Reducing the Environmental Impact of Large Yachts

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ABSTRACT

Over recent decades the global yachting community has become increasingly concerned with its influence on the environment. Considering the size and energy use of a large yacht it is clear that their impact can be significant. This paper looks at two mechanisms through which yachts can reduce their environmental footprint; compliance with regulation, and optimisation of design.

Progress on environmental regulation at the IMO has seen recent amendments to MARPOL and the introduction of the Ballast Water Convention. The paper will examine MARPOL exhaust emissions, MARPOL fuel tank protection and BWM requirements and qualify the impact that these environmentally targeted regulations will have on large yacht design practices and vessel arrangements.

The operating profile of a modern yacht dictates that auxiliary systems far outweigh the propulsion system in terms of contribution to the operational environmental footprint. The paper will illustrate how ancillary systems can be optimised in order to reduce auxiliary loads and therefore overall environmental impact of the vessel.

1. INTRODUCTION & BACKGROUND

With an expanding global fleet of large yachts consuming ever greater quantities of energy, growing legislation and increasing social pressure to reduce environmental impact the large yacht industry and yacht owners need to respond accordingly. This paper considers current and forthcoming regulation to identify whether or not such obligations will help to address reducing emissions and also illustrates simple technological changes that can be made today, to ensure that vessels of the future are more energy efficient.

Legislation and regulation impacting the design of large yachts is generally focused on two main areas – safety and the environment. The amount of legislation surrounding environmental protection has seen some significant change in recent years with a number of new regulations either in force, or on the horizon. However it is important to understand the context of environmental protection as some regulations are designed purely to protect in the event of an accident, whilst others are designed to reduce emissions. MARPOL Regulation 12A is an excellent example of the former case which has been brought into force to minimise the quantity of fuel oil lost from a vessel, following damage from grounding or collision. The International Convention for the Control and Management of Ships' Ballast Water and Sediments (The Ballast Water Convention), is an example of the latter and is designed to protect the transfer of harmful and invasive aquatic organisms as well as pathogens, through discharge of ships' ballast water.

Atmospheric pollutants are perhaps the most widely recognised target for discussion. Regulations governing the prevention of air pollution from ships are dealt within Annex VI of MARPOL which covers exhaust emissions such as nitrogen oxides (NOx), sulphur oxides (SOx) and particulate matter (PM). These cause harm to the environment as well as human health. IMO Resolution MEPC 176 (58) contains amendments to Annex VI, which enforces tighter emissions standards. These are the addition of tier II (now in force) and tier III nitrogen oxide limits, more onerous sulphur content limits on fuel oil and updates to the definition of Emission Control Areas (ECA).

This paper will review the impact of these regulations on the design of large yachts.

The main pollutant that hasn't yet been addressed by marine legislation is CO_2, the principal greenhouse gas. The IMO currently has draft amendments to MARPOL Annex VI in review for the adoption of an Energy Efficiency Design Index (EEDI) and Shipboard Energy Efficiency Management Plan (SEEMP), which are aimed at improving the energy efficiency of new vessels and increasing the efficiency of operational vessels respectively. The paper will provide an overview of this forthcoming regulation and possible impacts on the design and operation of large yachts.

It is evident that despite the raft of new environmentally focused regulations, compliance at the present time may not lead to a lower environmental footprint. Builders and naval architects must focus on efficient design in order to reduce emissions. Although in recent years significant progress has been made to ensure that new and emerging technology is helping to overcome this challenge, much of the work is not ready for market in full scale application. However a significant amount of action can still be taken without recourse to novel, emerging or expensive technology. This paper will highlight and quantify the benefit of a number of simple technologies that can be easily implemented.

2. MARPOL REGULATION 12A

The MARPOL Convention covers pollution of the marine environment by ships. MARPOL Annex I covers the prevention of pollution by oil. Regulation 12A is an amendment which entered into force in August 2007. The purpose of the regulation is to minimise the quantity of oil lost from a vessel following damage from grounding or collision. This is achieved by enforcing a certain level of oil fuel tank protection. The new regulation applies to all ships with a fuel oil capacity of greater than 600m^3 delivered on or after 1st August 2010. The regulation provides two methods through which suitable oil fuel tank protection can be achieved.

2.1. PROTECTED FUEL TANKS

This method achieves adequate protection by positioning fuel tanks a required distance (typically 0.76m – 1.1m for large yachts) from the hull shell of the vessel effectively creating a double skin.

There are several issues associated with protected fuel tanks that are likely to discourage naval architects from pursuing the protected fuel tank route. The current yacht practice of using double bottom fuel storage is beneficial because it makes use of awkward, otherwise unusable void spaces. The protected tank method effectively creates more void space. Figure 2-1 shows a possible protected fuel tank arrangement. In order to accommodate an equivalent capacity of fuel the tank top height has to be increased significantly. In the example shown an additional 75% of volume was required compared to a pre regulation arrangement. This significantly impacts internal accommodation volume and the deck arrangement of the vessel. Wing tanks and tanks near the bow and stern, where there is high curvature, become very ineffective. The structural design and production of such a protected fuel tank arrangement would be significantly more challenging than current bottom arrangements, especially in areas of hull curvature. The additional tank boundary and supporting structure will increase structural weight. The increase in the double bottom height also shifts the decks above increasing lightship VCG impacting on stability and aesthetic profile. Deadweight VCG is also increased.

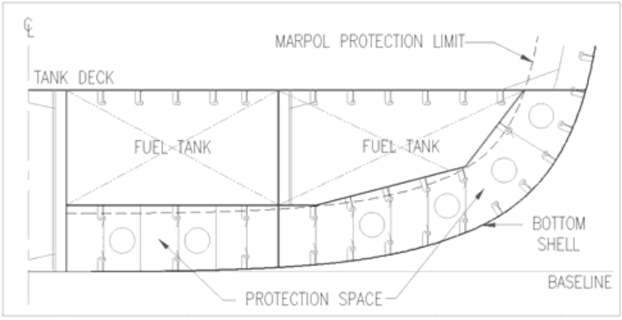


Figure 2-1: A Protected Tank Arrangement

2.2 ACCIDENTAL OIL FUEL OUTFLOW

The second method of compliance is a performance based method involving a probabilistic analysis of the fuel tank arrangement focussing on the likelihood of damage to each tank, and the subsequent quantity of oil that would be lost. A certain score must be achieved to demonstrate the required level of protection.

The main advantage of the outflow performance standard is that fuel tanks can remain in contact with the hull shell in line with current yacht design and production practices for double bottoms. However, the arrangement of tanks is severely restricted in order to pass the outflow standard and needs to be considered from the outset of the design process. The calculation effectively achieves protection by driving the designer to position tanks in areas where probability of damage is low, and where outflow resulting from damage will be minimal. From the authors experience it has been found generally that to achieve a suitable outflow score tanks need to be positioned in the bottom away from the shell sides. Tanks may also need to be deeper than is current normal practice, in some cases extending up to the deck above the inner bottom. The main two factors that influence the impact on vessel design is the overall fuel capacity and longitudinal tank distribution (fuel LCG). As the requirements for either become more extreme, flexibility in the arrangement is quickly lost. Where this is the case, tank top heights will generally increase impacting internal accommodation volume and the deck arrangement of the vessel.

Other points to note are that impact on vessel lightship and deadweight VCG is less significant than with protected fuel tanks. The outflow result can also be improved by subdividing or making fuel tanks smaller. This will drive up the number of tanks resulting in a more complex, heavier fuel transfer, bunkering and supply systems.

2.3. COMPARISON STUDY

A study was carried out that looked at these two methods and investigated the requirements and the impact of each method when applied to large yacht design. The impact was assessed and quantified for two concept designs by looking at the effect on various design parameters. These where the number of bunker tanks (an indication of complexity), fuel LCG (ability to control design trim and LCB), fuel VCG (impact on deadweight VCG) and the lower deck height (to indicate impact on deck arrangement and lightship VCG). The lower deck is the deck above the tank deck.

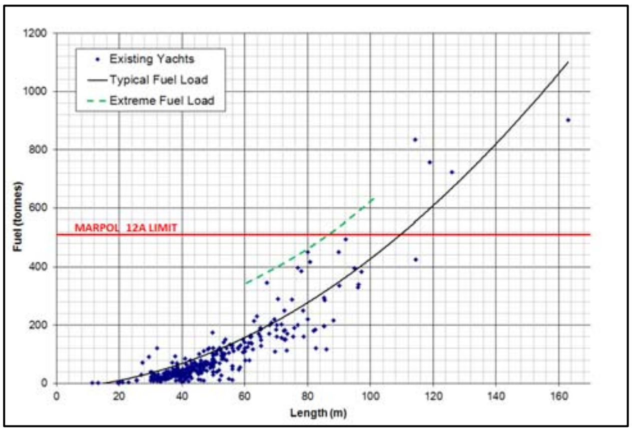


Figure 2-2: Regulation Threshold Length

An initial assessment of existing yachts was made to identify what size yacht the 600m^3 fuel threshold is reached. This showed that 110m was the typical size, and in extreme cases as small as 85m. See Figure 2-2. These two sizes of yacht where used as the subject of the quantitative study, each with a design fuel load of 600 m^3. The results for the parameters investigated are shown in Table 2-1. From the results of the study it can be seen that in general the number of bunker tanks, the fuel VCG and the lower deck height are less for the oil outflow method. It can be seen that for the typical threshold yacht (110m) the impact on these three parameters is minimal. However, there was a significant restriction on fuel LCG. It was found that a suitable fuel LCG of 43.5%LWL could be achieved, but any further forward and an increase in tank top height would be required. A pre-12A arrangement could achieve a fuel LCG 6% further forward with no need to increase tank top height. The ability to adjust fuel LCG is useful during the design process to achieve suitable trim and LCB.

The loss of flexibility needs to be considered from the outset of a design. It can be seen that the protected tanks method can achieve more flexibility in fuel LCG (about 2%), but the designer has to balance the benefit of this with the increased impact on build complexity, stability and internal arrangement. A further point to note is that the required bottom clearance for protected tanks is calculated from beam. Therefore as vessels get larger the protected fuel tanks method will impact more on the internal volume and arrangement of the ship.

85m Motor Yacht	Pre-Reg. 12A Unrestricted Tanks	Reg. 12A Protected Tanks	Reg. 12A Oil Outflow
No. of Bunker Tanks	12	13	10
Fuel LCG (%LWL)	43.5	43.5	41.9
Fuel VCG/Reduction GM (m)	1.81	2.22 / 0.08	1.95 / 0.03
Lower Deck Height (m)	4.70	5.10	5.10

110m Motor Yacht	Pre-Reg. 12A Unrestricted Tanks	Reg. 12A Protected Tanks	Reg. 12A Oil Outflow
No. of Bunker Tanks	10	12	10
Fuel LCG (%LWL)	49.4	45.3	43.5
Fuel VCG/Reduction GM (m)	1.48	2.55 / 0.09	1.49 / 0.00
Lower Deck Height (m)	4.70	5.20	4.70

Table 2-1: Study Results

The results considered in this paper are for two specific vessels. They have been presented to illustrate some of the issues that must be considered, but it should be noted that every yacht is different with their own design priorities. What can be said with certainty is that Regulation 12A is a dominant factor that must be considered at an early stage.

3. BALLAST WATER CONVENTION

The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) has been developed to control the transfer of harmful and invasive aquatic organisms and pathogens through ships' ballast water and sediments. This has become a significant problem due to the expanded trade and traffic volume over the last few decades. The effects in many areas of the world have been devastating. Data shows that the rate of bio-invasions is continuing to increase at an alarming rate. Effects such as invasive fouling and extinction of local fish stocks have been reported. The convention was adopted by the IMO in Feb 2004 but has not yet entered into force. The BWM will enter into force 12 months after it has been ratified by not less than thirty States, constituting not less than thirty five per cent of the gross tonnage of the world's merchant shipping fleet.

All yachts with seawater ballast will have to comply with Regulation D-2 of the convention by 2016. Some flags may implement the Regulation on new yachts (constructed in or after 2009) before that date. Regulation D-2 is the Ballast Water Performance Standard which states the required water quality that must be achieved for any ballast water that is being discharged. An acceptable water quality is defined by achieving maximum numbers of various micro-organisms per volume of water. To meet this standard, ballast water will need to be treated.

A review into the types and availability of systems suitable for yachts was undertaken. In general treatment units available use a two stage process which first filters the water and then sterilises it. The methods of sterilisation vary between manufacturers, examples being UV light, electrolysis, additives, and oxidation. With the aid of a technology review carried out by Lloyds' Register [1] it was found that the availability of suitably sized units for yachts was seriously restricted at this time. Most systems have been developed for large commercial vessels. From the research carried out, only one approved system was found that offered a low enough capacity to be suitable on a yacht. An assessment was carried out to ascertain the impact of installing such a system by looking at the size, weight and required power demand. For a 90m yacht the system would need a footprint area of approximately 3m^2, weigh 1.5t (wet) and use 15 kW of power. Apart from the additional space requirements in what are usually already very tight machinery spaces, it was concluded that the impact of installing the system on a large yacht would be relatively small.

As a result of the review it was concluded that there is a lack of availability of suitably sized, approved systems for a yacht application. Considering the current status, the most sensible course of action at this stage would be to reserve space in current yacht designs for a ballast water treatment unit but not install it. Once the convention is ratified, it is likely there will be more choice of products for large yachts thus allowing the most suitable system to be installed.

4. MARPOL NOX EXHAUST EMISSIONS

Annex VI of MARPOL contains regulations governing the prevention of air pollution from ships. IMO Resolution MEPC 176 (58) contains amendments to Annex VI which has seen a framework for higher emission standards come into force. For background on the regulations and their impact on yachts see Paper Reference [1]. This chapter of this paper focuses on the Nitrogen Oxide (NOx) Tier III requirements. This is the area of the IMO Amendments which will have the most significant impact on the design of large yachts. The requirements are of considerable concern to the yachting industry and a working group has been formed under ICOMIA to look at the problems that must be faced.

As the previously mentioned paper describes, the NOx Tier III requirements will mean that after 1st January 2016, diesel engines larger than 130 kW will require exhaust after treatment when operating in an Emission Control Area (ECA). Recreational craft under 24m in length will be exempt, however there is currently no IMO definition of recreational craft, leaving a potential problem in terms of how it is interpreted.The nature of yacht operating profiles and the wide variation of engine load factors means that currently the most feasible treatment option for yacht application is Selective Catalytic Reduction (SCR). The yachting industry and some engine manufactures are investigating the feasibility and impact of installing such a system. The previous paper concluded that the components of such a system would take up considerable volume in a yacht and also increase the design displacement by more than 1%.

Aside from the space and weight issue, there are some other challenges that will have to be overcome. The catalyst in a SCR reactor unit is very sensitive to the sulphur content of the fuel used. High sulphur content can damage the unit and reduce its effectiveness. The exact level of sulphur that will start to cause damage is a matter of opinion between engine manufacturers with values of between 0.01% - 0.1% being quoted. This raises the question of low sulphur fuel availability. Availability should be less of a problem in ECAs where the sulphur content of fuel will already be limited to 0.1% by 2015. However, outside ECAs the global sulphur limit will be 3.5% from 2012 and 0.5% from 2020. It is unknown at this time whether a global supply of low sulphur fuel (<0.1%) will be feasible by 2016. A potential solution is to introduce an exhaust bypass so that the SCR can be bypassed when operating outside an ECA. Dry SOx scrubbers, which could negate this requirement are being developed but are currently unsuitable for yacht application due to their size and mass. Both these options increase the complexity, weight and space requirement of a system that will already have a significant impact on a large yacht. The whole question of specific fuel grade availability and how it affects the ability of engine manufactures to provide warranty to these types of systems is of great concern to the industry.

In the SCR process a reactant (urea) is sprayed into the hot exhaust gas before flowing through the catalyst which causes the NOx gases and reactant to breakdown into harmless nitrogen and water. Another complication is the storage of the urea and the effect of temperature on the life of the fluid. Above 35°C the life of the urea is reduced to less than 6 months. This could have implications on storage locations which may have to be outside the engine room.

Engine manufacturers are currently assessing the feasibility of "on engine" solutions to achieve Tier III, without using after treatment. There is some expectation that the combination of exhaust gas recirculation (EGR) with improvements in turbocharging, injection and combustion pressures and timing cycles may reliably achieve Tier III targets. This technology is unlikely to be suited to yacht propulsion application because it requires a relatively high load factor one the engine to work reliably. The technology is still in development for marine engines, but may be suitable for engines with higher load factors and therefore potentially generator sets. Subsequently, a potential consequence of the IMO emissions regulations may be an increase in development and use of alternative propulsion systems such as diesel electric and hybrid options. Also the use of alternative, low emission fuels (such as LNG) will also be subject to further consideration and development. This shows that although regulation can be restrictive in certain areas of design, it is also a driver for innovation and the development of new technology.

5. GREENHOUSE GAS & EEDI

The main pollutant that hasn't yet been addressed by marine legislation is CO_2, the principal greenhouse gas. The IMO currently has papers in review for the adoption of an Energy Efficiency Design Index (EEDI) which is aimed primarily at commercial shipping and has created much debate within the marine industry. The basis of this index is the ratio of emissions output verses the benefit to society generated by the ship in question. That is, it provides a ratio of CO_2 output (in grams) to the work done (in tonne.miles) and is therefore based on the installed power (propulsive and auxiliary), specific fuel consumption, cargo carrying capacity and speed. The current version of the EEDI formula is shown below, in Figure 5-1.

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

Figure 5-1: Current EEDI Formula [2]

Fundamentally the EEDI formula was designed for typical commercial cargo vessels with simple propulsive systems (e.g. direct drive slow speed diesel engines). As can be seen from Figure 5-1, there are numerous correction factors to account for shaft generators / power-take-offs, electrical loads and factors such as weather effects, all of which provide a combination of 'debits' and 'credits' to the obtained index value.

Once the EEDI is in force, all new ships above a defined tonnage level will be required to meet required EEDI target levels as set by the IMO, which will reduce with time. It is likely that the determination of an EEDI will apply to all vessels greater than 400 GRT, although the exact reduction targets are still in discussion.

As far as large yachts are concerned, they are not included in the first version of the EEDI requirement (currently applicable to tankers, bulk carriers and container vessels) as like cruise ships, ferries and ro-pax type vessels, their propulsive and auxiliary systems are more complex than that allowed for in the current EEDI formulation and there has been considerable difficulties in achieving any agreement on the details for these more specialist vessel types.

However, there is clearly a strong marine industry drive to make all vessels as efficient as possible and therefore decrease the levels of air emissions due to sea borne trade and activity. This means that it is a matter of time before these regulations or similar incarnations will apply to large yachts. Given that an Emission Control Area (ECA), which limits airborne emissions from ships, has now been agreed for US coastal waters (up to 200 nautical miles off all US coastline) in addition to the ECA in the Baltic Sea, it is only a matter of time before other coastal states follow suit. Indeed, the EU is already known to be drawing up its own regulations should the IMO not be able to agree anything at the next MEPC (62) session this year.

This may mean the large yachts may come under increasing focus sooner than expected as the regulatory drive would be taken out of the hands of the industry itself. So there is increasing pressure on the yacht designer, builder, operator and owner to increase the efficiency of the yacht. What should not be forgotten, is that an improvement in efficiency should result in reduced operating costs and hence this pressure to reduce emissions can also result in commercial advantages to the owner and operator and not simply be a cost to be borne.

There are a range of design and operational tools that can be employed to improve the efficiency of the vessel and reduce the air emissions. Table 5-1 presents a summary of these as reported in the Second IMO GHG study [3].

DESIGN (New ships)	**Saving of CO_2/tonne-mile**
Concept, speed and capability	2% to 50%$^+$
Hull and superstructure	2% to 20%
Power and propulsion systems	5% to 15%
Low-carbon fuels	5% to 15%*
Renewable energy	1% to 10%
Exhaust gas CO_2 reduction	0%
OPERATION (All ships)	
Fleet management, logistics and incentives	5% to 50%$^+$
Voyage optimization	1% to 10%
Energy management	1% to 10%

Table 5-1: Potential CO_2 Emissions Reductions

The figures presented cover a wide range of potential savings and there is uncertainty as to how robust these figures are given their input data, the lack of proven trials and the inherently ship specific nature of these methods. However, what is clear is that with careful hull design, well thought out machinery design, use of proven new technologies as they become available and good operational practice, there are significant fuel savings (and hence emissions) to be made.

At the current time it is unclear how the evolving regulations will apply to large yachts, but despite their infancy, the message is clear – if your vessel is more efficient in terms of installed power and fuel burn, you will incur less penalties as newer legislation is introduced and it will provide clear commercial advantages through reduced operating costs.

6. QUANTIFYING YACHT EMISSIONS

To quantify, and put into perspective how significant greenhouse gas emissions of a large motor yacht are, Figure 6-1 presents the CO_2 emissions of a 110m motor yacht cruising at 17 knots (compliment of 80). These numbers are based on a passenger mile so are only relative when under way.

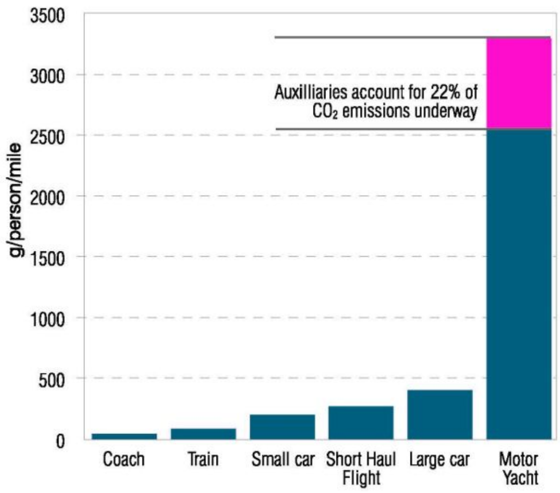


Figure 6-1: CO_2 Emission's Per Person Mile

An important characteristic of a yacht is that it spends a significant amount of time at rest; either within a port, marina or at anchor. Defining the operating profile for a yacht is very difficult as the usage depends solely on an unpredictable pattern of movement. However it is possible, given the right data, to make some broad assumptions. Within the Author's experience Figure 6-2 below represents a typical operating profile, illustrating that by far the greater majority of the time is spent at rest.

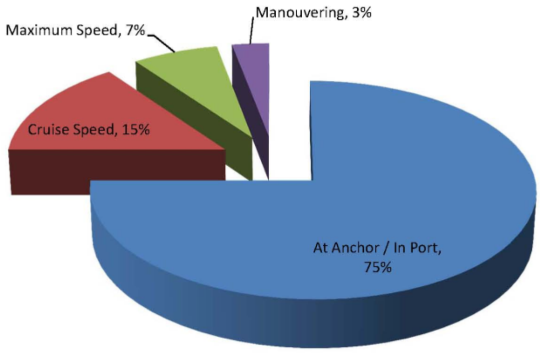


Figure 6-2: Typical Operational Profile

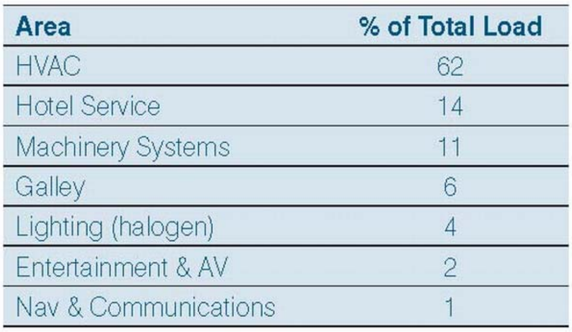
Whilst the loads from propulsive power dominate the whole picture it is suggested that a typical yacht will only spend around 25% of its time at sea. The loads from auxiliary systems, which will typically equate to 22% of hotel cruising loads, can run 24 hours a day all year round.

So while hull and propulsion efficiency improvements are a key part of reducing emissions, it can be argued there are greater gains to be made from reducing auxiliary loads.

7. REDUCING AUXILIARY LOADS

Before examining a series of technologies that can assist in reduction of auxiliary loads it is necessary to set a baseline load balance and therefore the resulting fuel burn, cost and CO2 emissions. For each technology presented within this paper the results are then compared with this baseline.

Referring to the design referenced in Section 6 the load balance breakdown for the auxiliary loads is as shown in Table 7-1.



Area	% of Total Load
HVAC	62
Hotel Service	14
Machinery Systems	11
Galley	6
Lighting (halogen)	4
Entertainment & AV	2
Nav & Communications	1

Table 7-1: Auxiliary Load Profile Breakdown

This load profile is for the yacht when operating with a full complement of crew and guests. Within this study all data is diversified to approximate a real life operational profile for the yacht. Based on the bunker price at the date of publication Table 7-2 presents the annual fuel burn, the cost and corresponding CO_2 emissions (excluding propulsive loads, auxiliaries only).

Fuel Consumed (Tonnes)	2500
Fuel Consumed (US$)	2.43m
CO2 Emitted (Tonnes)	7850

Table 7-2: Annual Fuel Use and CO_2 Emission

A series of three simple and implementable technologies have been investigated with the fuel and CO2 savings quantified for each.

7.1. WASTE HEAT RECOVERY

A typical high-speed generator set is only around 35% efficient between the point of combustion and the electrical energy delivered to the end receiver. Apart from the pure mechanical efficiency of the generator itself a significant amount of energy is lost in cooling water, exhaust gas heat and radiated heat. This lost heat can be harnessed to heat the vessel, calorifiers and swimming pool water. Engine jacket water is typically 85-90 degrees C at the input to heat exchangers. On a typical high speed engine around 30% of burned energy is dissipated in the engine coolant. A waste heat recovery (WHR) system can be used to recover this energy.

The design of such a system would require a heat exchanger placed in the jacket cooling water circuit to recover heat from the jacket water before it passes through the traditional sea water heat exchanger. A heat recovery circuit is then connected to the heat exchanger which can distribute water at a set temperature through to consumers to provide heating. If HVAC heating is to be provided then this can be configured through a hot water piping network run in parallel to the chilled water piping, distributing to the relevant HVAC duct heaters located throughout the vessel. Calorifiers can be arranged with additional water coils that the heat recovery circuit passes through, easily heating water to well above 60 °C.

With ambient outside air temperatures at 10°C it is predicted that the HVAC load of the yacht would reduce by 48% (440kW) when crew and guests are on board. In addition to this saving there is an additional load reduction for heating calorifiers and swimming pool water, further enhancing the savings.

Using WHR increases the generator efficiency to 53% at 10°C whilst reducing fuel burn. Installation of this system on a yacht the size of the example used is predicted to cost in the region of US$475,000. The anticipated savings are presented in Table 7-4. Based on these savings the payback period would be around 2.5 years.

7.2. FRESH WATER COOLING SYSTEM

The cooling systems on large yachts are frequently based on a fresh water intercooling principal. These systems are typically arranged to run at 100% duty 100% of the operational time. However the auxiliary equipment connected to the intercooling circuit will not be operating at full capacity all of the time. Additionally it is very common to arrange the intercooling system to meet the demands of the maximum likely sea water temperature which is often specified as 32 °C.

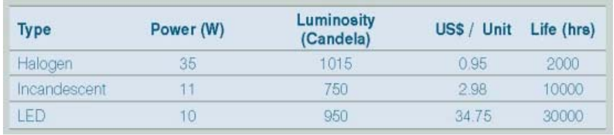
If the intercooling system is designed to adjust pump duty to reflect consumer demand as well as actual sea water temperature then significant energy savings can be made through reduced demand from cooling pumps. Assessment of such savings have been made for the example yacht and savings are presented in Table 7-4.

Installation costs are anticipated to be low for this technology, the only changes required to current system designs would be variable frequency drives (VFDs) on pumps, actuated valves at consumers, additional temperature sensors and modifications to the control system. Based on the predicted installation cost it is anticipated that the payback period would be less than one year.

7.3. CHANGING LIGHTING SYSTEMS

Many yachts still feature extensive use of halogen lighting. LED technology has progressed significantly over the past few years and the large yacht industry has been quick to recognise the increased potential / capacity of this type of light in the various forms that it is packaged.

For a similar incandescent output (in candela's) the latest proven LED lights consume only 30% of the power demanded by an equivalent Halogen bulb, but have significantly higher initial investment cost. Table 7-3 presents a comparison of alternate lighting types.



Type	Power (W)	Luminosity (Candela)	US$ / Unit	Life (hrs)
Halogen	35	1015	0.95	2000
Incandescent	11	750	2.98	10000
LED	10	950	34.75	30000

Table 7-3: Comparison of Lighting Technologies

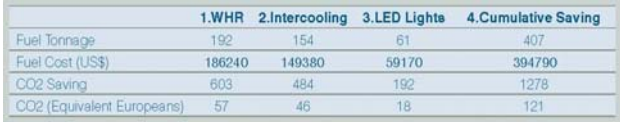
The initial investment cost differential between LED and Halogen would pay back in approximately 2~~.5~~ years. This is due in part to the high replacement rate of halogen bulbs as well as the reductions in heating load in the vessel from energy efficient bulbs.

7.4. CUMULATIVE SAVINGS OF TECHNOLOGIES

The aim of applying energy saving technologies is to reduce the auxiliary load of the vessels across all seasons (heating and cooling) while also aiming to reduce annual operating costs.

Table 7-4 presents the cumulative savings resulting from application of the three technologies presented to the baseline auxiliary load of the yacht.

Referring to Table 7-4 it can be seen that this equates to a 16% saving in auxiliary fuel consumption compared to the baseline data.



	1.WHR	2.Intercooling	3.LED Lights	4.Cumulative Saving
Fuel Tonnage	192	154	61	407
Fuel Cost (US$)	186240	149380	59170	394790
CO2 Saving	603	484	192	1278
CO2 (Equivalent Europeans)	57	46	18	121

Table 7-4: Cumulative Savings

The energy balance may also be altered such that smaller generator sets can be installed while also allowing the yacht to run for longer periods between bunkering, or reduce the level of bunkered fuel carried.

7.5. OTHER ENERGY SAVING MEASURES

In addition to the case studies presented there are a significant number of other opportunities to reduce auxiliary loads. Examining HVAC as the largest contributor to these loads the following measures can be applied;

- Application of turbocor compressors which are more energy efficient at partial loads.

- Use of enthalpy heat wheels to transfer energy to incoming fresh air. Therefore reducing the heating/cooling burden on the system.

- Adjustment of recirculation percentages to reduce the heating/cooling requirements to incoming air. Typical ratios are 50% fresh / 50% recirculation air. Significant savings can be made by adjustment to 40% fresh / 60% recirculation, without noticeable difference to occupants.

- Smart cabin management where both temperature and lighting are adjusted automatically to reflect cabin occupancy.

The key to reducing the HVAC load lies in reducing the heat burden that needs to be managed by the HVAC system. This can be achieved through;

- Application of greater, or more efficient thermal insulation to the vessels shell.

- Installation of more energy efficient glass.

- Exterior styling that reduces the impact of direct sunlight on windows and the use of architectural techniques to provide shaded exterior spaces and natural ventilation paths.

The cumulative benefits of these technologies will enable greater improvements in vessel efficiency.

8. CONCLUSIONS

An assessment of recent and forthcoming regulations impacting the design of large yachts has been presented with a specific focus on environmental protection.

It has been highlighted that compliance with such regulations will not per se lead to a lower environmental footprint. In particular it has been discussed that current regulation and legislation is not focused on reduction of greenhouse gas emissions (CO_2).

The future of legislation surrounding such emissions has been discussed and the framework of a proposed Environmental Efficiency Design Index (EEDI) has been presented.

The emissions of a large yacht have been quantified and it has been shown that a significant portion of such emissions are attributable to the loads from auxiliary systems. Analysis of a typical operating profile for a yacht has further shown that auxiliary system loads are the dominant contributor in operation.

It has been highlighted that in order to reduce emissions from these sources there are a number of relatively simple technologies that can be applied without recourse to novel or expensive technology. The three case studies presented are examples of where existing technology can be applied to a yacht to reduce auxiliary loads, emissions and also reduce the annual running costs.

Upcoming legislation (especially with regard to CO_2 emissions), along with rising bunker fuel prices will make energy efficient design a necessity rather than a desire. Through more efficient auxiliary design, simple technological changes can be made today to ensure that vessels of the future are more energy efficient. Such a responsible environmental approach will not only pay back initial investments quickly but will help to further reduce the operational costs of the vessel in the long term.

9. REFERENCES

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