year}} \tag{6.11c}$$

$$\text{Equivalent CO}_2\text{ reduction} = 13\,\frac{\text{MT}_{\text{Fuel}}}{\text{year}}\cdot 3.20\,\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}} = 41.6\,\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.11d}$$

$$\text{Fuel price} = 1100\,\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs} = 1100\,\frac{\text{USD}}{\text{MT}}\cdot 13\,\frac{\text{MT}_{\text{Fuel}}}{\text{year}} = 14300\,\frac{\text{USD}}{\text{year}} \tag{6.11e}$$

6.5.9. Lighting Loads

A) Cabin and Recreation Rooms Lighting Loads Daily Fluctuation

Recording of the total lighting load operational pattern was not possible, since the load includes areas such as bridge equipment and galley. The daily fluctuation as recorded is given in Figure 6.35.

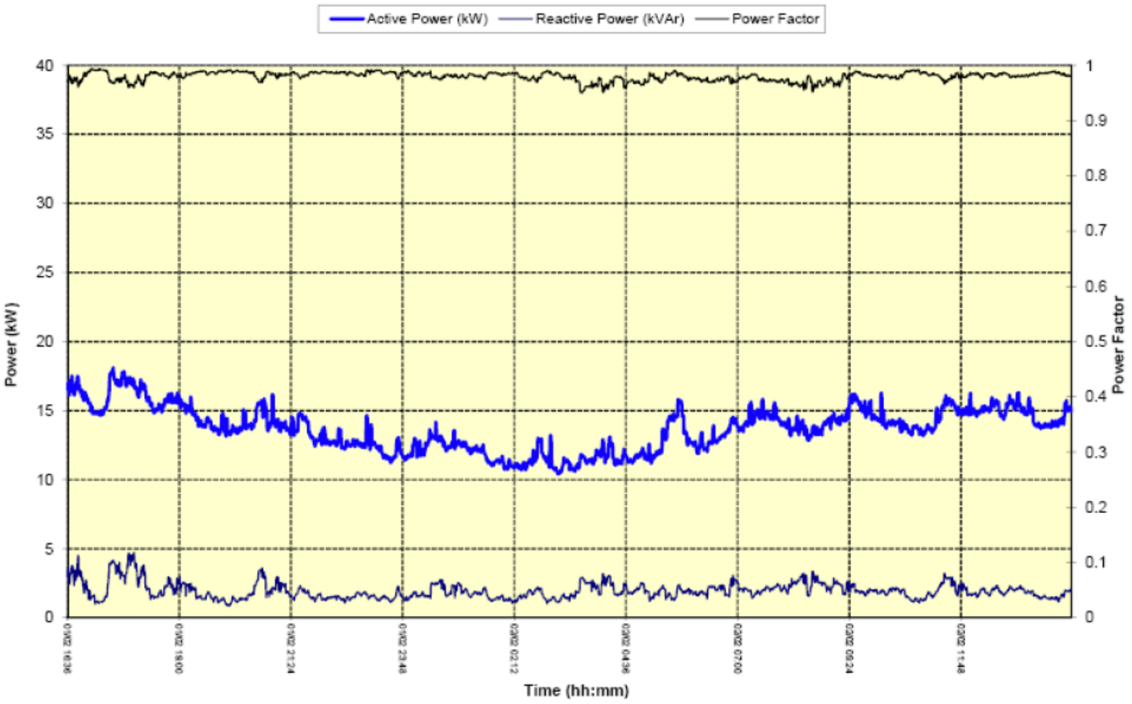

Figure 6.36- Feeder Panel Daily Fluctuation (Active Power, Reactive Power and Power Factor vs. Time) [1]

The diagram shows a high power demand period of average 14.8 kW between 7:00 and 18:00 in the afternoon. The power demand shows a low average of 12.0 kW between 00:00 and 06:00 which is obviously corresponding to crew main resting / sleeping period.

B) Accommodation and E/R Spaces Lighting Levels

During the shipboard audit, a number of spaces were identified, which normally are not occupied, or are attended for very short time intervals. However the lighting fixtures are kept "on" continuously. These spaces are identified (e.g. laundry, drying room, hydraulic power unit room etc.) and have a total installed lighting power of 4.5 kW. Taking into account that the occupancy time may not exceed an average of 8 hours per day, the following ESP is identified:

ESP-10	**Accommodation's lighting loads rational use**
Type:	Zero cost/medium benefit
Feasibility:	High

Relevant Parameters:

Estimated power demand reduction during working hours=4.5 kW

Corresponding working interval=8 h

$$\text{Corresponding daily energy conservation}=4.5\text{kW}\cdot 8\frac{\text{h}}{\text{day}}=36\frac{\text{kWh}}{\text{day}} \tag{6.12a}$$

$$\text{Total yearly conservation}=365\frac{\text{days}}{\text{year}}\cdot 36\frac{\text{kWh}}{\text{day}}=13140\frac{\text{kWh}}{\text{year}} \tag{6.12b}$$

$$\text{Average DO consumption}=212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{Fuel conservation estimate}=212.5\frac{\text{gr}}{\text{kWh}}\cdot 13140\frac{\text{kWh}}{\text{year}}=2.79\frac{\text{MT}}{\text{year}} \tag{6.12c}$$

$$\text{Equivalent CO}_2\text{ reduction}=2.79\frac{\text{MT}_{\text{Fuel}}}{\text{year}}\cdot 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}=8.9\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.12d}$$

$$\text{Fuel price}=1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs}=1100\frac{\text{USD}}{\text{MT}}\cdot 2.79\frac{\text{MT}}{\text{year}}=3069\frac{\text{USD}}{\text{year}} \tag{6.12e}$$

C) Lighting Power Demand of Very Low Occupancy Spaces

During the shipboard audit, a number of spaces were identified, which normally are not occupied, such us cargo spaces, to be unattended for big time intervals. However the lighting fixtures of these areas were kept "on" continuously.

Taking into account that the occupancy time may not exceed an average of 2 hours per day, the following ESP is identified:

ESP-11	**Cargo spaces lighting minimization**
Type:	Zero cost/high benefit
Feasibility:	High

Relevant Parameters:

Power demand= 56 kW

$$\text{Present operation duration}=24\frac{\text{h}}{\text{day}}$$

$$\text{Estimated average actual occupancy time}=0\frac{\text{h}}{\text{day}}$$

$$\text{Estimated possible conservation time}=(24-0)\frac{\text{h}}{\text{day}}=24\frac{\text{h}}{\text{day}} \tag{6.13a}$$

$$\text{Estimated daily conservation time}=24\frac{\text{h}}{\text{day}}\cdot 56\text{kW}=1344\frac{\text{kWh}}{\text{day}} \tag{6.13b}$$

$$\text{Total yearly conservation}=365\frac{\text{days}}{\text{year}}\cdot 1344\frac{\text{kWh}}{\text{day}}=490560\frac{\text{kWh}}{\text{year}} \tag{6.13c}$$

$$\text{Average DO consumption}=212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{DO conservation estimation} = 212.5\frac{\text{gr}}{\text{kWh}}\cdot 490560\frac{\text{kWh}}{\text{year}} = 104.2\frac{\text{MT}}{\text{year}} \tag{6.13d}$$

$$\text{Equivalent CO}_2\text{ reduction} = 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}\cdot 104.2\frac{\text{MT}_{\text{Fuel}}}{\text{year}} = 333.44\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.13e}$$

$$\text{Fuel price} = 670\ \frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs} = 670\ \frac{\text{USD}}{\text{MT}}\cdot 104.2\frac{\text{MT}}{\text{year}} = 69814\frac{\text{USD}}{\text{year}} \tag{6.13f}$$

D) Lamp Types Installed Onboard

A review of the number and type of lamps used in the luminaries was carried out according to the wiring diagrams of lighting systems. The majority of luminaries installed onboard are for TFL lamps. However, several incandescent lamps at external accommodation and E/R luminaries were identified. Each 100W lamp can be replaced by a compact fluorescent lamp (CFL) of 18W power and each 60W lamp by a 13W CFL. Based on the above consideration the following ESP is identified:

ESP-12	**Replacement of incandescent lamps by CFLs**
Type:	Low cost/Medium benefit
Feasibility:	High

Relevant Parameters:

Total number of incandescent lamps=86

Installed power= 2.950kW

Equivalent power for CFLs= 0.738kW

$$\text{Installed power saving} = (2.950-0.738) = 2.212\text{kW} \tag{6.14a}$$

Utilization factor=1

$$\text{Net power saving} = 1\cdot 2.212\text{kW} = 2.212\text{kW} \tag{6.14b}$$

$$\text{Electric energy conservation} = 365\frac{\text{days}}{\text{year}}\cdot 24\frac{\text{h}}{\text{day}}\cdot 2.212\text{kW} = 19377\frac{\text{kWh}}{\text{year}} \tag{6.14c}$$

$$\text{Average DO consumption} = 212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{DO conservation estimation} = 212.5\frac{\text{gr}}{\text{kWh}}\cdot 19377\frac{\text{kWh}}{\text{year}} = 4.1\frac{\text{MT}}{\text{year}} \tag{6.14d}$$

$$\text{Equivalent CO}_2\text{ reduction} = 4.1\frac{\text{MT}_{\text{Fuel}}}{\text{year}}\cdot 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}} = 13.12\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \tag{6.14e}$$

$$\text{Fuel price} = 1100\ \frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs} = 1100\frac{\text{USD}}{\text{MT}}\cdot 4.1\frac{\text{MT}}{\text{year}} = 4510\frac{\text{USD}}{\text{year}} \tag{6.14f}$$

$$\text{Investment amount estimate} = 11\frac{\text{USD}}{\text{lamp}}\cdot 86\text{ lamps} = 946\text{ USD} \tag{6.14g}$$

$$\text{Payback Time} = \frac{946\text{ USD}}{4510\frac{\text{USD}}{\text{year}}} = 0.2\text{year} = 2.4\text{months} \tag{6.14h}$$

Notes:

1. Only normal operation lamps are included in the calculation, since it is not feasible to replace the emergency lamps or EX lamps with CFLs.
2. The CFL lamps are not generally recommended by manufacturers as vibration resistant. Nevertheless, good quality CFLs are expected to operate well in an environment with vibration. Therefore, attention should be paid to the quality of CFLs provided onboard.
3. There is a new generation of LED lamps, which are even more economical than CFLs, since they have life duration around 100,000 hours (compared with 10,000 for CFL and 1,000 hours for incandescent) and are certified as vibration resistant. In addition, there are manufactured types with conventional screw base for direct fitting to existing luminaries. However, this type of lamp, is not yet widely available and the cost is still very high (around 100$ each for the 100W equivalent), therefore they do not present a feasible alternative for now.

6.5.10. Investigation of motors voltage unbalanced

Voltage unbalance degrades the performance and shortens the life of a three-phase motor. Voltage unbalance at the motor stator terminals causes phase current unbalance far out of proportion to the voltage unbalance. Unbalanced currents lead to torque pulsations, increased vibrations and mechanical stresses, increased losses, and motor overheating, which results in a shorter winding insulation life.

Voltage unbalance is defined by the National Electrical Manufacturers Association (NEMA) as 100 times the absolute value of the maximum deviation of the line voltage from the average voltage on a three-phase system, divided by the average voltage.

$$Voltage\ Unbalance = 100 \cdot \frac{|V - V_{average}|}{V_{average}} \qquad (6.15)$$

It is recommended that the voltage unbalances at the motor terminals not exceed 1%. Unbalances over 1% require derating of the motor and will void most manufacturers' warranties.

Voltage unbalance is probably the leading power quality problem that results in motor overheating and premature motor failure. If unbalanced voltages are detected, a thorough investigation should be undertaken to determine the cause.

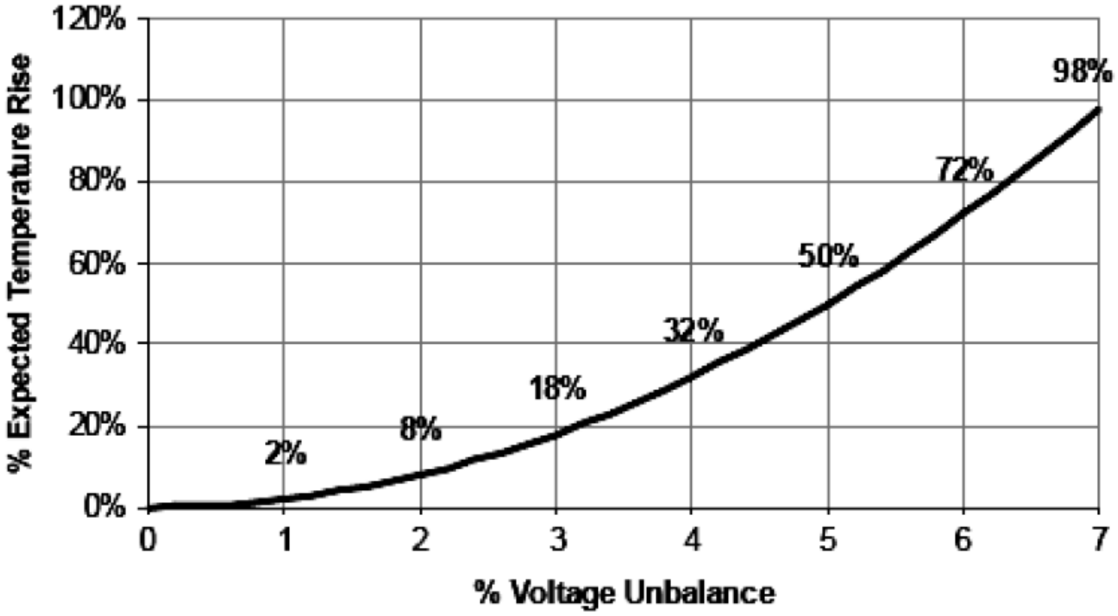

Figure 6.37- Temperature rise caused by unbalanced voltages [1]

Voltage unbalance causes extremely high current unbalance. The magnitude of current unbalance may be 6 to 10 times as large as the voltage unbalance. A motor will run hotter when operating on a power supply with voltage unbalance. The additional temperature rise is estimated with the Eq. (6.2).

$$\%\ additional\ temperature\ rise = 2 \cdot (\%\ Voltage\ Unbalance)^2 \tag{6.16}$$

For example, a motor with a 100°C temperature rise would experience a temperature increase of 8°C when operated under conditions of 2% voltage unbalance. Winding insulation life is reduced by one-half for each 10°C increase in operating temperature.

Voltage unbalance issues for motors can come from three possible sources: the utility, the facility housing the motor, and the motor itself.

Sometimes the power supplied by the utility can be the source of unbalanced voltages. This can be due to malfunctioning equipment including blown capacitor fuses, open-delta regulators, and opendelta transformers. Open-delta equipment can be more susceptible to unbalance issues than closed-delta equipment because they only use two phases to perform their transformations. In addition to faulty equipment, voltage unbalance can also be caused by uneven single-phase load distribution among the three phases.

The facility housing the motor can create unbalanced voltages even if the utility supplied power is well balanced. Again, this could be caused by malfunctioning equipment or even mismatched transformer taps. Similar to the utility, poor load distribution within the facility can create voltage unbalance issues. To help ensure proper load distribution for customer three-wire single-phase and three-phase services, the “difference in amperes between any two phases at the customer’s peak load should not be greater than 10 percent or 50 amperes, whichever is greater.”

The motor itself can also be the source of unbalance issues. Resistive and inductive unbalances within the motor can create unbalanced currents and unbalanced voltages. Defects in the power circuit connections, the motor contacts, or the rotor and stator windings, can all cause irregular impedances between phases in the motor that lead to unbalanced conditions.

The causes of voltage unbalance may be the following:

- Faulty operation of power factor correction equipment.

- Unbalanced or unstable utility supply.
- Unbalanced transformer bank supplying a three-phase load that is too large for the bank.
- Unevenly distributed single-phase loads on the same power system.
- Unidentified single-phase to ground faults.
- An open circuit on the distribution system.

When testing for voltage unbalance, the phase-to-phase voltages should be measured rather than the phase-to-neutral voltages since poly-phase motors are connected across phases. After measuring the phase-phase voltages with a properly calibrated voltmeter, the following calculation can determine the percent of voltage unbalance.

During the shipboard audit, a number of motors were checked, in order to identify the voltage unbalanced.

Table 6.28- Measurements for certain motors (Voltage, average voltage, and voltage unbalanced for three phases) [1]

Motors	Voltage				Voltage Unbalanced %		
	L1	L2	L3	Average	L1	L2	L3
Air Condition	443	451	440	445	0.45	1.34	1.12
Camshaft Lube Oil Pump	443	452	440	445	0.45	1.57	1.12
Cargo fans	443	451	440	445	0.45	1.34	1.12
Cooling SW Pump	443	453	440	445	0.45	1.79	1.12
Engine Room Fan	441	449	438	445	0.89	0.89	1.57
Fuel Oil Supply Pump	443	452	440	445	0.45	1.57	1.12
Port Cooling FW Pump	442	452	440	445	0.67	1.57	1.12
Port Lube Oil Pump	443	452	439	445	0.45	1.57	1.34
Topping Up Air Compressor	443	452	440	445	0.45	1.57	1.12

Taking into account Table 6.28, the following ESP is identified:

ESP-13	**Minimization of voltage unbalanced in motors**
Type:	Low cost/medium benefit
Feasibility:	Medium

Relevant Parameters:

$$\text{Present operation time}= 21\frac{\text{h}}{\text{day}}$$

$$\text{Estimated possible energy conservation}=43\frac{\text{kWh}}{\text{day}}$$

$$\text{Total yearly conservation}=43\frac{\text{kWh}}{\text{day}}\cdot 365\frac{\text{days}}{\text{year}}=15695\frac{\text{kWh}}{\text{year}} \quad (6.17a)$$

$$\text{Average DO consumption}= 212.5\frac{\text{gr}}{\text{kWh}}$$

$$\text{Fuel conservation estimation}= 212.5\frac{\text{gr}}{\text{kWh}}\cdot 15695\frac{\text{kWh}}{\text{year}}=3.33\frac{\text{MT}}{\text{year}} \quad (6.17b)$$

$$\text{Equivalent CO}_2\text{ reduction}= 3.33\frac{\text{MT}_{\text{Fuel}}}{\text{year}}\cdot 3.20\frac{\text{MT}_{\text{CO}_2}}{\text{MT}_{\text{Fuel}}}=10.6\frac{\text{MT}_{\text{CO}_2}}{\text{year}} \quad (6.17c)$$

$$\text{Fuel price}= 1100\frac{\text{USD}}{\text{MT}}$$

$$\text{Avoided costs} = 1100\frac{\text{USD}}{\text{MT}}\cdot 3.33\frac{\text{MT}}{\text{year}} = 3663\frac{\text{USD}}{\text{year}} \tag{6.17d}$$

6.5.11. Company personnel and crew training

The awareness and motivation of the personnel is considered very high and they really seem to be concerned regarding energy conservation. The crew members during the audit showed that they have the aim to improve and change their existing practices in order to reduce the consumed power on board during the operation. Many of the identified ESPs were already implemented directly upon observation and discussion.

Furthermore, in order to help the crew members to beat the target for a more energy efficient vessel, it is suggested that short seminars to be planned with the aim to increase the awareness of the office and shipboard personnel on energy conservation matters and practices.Such a training seminar could include the following topics:

- “Doing more with less” concept.
- Domestic energy conservation practices, lighting management, electrical appliances management.
- Heating control energy efficiency settings.
- Effective transportation.
- CO_2 and CH_4 emissions impact to the Earth’s atmosphere and global warming.

Further to the above general seminar, more ship specific information could be provided through technical seminars to be set up and attended by technical department personnel and vessel officers. Such seminars could include topics like the following:

- The effect of hull fouling and roughness on increase in power requirements.
- Energy efficient motors and variable speed drives.
- Engine room load management practices that increase energy conservation and efficiency.
- Effective monitoring and interpretation of voyage data and engine performance reports.

6.6. References

[1] Energy Audit Report written in cooperation with Alpha Marine Services Ltd. for an existing Car Carrier (2012)

Greek:

[2] ’’Systemic Methodology and Technical Economics’’, Dimitrios Panagiotakopoulos, (2008)

[3] EuroDEEM Motor Brochure Vol.3 (http://re.jrc.ec.europa.eu/energyefficiency/eurodeem/index.htm) (2002)

[4] ’’Influence of Ambient Temperature Conditions’’, MAN B&W (www.mandieselturbo.com)

7. EVALUATION OF ENERGY AUDIT- ASSESSMENT OF SHIP'S ENERGY MANAGEMENT IMPROVEMENT

In the present chapter, we shall assess the improvement of the energy management of the audited ship. The EEOI will be calculated under two conditions:

- before the implementation of the Energy Saving Measures, and
- after the implementation of Energy Saving Measures proposed in the previous chapter.

The Energy Saving Potentials will be classified according to their feasibility, as shown in the previous chapter. The reason for this classification is to clarify which of them are more possible to be implemented.

7.1. Ship's particulars

The main particulars of the audited ship are shown in Table 6.5.

7.2. Executive summary of identified ESPs

ESPs are summarized and classified according to their feasibility in Table 7.1.

Table 7.1- ESP categorization according to their feasibility

ESP	Description	Est. Fuel Savings (t/year)	Eqv. CO_2 Reduction (t/year)	Estimated Avoid. Cost (USD/year)	Est. Capital Investment (USD)	Cost / Benefit	Materiali-zation Feasibility
11	Cargo spaces lighting minimization	104.2	333.4	69814	-	Zero /High	High
01	Critical SFOC reduction to benefit from M/E overhaul	37.6	116.94	25200	70000	High / High	High
04	E/R fan efficient operation management	9.88	31.62	10868	-	Zero/ Medium	High
12	Replacement of incandescent lamps by CFLs	4.1	13.12	4510	946	Low/ Medium	High
10	Accommodation's lighting loads rational use	2.79	8.9	3069	-	Zero/ Medium	High
07	Minimization of compressed air service system leakages	1.72	5.50	1892	300	Low / Low	High
09	Minimization of HVAC system operation during medium ambient temperature conditions	13	41.6	14300	-	Zero / Medium	High
08	Optimum adjustment of HVAC fresh/return air ratio	0.64	2.05	704	-	Zero / Low	High
05	Use of auxiliary boilers for the incineration of sludge residues	0.28	0.896	308	-	Zero /Low	High
03	Replacement of Cooling SW Pump & General Service Pump Motors with High Efficiency Motors	12.57 (Total)	40.22 (Total)	13831.7 (Total)	3400 (Total)	Medium / Medium	Medium
02	Estimated benefit from D/G maintenance (improvement of SFOC)	11.07	34.4	12177	9720	Medium / Medium	Medium
13	Minimization of voltage unbalanced in motors	3.33	10.6	3663	-	Low / Medium	Medium
06	Installation of FUEL MILL MC Homogenizer	25.55	79.5	17118.5	45000	High / Medium	Low

It should be noted that ESPs 01 and 06 are related to HFO conservation, whereas the rest of ESPs are related to DO conservation.

7.3. Calculation of EEOI for the subject ship before and after the implementation of Energy Saving Potentials

7.3.1. Interpretation of EEOI formula

According to Eq.2.14, the Average EEOI is calculated as:

$$Average\ EEOI = \frac{\sum_i \sum_j (FC_{ij} \cdot C_{Fj})}{\sum_i (m_{CARGO,i} \cdot D_i)}$$

where:

- j: fuel type;for the relevant calculations, we shall consider **j=1 for Fuel Oil and j=2 for Diesel Oil**
- i: voyage number;
- FC_{ij}: mass of consumed fuel j at voyage i;
- C_{Fj}: is the fuel mass to CO_2 mass conversion factor for fuel j; from Table 2.3, it can be observed that $\boldsymbol{C_{F1}=3.11}$ and $\boldsymbol{C_{F2}=3.20}$
- m_{CARGO}: is cargo carried (tones) or work done (number of TEU or passengers) or gross tones for passenger ships; for the simplicity of the relevant calculations, **we shall consider that m_{CARGO}=*DWT* , common for all laden voyages**
- D_i: distance in nautical miles corresponding to the cargo carried or work done.

7.3.2. Calculation of annual FO and DO savings

The ESPs are divided into two categories: The first category contains the ESPs that are related with HFO conservation (ESPs 01 and 06) and the second category contains all the rest ESPs, which are related with DO conservation. For each one category, the total amount of annually saved fuel shall be calculated. The amount of annually saved fuel shall be deducted appropriately from the amount of consumed fuel which appears in the EEOI formula.

The two categories are presented in Tables 7.2 and 7.3 respectively.

Table 7.2- ESPs related to HFO conservation

ESP	Description	Est. Fuel Savings (t/year)
01	Critical SFOC reduction to benefit from M/E overhaul	37.6
06	Installation of FUEL MILL MC Homogenizer	25.55
Total Estimated FO saving per year		**63.15**

Table 7.3- ESPs related to DO conservation

ESP	Description	Est. Fuel Savings (t/year)
11	Cargo spaces lighting minimization	104.2
04	E/R fan efficient operation management	9.88
12	Replacement of incandescent lamps by CFLs	4.1
10	Accommodation's lighting loads rational use	2.79
07	Minimization of compressed air service system leakages	1.72
09	Minimization of HVAC system operation during medium ambient temperature conditions	13
08	Optimum adjustment of HVAC fresh/return air ratio	0.64
05	Use of auxiliary boilers for the incineration of sludge residues	0.28
03	Replacement of Cooling SW Pump & General Service Pump Motors with High Efficiency Motors	12.57
02	Estimated benefit from D/G maintenance (improvement of SFOC)	11.07
13	Minimization of voltage unbalanced in motors	3.33
Total Estimated DO saving per year		**163.58**

7.3.3. Calculation of Average EEOI

The calculation of average EEOI before and after the implementation of ESPs is shown in Table 7.4. For the relevant calculations, the data shown in Table 6.15 will be used.

Table 7.4- Calculation of EEOI before the implementation of ESPs

Voyage	Distance	Duration	FCi1		(CF1*FCi1)	FCi2		(CF2*FCi2)
i	nautical miles	h	kg/h	kg	kgCO2	kg/h	kg	kgCO2
1	4419	239.05	1295.24	309622.29	962925.31	127.84	30559.67	97790.96
2	976.72	52.84	843.33	44557.99	138575.35	68.29	3608.15	11546.10
3	5289	286.11	1455.54	416443.11	1295138.06	81.09	23200.58	74241.85
4	370	20.02	629.14	12592.36	39162.23	90.76	1816.58	5813.05
5	5640	305.10	1267.69	386767.64	1202847.37	243.2	74199.44	237438.21
6	5651	305.69	1400.41	428093.34	1331370.30	94.03	28744.17	91981.33
7	976.72	52.84	972.41	51378.03	159785.68	74.76	3950.00	12640.01
8	5727.5	309.83	1355.73	420045.43	1306341.30	81.14	25139.58	80446.66
9	2876.4	155.60	98.86	15382.53	47839.68	153.24	23844.02	76300.85
10	1455.72	78.75	1514.16	119236.05	370824.12	99.49	7834.57	25070.63
11	833	45.06	1532.69	69064.88	214791.79	107.72	4853.99	15532.78
12	1613	87.26	1395.1	121730.01	378580.34	74.18	6472.61	20712.34
Summation	35828.06	1938.12		2394913.67	7448181.52		234223.37	749514.78

- For each voyage, traveling hours were calculated, considering the service speed of the vessel (18.5 kn) , and the respective distance.
- The voyages shown in Table 7.5 are representative of the annual number of voyages, and are repeated during the year.

The EEOI before and after the implementation of ESPs will be calculated through Eq.7.1 to 7.17, as follow:

$$\text{Total } CO_2 \text{ emissions= 7448181.52 kg+ 749514.78 kg= 8197696.30 kg} \tag{7.1}$$

$$\text{Total Distance covered during voyages 1-12= 35828.06 nm} \tag{7.2}$$

$$m_{CARGO} = 16141 \text{ MT} \tag{7.3}$$

$$\text{EEOI}_{\text{before}} = \frac{8197696.30 \text{ kg}}{35828.06 \text{ nm} \cdot 16141 \text{ MT}} = 0.014175 \frac{\text{kg}}{\text{nm} \cdot \text{MT}} \tag{7.4}$$

$$h_{\text{total}} = \text{ Total hours of operation per year= } 0.74 \cdot 365\text{days} \cdot 24\text{h= } 6482.4\text{h} \tag{7.5}$$

$$\text{Total FO consumption per year= (Total FOC)} \cdot \frac{h_{\text{total}}}{h_{1\text{-}12}} = 2394.91\text{tons} \cdot \frac{6482.4\text{h}}{1938.2\text{h}} = 8009.88\text{tons} \tag{7.6}$$

$$\text{Total DO consumption per year= (Total DOC)} \cdot \frac{h_{\text{total}}}{h_{1\text{-}12}} = 234.22\text{tons} \cdot \frac{6482.4\text{h}}{1938.2\text{h}} = 783.36\text{tons} \tag{7.7}$$

$$\text{Total estimated FO savings per year} = 63.15 \text{ tons} \tag{7.8}$$

$$\text{Total estimated FO savings per year (\%)} = \frac{63.15 \text{ tons}}{8009.88 \text{ tons}} = 7.88 \cdot 10^{-3} = 0.78\% \tag{7.9}$$

$$\text{Total estimated DO savings per year} = 163.58 \text{ tons} \tag{7.10}$$

$$\text{Total estimated DO savings per year (\%)} = \frac{163.58 \text{ tons}}{783.36 \text{ tons}} = 0.2088 = 20.88\% \tag{7.11}$$

$$\text{Total amount of money saved= } 63.15 \frac{MT}{year} \cdot 670 \frac{USD}{MT} + 163.58 \frac{MT}{year} \cdot 1100 \frac{USD}{MT} = 222249 \frac{USD}{year} \tag{7.12}$$

$$CO_2 \text{ emission reduction= } C_{F1} \cdot (\text{FO savings}) + C_{F2} \cdot (\text{DO savings}) =$$

$$= 3.11 \frac{MT_{CO_2}}{MT_{Fuel}} \cdot 63.15 \frac{MT}{year} + 3.20 \frac{MT_{CO_2}}{MT_{Fuel}} \cdot 163.58 \frac{MT}{year} = 719.85 \frac{MT_{CO_2}}{year} \tag{7.13}$$

$$CO_2 \text{ emissions after the implementation= 8197696.30 kg - 719850 kg = 7477846.3 kg} \tag{7.14}$$

$$\text{EEOI}_{\text{after}} = \frac{7477846.30 \; kg}{35828.06 \; nm \cdot 16141 \; MT} = 0.01293 \frac{kg}{nm \cdot MT} \tag{7.15}$$

$$\text{EEOI reduction =EEOI}_{\text{before}}\text{-EEOI}_{\text{after}} = 0.014175 - 0.01293 = 1.245 \cdot 10^{-3} \frac{\text{kg}}{\text{nm} \cdot \text{MT}} \tag{7.16}$$

$$\text{EEOI reduction}(\%) = \frac{1.245 \cdot 10^{-3} \dfrac{\text{kg}}{\text{nm} \cdot \text{MT}}}{0.014175 \dfrac{\text{kg}}{\text{nm} \cdot \text{MT}}} = 0.087 = 8.7\% \tag{7.17}$$

7.4. Conclusions and recommendations for future work

The procedure of Energy Audit, as described in Chapters 5 and 6, gives the owner the ability to record the energy management of the ship. Energy Audit demonstrates the weaknesses that exist in energy management, and proposes methods for correction. The implementation of the proposed measures is associated with financial benefits and, apart from that, it renders the operation of ship more environmentally friendly. The improvement of ship's environmental operation is clearly shown by the reduction of the relevant emission indicator (EEOI).

The Energy Audit gives a quantitative assessment of the improvement of Energy Efficiency. This improvement is obviously proportional to the amount of money that the owner accepts to dispose, and the time needed to conduct the Audit and prepare the Energy Audit Report. The duration of the Audit varies from 5 to 12 days, depending on the duration of the voyage. Once the Audit has been completed, the Report is delivered to the owner in 2-3 days. According to these details, the total time required for the conduction of the Audit and the delivery of the Report is usually 1-2 weeks. So, while the reduction of EEOI seems to be slight, it should be taken into account that the investment made by the owner is small compared to the investment needed for other major energy-related modifications.

Regarding the Energy Audit, one of the main difficulties is that the Audit could easily be postponed, as the subject ship may not arrive on time at the port where the auditors have planned to embark. Another problem is that many audited ships had not retain important details of the Sea Trials, so there could be no comparison with the respective Audit measured values.

A further step towards improving Energy Efficiency and the environmental performance of the ship would be the application of optimization procedures, taking into consideration both technical and economic aspects, either at the operational level of an existing vessel, or at both the design and operational level of a newbuilding. The extra time and effort required may be more than compensated by the anticipated benefits.

In this respect, some procedures followed during the Energy Audit could be improved in the future. For instance, the Audit could be conducted in a small number of different voyages, perhaps two or three, and not only one voyage, so that the auditors are able to measure the relevant parameters in different voyages. In addition, the owner, or the captain should ensure that the auditors are given as much as possible details, regarding the ship's voyages and fuel consumption, in order to assess satisfactorily the present performance of the subject ship.

The process of Energy Audit intends to add another block to the efforts being made internationally towards more economical and greener ships simultaneously. However, there is need for further research, development and penetration effort in order to render the ''green'' growth on ships economically viable and profitable.

The purity, as much as possible, of the environment is not only a requirement of the regulations, but mainly of the people who live and will live on this planet.

7.5. References

[1] Energy Audit Report written by Alpha Marine Services Ltd. for an existing Car Carrier (2011)