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CONSIDERATION OF THE ENERGY EFFICIENCY DESIGN INDEX FOR NEW SHIPS

Fine-tuning of the Energy Efficiency Design Index (EEDI)

Submitted by Japan

SUMMARY

Executive summary:	This document provides an analysis and considerations of various elements relating to calculation of the Energy Efficiency Design Index (EEDI) and possible amendments to the Interim Guidelines on the Calculation of the EEDI for New Ships based on trial calculation conducted for 276 vessels in Japan
Strategic direction:	7.3
High-level action:	7.3.1
Planned output:	7.3.1.1 and 7.3.1.3
Action to be taken:	Paragraph 48
Related documents:	MEPC/Circ.471; GHG-WG 1/3/1; MEPC 58/4/3 and MEPC 58/23

Introduction

1 MEPC 58 approved the use of the draft Interim Guidelines on the method of calculation of the Energy Efficiency Design Index (EEDI) for new ships (hereinafter referred to as the Interim Guidelines), for calculation/trial purpose with a view to further refinement and improvement (paragraph 4.54.1 of MEPC 58/23).

2 In order to refine the Interim Guidelines (annex 11 to MEPC 58/23), Japan has conducted trials by carefully calculating the EEDIs for 276 vessels following the definition and explanation in the Interim Guidelines as far as possible[1]. As many as 33 shipbuilders of the Shipbuilders' Association of Japan (SAJ) and the Cooperative Association of Japan Shipbuilders (CAJS), as well as five shipping companies of the Japanese Shipowners' Association (JSA), have participated in this exercise. The calculated EEDIs include a wide variety of vessels as shown in

[1] *fj, fw, feff, fi* and *Peff* have not been examined in this trial; i.e. *fj, fi* and *fw* are assumed to be 1.0, and *feff* and *Peff* are assumed to be zero, in the calculation.

table 1 and also include vessels not only built in Japan, but also in China, Korea, and Germany, the data of which were provided by the shipping companies. The trial calculations also include vessels with special propulsion/engine systems, e.g., steam turbine engines, electrical propulsion systems and special shaft generator (SSG) systems[2], in order to identify the areas that the present text of the Interim Guidelines cannot fully address, and to consider possible improvements of the Interim Guidelines, by adding appropriate clarifications and interpretations in those areas.

Table 1 – Type and number of vessels of which EEDIs were calculated

	Data source			
type of ship	shipbuilders	shipping companies	sub total	Remarks
dry cargo carriers	34	57	91	including bulk carriers, chip carriers, cement carriers, and ore carriers
tankers	38	21	59	including crude oil tankers, product tankers, chemical tankers, and Ice-class tankers
gas carriers	15	16	31	including LNG carriers (diesel engine ships, steam turbine ships), and LPG carriers
container ships	10	16	26	including a SSG system ship
general cargo ships	12	2	14	
ro-ro ships	1	-	1	
ro-ro passenger ships	1	-	1	
Pure Car/Truck Carriers (PCC/PCTC)	9	36	45	
passenger ships	2	2	4	including an electric propulsion ship
other ships	3	1	4	including reefers and a reefer with ice class
Total	125	151	276	

3 The result and process of calculation of each vessel's EEDI were scrutinized by the Japanese Administration (MLIT: Ministry of Land, Infrastructure and Transport), and the MLIT and the shipbuilding and shipping industry discussed the problems that were identified through the trial calculation and possible solutions to these problems. As outcome of this exercise, Japan has identified necessary amendments to the present text of the Interim Guidelines, as follows:

.1 to add definitions/explanations that are missing in the Interim Guideline:

- definition of C_F,

- definition of P_{PTIi},

[2] SSG system consists of a main engine, a power recovery turbine, a turbo generator and a normal diesel generator.

- determination of P_{AE}, in particular for ships without the distinction of main and auxiliary engines (electric propulsion),

- determination of SFC, in particular SFC_{AE} in cases that more than one type of auxiliary engines are on board a ship,

- calculation method for steam turbine ships (LNG carriers), and

- treatment of the ships that can use more than one type of fuels.

.2 to modify the calculation method for energy recovery devices relating to:

- the effect of shaft generators, and

- the cases where the energy recovery part of the EEDI calculation formula becomes larger than the total of the auxiliary engine part and the shaft motor part.

4 The EEDI formula is reproduced for reference (annex 11 to MEPC 58/23). Details of the considerations and proposals are described below.

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} C_{FMEi}\ SFC_{MEi}\ P_{MEi}\right) + P_{AE}\ C_{FAE}\ SFC^{*}_{AE} + \left(\sum_{i=1}^{nPTI} P_{PTIi} - \sum_{i=1}^{nWHR} P_{WHRi}\right) C_{FAE}\ SFC_{AE} - \left(\sum_{i=1}^{neff} f_{eff}\ P_{eff}\ C_{FMEi}\ SFC_{MEi}\right)}{f_i\ Capafity\ V_{ref}\ f_W}$$

Clear indication of C_F values

5 The Interim Guidelines define the conversion factor between fuel consumption and CO_2 emission, *CF*, as follows:

> "*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 subscripts $_{MEi}$ and $_{AEi}$ refer to the main and auxiliary engine respectively.*
>
> *(Refer to the 2006 IPCC Guidelines and paragraph 15 of MEPC 58/4/3)*"

6 While the present text of the Interim Guidelines refer to the 2006 IPCC Guidelines only, the IPCC Guidelines do not directly give the values for the conversion factors (C_F). Instead, the 2006 IPCC Guidelines show Default Net Calorific Values (NCVs) and Lower and Upper Limits of the 95% Confidence Intervals (in table 1.2, volume 2 of the Guidelines) as well as CO_2 Emission Factors (in table 3.5.2, volume 2 of the Guidelines); thus, a conversion factor for a specific fuel type can be obtained by multiplying an NCV of such a fuel type by a CO_2 Emission Factor of the fuel.

7 It should be noted that the conversion factors are also given in Appendix to the Interim Guidelines for Voluntary Ship CO_2 Emission Indexing for Use in Trials (MEPC/Circ.471), which is the guidance for the calculation of the EEOI (Energy Efficiency Operational Index). It may be also recalled that INTERTANKO proposed to review those factors (GHG-WG 1/3/1), and the IMO Secretariat reported the outcome of the liaison with the Secretariats of UNFCCC and IPCC to harmonize the conversion factors (MEPC 58/4/3). Such guidelines for the calculation of EEOI are being reviewed in the Correspondence Group established by MEPC 58.

8 Japan believes that conversion factors to be used for EEDI calculation should be consistent with those for the EEOI, and the Interim Guidelines for EEDI should have a table clearly and directly showing the conversion factors on fuel types for ensuring the user-friendliness; the same table should be used in the Guidelines for EEOI as well.

9 The proposal made by INTERTANKO (GHG-WG 1/3/1) based on a theoretical consideration of molecular composition and weight of each fuel is well considered. However, Japan is of the view that the classification of fuel type should be the same as the one widely used in the world, i.e. ISO 8217:2005, which is also referred to in 5.3.2 of the NO_x Technical Code (2008).

10 Based on the above considerations as well as recent developments regarding CO_2 emission factors in the 2006 IPCC Guidelines, it is proposed to insert the following table instead of the reference clause "*(Refer to the 2006 IPCC Guidelines and paragraph 15 of MEPC 58/4/3)*" in paragraph 1 of the Interim Guidelines.

Table 2 – Conversion factors between fuel consumption and CO_2 emission, C_F

Type of fuel	ISO specification	C_F□t-CO_2 / t-Fuel□
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	3.186[3]
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	3.151
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	3.114
4. Liquid Petrol Gas (LPG)		2.985[3]
5. Natural Gas		2.693[3]

Definition of P_{PTIi}

11 P_{PTIi} is defined as "the 75% of the rated power consumption of shaft motors" in paragraph 5.2 of the Interim Guidelines. This definition, however, is not clear whether P_{PTI} is the 75% of the rated electric power of a motor for propulsion in electric kW (ekW) or the value converted from the 75% of the rated electric power to diesel engine power in kW taking into account the power losses which occur in converting diesel engine power to electric power, e.g., 0.9. Without this clarification of the definition, miscalculation will be made for ships with shaft motors or (fully) electric propulsion ships. To avoid such circumstances, P_{PTIi} should be clearly defined.

12 To ensure consistency of the units of P_{ME} and P_{AE}, P_{PTI} should be engine power in kW but not in electric power in ekW, and paragraph 5.2 of the Interim Guidelines should be amended as follows:

> *5.2 P_{PTIi} is 75% of the rated electric power ~~consumption~~ of shaft motors divided by conversion efficiency from diesel engine power to electric power, [0.9].*

3 NOTE: Conversion factors for Diesel/Gas Oil, LPG and Natural Gas are calculated by default value of those fuels in table 1.2 (Default Net Calorific Values (NCVs) and Lower and Upper Limits of the 95% Confidence Intervals) and table 3.5.2 (CO2 Emission Factors) in volume 2 of the 2006 IPCC Guidelines. As LFO and HFO are classified in one category as "Residual Fuel Oil" in the 2006 IPCC Guidelines, CO2 emission factors on LFO and HFO remain as they are in MEPC/Circ.471.

Calculation formulas for P_{AE}

13 Although actual auxiliary engine power installed on vessels significantly varies by ship types and individual designs of power systems, P_{AE} is defined in the Interim Guidelines as a simple formula where P_{AE} is assumed to be proportional to the maximum installed power of the main engine (hereinafter MCR_{ME}), as follows:

"*5.5 P_{AE} is the required auxiliary engine power to supply normal maximum sea load including necessary power for machinery, systems, equipment and living on board in the condition where the ship is engaged in a voyage at reference speed (V_{ref}) under the design loading condition of Capacity.*

.1 For ships with a main engine power of 10000 kW or above P_{AE}, is defined as:

$$P_{AE(MCRME > 10000KW)} = \left(0,025 \times \sum_{i=1}^{nME} MCR_{MEi}\right) + 250$$

.2 For ships with a main engine power below 10000 kW P_{AE}, is defined as:

$$P_{AE(MCRME < 10000KW)} = 0,05 \times \sum_{i=1}^{nME} MCR_{MEi}$$ "

14 Throughout the process of the trial calculation of EEDI, questions were raised by the industries about the validity of such a simplistic approach of calculating P_{AE} based on only one parameter of MCR_{ME}. Depending upon the configuration of a power system used on board, the actual auxiliary engine power required to supply normal maximum sea load could be significantly different from the one that is derived from the formula in paragraphs 5.5.1 and 5.5.2 of the Interim Guidelines. To test the applicability of the formulas for P_{AE}, the following two methods of P_{AE} estimation have been tested for 150 vessels, and the results are summarized in table 3:

.1 *Alternative method 1 of P_{AE} estimation: bottom-up approach*

To sum up all auxiliary engine output power (at 100% engine speed, 50% power, corresponding to test cycle D2 condition with 25% weight) documented in the technical file of the Engine International Air Pollution Prevention Certificate (EIAPPC).

.2 *Alternative method 2 of P_{AE} estimation: backward calculation approach using electric power table*

To estimate required auxiliary engine power with the maximum total electric power at normal seagoing conditions in the electric power table[4] divided by conversion efficiency from engine power to electric power, 0.9.

Table 3 – Comparisons of estimated P_{AE} by Alternative Methods 1 and 2 with the estimation using the formula of the Interim Guidelines based on MCR_{ME}

Type of vessel	Number of Available data	Percentage of the estimated P_{AE} against the P_{AE} using the formula of the Interim Guidelines (i.e. based on MCR_{ME} only) Figures in parentheses are average for each category.		Remarks
		Alternative Method 1 – Bottom-Up	Alternative Method 2 – using electric power table	
dry cargo carriers	42	122.95% ~ 467.8% (212.4%)	47.5% ~ 181.1% (89.7%)	24 vessels less than 10,000 kW MCR_{ME}
Tankers	40	118.4% ~ 412.2% (225.0%)	65.1% ~ 127.3% (94.0%)	22 vessels less than 10,000 kW MCR_{ME}
gas carriers	17	173.3% ~ 528.4% (254.4%)	82.1% ~ 296.6% (130.3%)	15 vessels less than 10,000 kW MCR_{ME}. Not including turbine engine ships.
container ships	15	224.4% ~ 423.0% (299.3%)	68.4% ~ 150.9% (102.2%)	4 vessels less than 10,000 kW MCR_{ME}
general cargo ships	14	162.2% ~ 199.2% (212.1%)	64.7% ~ 178.2% (109.8%)	13 vessels less than 10,000 kW MCR_{ME}
ro-ro ships	1	235.7%	147.7%	
PCC/PCTC	13	94.6% ~ 379% (255.1%)	88.2% ~ 170.5% (111.5%)	2 vessels less than 10,000 kW MCR_{ME}
ro-ro passenger ships	1	285.0%	259.0%	
passenger ships	3	236.5% ~ 2282.4% (929.1%)	178.8% ~ 197.3% (186.8%)	
others ships	4	195.8% ~ 664.6% (467.4%)	64.9% ~ 152.3% (104.2%)	Reefer, etc.
Total of major ship types[5]	128	(233.6%)	(100.7%)	

4 The electric power table is normally developed by a shipbuilder and kept on board as one of the accompanying documents as required by newbuilding contract. The electric power table is often verified and approved by the Administration/Recognized Organizations because it can be the documentation relating to the SOLAS chapter II-1 Part D regulation 40.1.1: "*Electrical installation shall be such that all electrical auxiliary services necessary for maintaining the ship in normal operational and habitable conditions will be ensured without recourse to the emergency source of electrical power*". The electric power table shows the generator load summary in kW and lists up generators in service by each condition of ship operation, e.g., "normal seagoing", "normal seagoing without REF.CON (in cases of container ships)", "manoeuvring with bow thruster", "loading and unloading", "rest in port", etc. Required auxiliary engine power to supply normal maximum sea load means necessary power for propulsion and accommodation, e.g., main engine pumps, navigational systems and equipment and living on board for normal seagoing, but excludes the power not for propulsion, e.g., thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g., reefers and cargo hold fans.

5 Major ships in the table are: dry cargo carriers, tankers, gas carriers, container ships, and general cargo ships.

15 The bottom-up approach (Alternative Method 1) is not considered as appropriate to estimate P_{AE}, because it can not exclude the electric power that is not used during normal seagoing, such as electric power for ballast exchange and cargo gears, and thus gives much higher values than the ones given by other approaches.

16 The backward calculation approach (Alternative Method 2) could be the most accurate estimation method because the electric power table is developed to indicate how electrical power is supplied under normal seagoing conditions for each ship in reality. This approach would be suitable for passenger ships (including both diesel and diesel-electric propulsion) which use much more electric power than cargo ships as hotel load; in other words, there is limited applicability of the simple formula in the Interim Guidelines to passenger ships. However, in using Alternative Method 2, it would be necessary to clearly define "normal seagoing" condition, such as inclusion/exclusion of electric power for cargo hold fan and reefer capacity, hotel load, etc.

17 P_{AE} values estimated by the simple formula in the Interim Guidelines based on MCR_{ME} only are not always close to the ones estimated by the back calculation approach (Alternative Method 2), yet the total average of estimated P_{AE} values for 128 vessels of five major types, i.e. dry cargo carriers, tankers, gas carriers, container ships and general cargo ships, shows no difference between Alternative Method 2, which is supposed to give the most accurate P_{AE} values, and the simple approach in the Interim Guidelines. In view of this, it is considered that the simple formulas to estimate P_{AE} from MCR_{ME} can be generally used as "default" P_{AE} estimation formula in the EEDI calculation, for most ship types.

18 On the other hand, such "default" formula has a clear limitation on the applicability; it is impossible to estimate P_{AE} for vessels where there is no distinction between main and auxiliary engines, i.e. diesel-electric propulsion ships. Therefore, it is necessary to have specific provisions for diesel-electric propulsion ships, where the "default" formula cannot be used.

19 In cases of diesel-electric propulsion ships, the following two options for P_{AE} estimation have been considered.

Option 1: backward calculation approach (described in paragraph 14.2 above)

Option 2: Using "Default" formula by assuming the rated electric power of shaft motors as MCR_{ME}

For ships with rated electric power of the total electric motors installed of 10,000 ekW or above, $P_{AE} = 0.025 \times$ (rated electric power of the total electric motors) / 0.9 + 250

For ships with rated electric power of the total electric motors installed below 10,000 ekW, $P_{AE} = 0.05 \times$ (rated electric power of the total of electric motors) / 0.9

20 As another possibility for passenger ships, the P_{AE} value could be estimated by an approximation formula expressed as a function of the gross tonnage (GT) based on data of existing vessels, noting that passenger ships use GT as Capacity in the Interim Guidelines. An example of an approximation formula is shown in figure 1.

Option 3: Using an approximation formula with GT as a parameter in cases of passenger ships

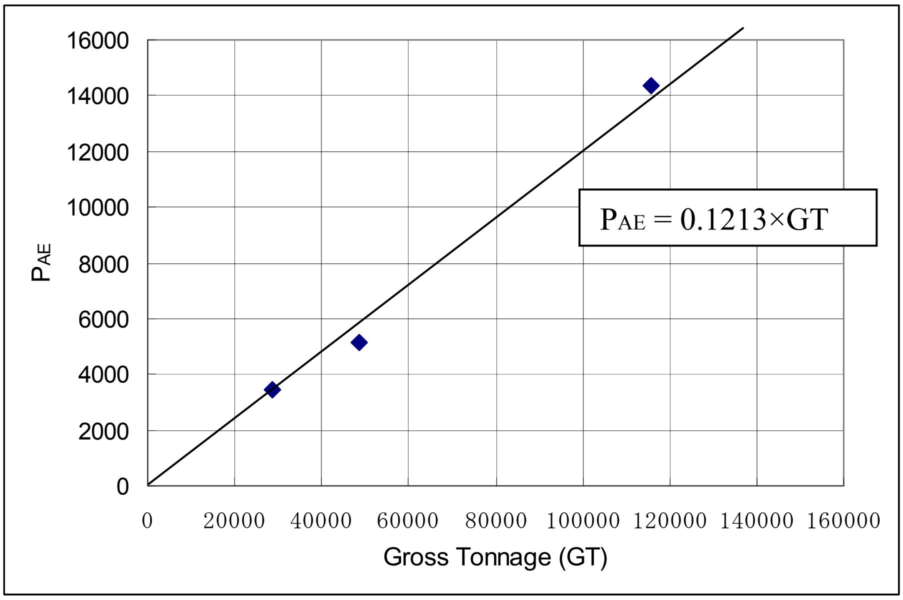


Figure 1 – An example of an approximation formula for estimating PAE of passenger ships

Table 4 – Comparison of option 1, 2 and 3 to determine P_{AE} for electric propulsion ships

Sample data used in the example of calculation	
Ship type: An electric propulsion passenger ship (48,600 GT) Main generators: 8,200 kW × 4 3,000 kW × 1 Rated power of motor for propulsion: 12,000 ekW × 2 the maximum total electric power consumption value at normal seagoing in the electric power table (excluding the propulsion purpose): 5,200 ekW	
Option 1	P_{AE} = 5,200 / 0.9 = 5,777.8 kW
Option 2	P_{AE} = 0.025 × (12,000 × 2 / 0.9) + 250 = 916.7 kW
Option 3	P_{AE} = 0.1213 × 48,600 / 0.9 = 6,550.2 kW

21 Table 4 shows examples of P_{AE} obtained by each option, and one may find that the value calculated by Option 2 is extremely small. This is because Option 2, as a variation of "default" formula in paragraph 5.5 of the Interim Guidelines, can not properly reflect the hotel load of a passenger ship during normal seagoing conditions. Option 2 may not be a viable method to estimate P_{AE} of passenger ships.

22 Option 3 could be a viable solution for P_{AE} estimation for passenger ships, however, the number of samples to determine the approximation formula is far from enough at this stage.

23 Taking into account the above observations, the proposed methods for P_{AE} estimation are summarized in the following table:

Table 5 – Proposed methods for P_{AE} estimation

<table>
<tr><td>Type of Ship and power system</td><td>Method of P_{AE} estimation</td></tr>
<tr><td>1 General (other than 2 and 3)</td><td><Default Method> the simple format based on MCR_{ME} only
Paragraphs 5.5.1 and 5.5.2 of the Interim Guidelines</td></tr>
<tr><td>2 Electric propulsion
(there is no distinction between main and auxiliary engines: “Default” method cannot be used, technically)</td><td rowspan="2"><Backward calculation approach using electric power table>
Supporting documents would be necessary for the verification, i.e. an electric power table showing generator load summary in kW and generators in service at the condition of “normal seagoing”, to be clarified in paragraph 5.5 of the Guidelines.</td></tr>
<tr><td>3 Passenger ships (including both of diesel propulsion and electric propulsion) where the estimated P_{AE} by “Default” method is significantly different from the actual total electric power at normal seagoing.</td></tr>
</table>

24 Paragraph 5.5 of the Interim Guidelines should be amended as follows:

5.5 P_{AE} is the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion and accommodation, e.g., main engine pumps, navigational ~~machinery,~~ systems~~,~~ and equipment and living on board, but excluding the power not used for propulsion, 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 reference speed (V_{ref}) under the design loading condition of Capacity.

.1 For ships with ~~a~~ main engine power of 10000 kW or above, P_{AE}~~,~~ is defined as:

$$P_{AE(MCRME\ >\ 10000KW)} = \left(0.025 \times \sum_{i=1}^{nME} MCR_{MEi}\right) + 250$$

.2 For ships with ~~a~~ main engine power below 10000 kW, P_{AE}~~,~~ is defined as:

$$P_{AE(MCRME\ <\ 10000KW)} = 0.05 \times \sum_{i=1}^{nME} MCR_{MEi}$$

.3 For ships where there is no distinction between main and auxiliary engines (electric propulsion) or ships where the P_{AE} value calculated by method .1 or .2 above is significantly different from the total power used at normal seagoing conditions, e.g., in cases of passenger ships, P_{AE} can be estimated by the total electric power (excluding propulsion) at normal seagoing, to be given in the electric power table, divided by the conversion efficiency from diesel engine power to electric power, [0.9].

Determination of SFC

25 Specific fuel consumption (SFC) is measured during factory acceptance tests and the results are documented in the technical file of the Engine International Air Pollution Prevention Certificate (EIAPPC), and the values recorded in the technical file should be used for calculation of the EEDI as described in paragraph 7 of the Interim Guidelines as follows:

"7 *SFC is the designed specific fuel consumption, measured in g/kWh, of the engines at the power output of P determined by paragraph 5. The subscripts $_{MEi}$ and $_{AEi}$ refer to the main and auxiliary engine, including any boilers, respectively. The auxiliary engine Specific Fuel Consumption (SFC_{AE}) is that recorded on the EIAPP Certificate at the engines 50% of P_{AE} MCR power or torque rating.*"

26 It should however be noted, that test fuel oil used for NO_x emission examination, a DM-grade marine fuel (gas/ diesel oil) specified in ISO 8217:2005 as recorded in the technical file, is different from the fuel oil used in actual ship operation, an RM-grade marine fuel oil (residual fuel oil) according to ISO 8217:2005. Therefore, the SFC in the technical file is different from the one during actual ship operation. For instance, while SFC is 170 g/kWh at NO_x examination, actual SFC would typically be 178.8 ~ 180.6 g/kWh assuming that the calorific values of gas/ diesel oil and residual fuel oil are 42.7 MJ/kg and 40.2 ~ 40.6 MJ/kg, respectively.

During actual operation

27 There are two options to address the above problem. One option is to simply use values recorded in the technical file of the EIAPPC, disregarding the difference from the real SFC value during actual ship operation, due to the difference in the fuel type. In this case, it is possible to verify SFC values easily with existing official documents, however, the SFC to be used for EEDI calculation is lower than the real SFC value by 5 ~ 6 %. Moreover, this option would cause a disadvantage for steam turbine ships because SFC of a turbine plant (main boiler and turbine generators) is tested on board a ship and the real value of SFC is obtained.

28 Another option is to convert a SFC value in the technical file to the one with a conversion formula, i.e. SFC real = SFC in the NO_x technical file × 1.064[6]. This would lead SFC values to be closer to the real ones, and can bridge the gap between diesel ships and steam turbine ships enabling fair comparison of these ships in the same ship category (i.e. LNG vessels), although an additional step would be required to calculate the EEDI.

29 Having considered the advantages and disadvantages of the above two options, it is proposed that SFC of any diesel engine should be determined by the uncorrected SFC values in the NO_x technical file to be multiplied by 1.064 representing the fuel type difference.

30 <u>Another issue</u> regarding SFC is the method of determination of SFC_{AE} in cases where more than one type of auxiliary engines are installed in a vessel. In the Interim Guidelines, only one value of SFC_{AE} is to be used as P_{AE} is simply calculated by the fixed percentage of MCR_{ME}, but it is unclear how to determine SFC_{AE} when two or more types of auxiliary engines are installed in the same vessel.

6 This conversion factor is derived from Default Net Calorific Values (NCVs) in table 1.2, volume 2 of 2006 IPCC Guidelines. 1.064 is derived from 43.0 (Gas/Diesel Oil) divided by 40.4 (Residual Fuel Oil).

Default Net Calorific Values (NCVs) and Lower and Upper Limits of the 95% Confidence Intervals (extract from table 1.2, volume 2 of 2006 IPCC Guidelines)

Fuel type English description	Default (TJ/Gg)	Lower (TJ/Gg)	Upper (TJ/Gg)
Gas/Diesel Oil	43.0	41.4	43.3
Residual Fuel Oil	40.4	39.8	41.7

31 One option is to take a simple mean value of SFC of each auxiliary engine. For example, if four auxiliary engines (generators) are installed in a vessel whose SFC are 180, 180, 180, 220 g/kWh respectively, having gone through the adjustment described in paragraph 29, SFC_{AE} will be determined simply as:

$$\frac{(180 + 180 + 180 + 220)}{4} = 190.0\ g/kWh$$

32 A second option is to calculate a weighted average value of SFC by using the maximum power of each auxiliary engine as "weight". For example, if the same generators as in paragraph 31 whose maximum powers are 8,000, 8,000, 8,000 and 3,000 kW are installed, SFC_{AE} will be determined as:

$$\frac{(8{,}000 \times 180 + 8{,}000 \times 180 + 8{,}000 \times 180 + 3{,}000 \times 220)}{(8{,}000 + 8{,}000 + 8{,}000 + 3{,}000)} = 184.4\ g/kWh$$

This method is simple and easy as well, and can reflect the reality.

33 A third option is to select SFC_{AE} of the auxiliary engine that is normally used during normal seagoing. This method, however, cannot appropriately deal with cases where no auxiliary engine is used because of the use of shaft generators and/or turbo generators, which can cover the power requirement during normal seagoing conditions. In addition, the same problem as described above would arise when two or more types of auxiliary engines are used at the same time.

34 Having considered the above three options, Japan proposes to choose the second option to determine SFC_{AE}. It is thus proposed to amend paragraph 7 of the Interim Guidelines as follows:

> *7 SFC is the ~~designed~~ specific fuel consumption, measured in g/kWh, of the engines at the power output of P determined by paragraph 5. The subscripts $_{MEi}$ and $_{AE}$~~$_{i}$~~ refer to the main and auxiliary engine~~, including any boilers~~, respectively.*
>
> *The main diesel engine Specific Fuel Consumption (SFC_{ME}) is determined by the uncorrected SFC value recorded in the technical file of the EIAPP Certificate at the engines 75% of MCR power to be multiplied by 1.064 which is the adjustment factor of different fuels used in the test bed and actual operation. The auxiliary engine Specific Fuel Consumption (SFC_{AE}) is ~~that~~ determined by a weighted mean value of SFC of each engine using, as a weight, the maximum power of each auxiliary engine that is recorded ~~on~~ in the technical file of the EIAPP Certificate at the engines 50% of ~~P_{AE}~~ MCR power or torque rating, to be multiplied by 1.064.*

Effect of shaft generators

35 The Interim Guidelines touches upon shaft generators only in the note accompanying the formula, referring to the auxiliary engine part of the denominator of the EEDI formula ($P_{AE}\ C_{FAE}\ SFC^{*}_{AE}$):

> "* *If a shaft generator is provided, the Normal Maximum Sea Load can be calculated using SFC_{ME} instead of SFC_{AE}*"

36 This arrangement for shaft generators, however, cannot deal appropriately with cases where no auxiliary engines are used because of the use of shaft generators that cover all the power requirement during normal seagoing. Using the present formula, P_{AE}, being determined solely by MCR_{ME}, would remain in the EEDI calculation, even though SFC_{ME} is used instead of SFC_{AE} thus the calculated value of EEDI is reduced marginally by the difference of SFC_{ME} and SFC_{AE}; this calculation would contradict the reality where no auxiliary engine is being used, thus fuel is not consumed by any auxiliary engine because of the utilization of shaft generators.

37 The easiest option is to deal with the effect of shaft generators as one of energy recovery systems in the same way as turbo generators and power turbine generators; in other words, to deduct the effect of the shaft generators together with other energy recovery systems from the total CO_2 emissions as shown in figure 2. This method is easy to understand and also simplifies the EEDI formula.

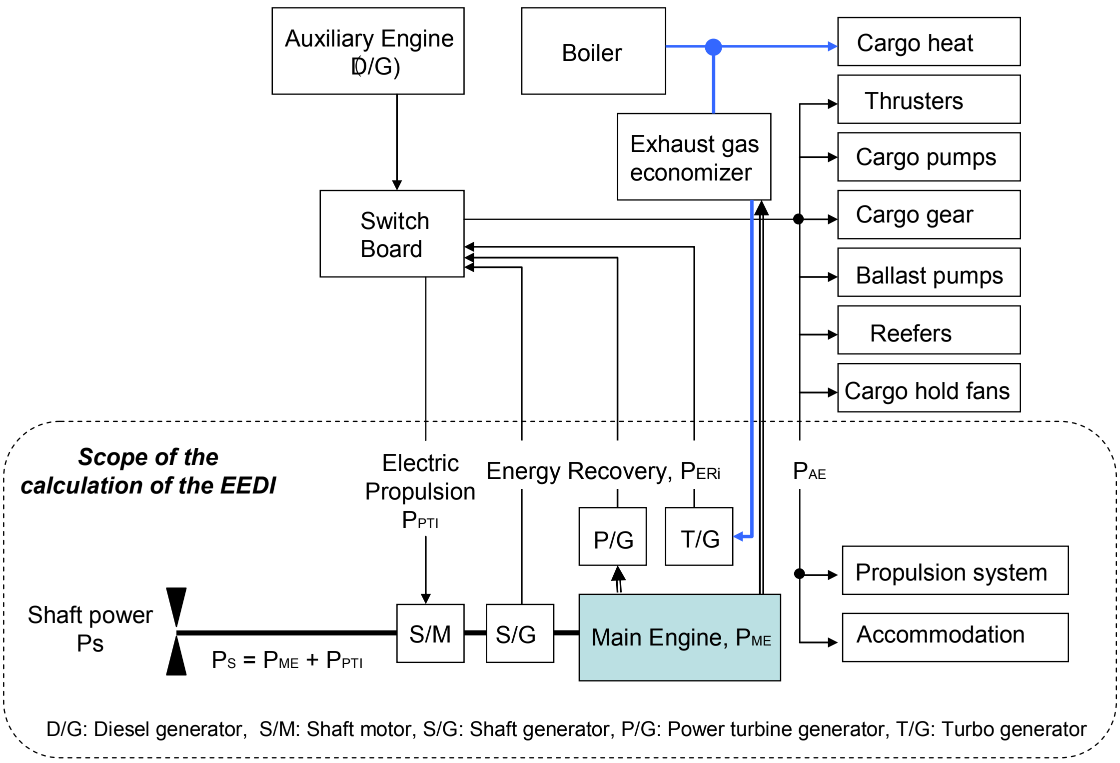


Figure 2 – Conceptual diagram of a generic marine power plant

38 One may think about another option to deduct the power of the shaft generator from that of the main engine. However, the base option as described in paragraph 36 would more appropriately represent the situation on board: because of the shaft generator, auxiliary engines are not in use. The purpose and effect of a shaft generator is to make the running of auxiliary engines unnecessary, which is the same as for other energy recovery devices such as power turbine generators and turbo generators, and such effects should be measured using the SFC_{AE}.

39 In view of the above, it is proposed to include the effect of shaft generators in line with those of waste heat recovery systems with a minor amendment of the definition. In addition, just as the case for shaft motors described in paragraphs 11 and 12, the unit for the power of shaft generators should be consistent with that of P_{ME} and P_{AE}, i.e. engine power in kW but not in electric power in ekW. It is thus proposed to delete the annotation on the shaft generator that appears in the beginning of the Interim Guidelines and to modify paragraph 5.3 as follows:

5.3 *P_{ERi} ~~P_{WHR}~~ is the rated electrical power generation of energy ~~waste heat~~ recovery system, such as shaft generators, power generators and turbo generators, at $P_{ME(i)}$, divided by conversion efficiency from diesel engine power to electric power, [0.9].*

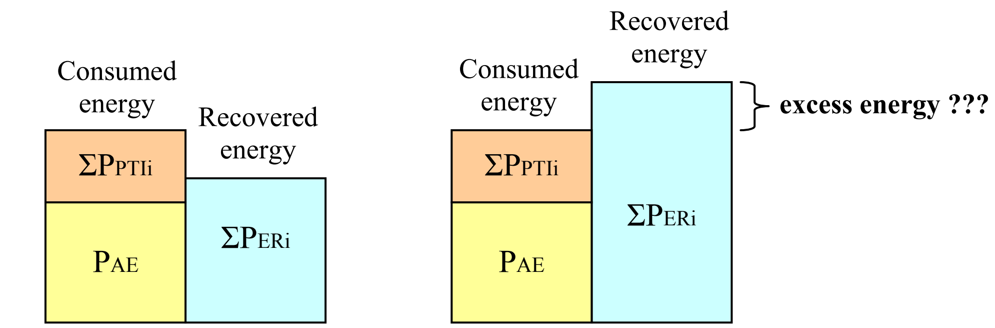
Also, numerator of the EEDI formula should be amended as follows:

$$\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} C_{FMEi}\ SFC_{MEi}\ P_{MEi}\right) + \left(P_{AE} + \sum_{i=1}^{nPTI} P_{PTIi} - \sum_{i=1}^{nWER} P_{ERi}\right) C_{FAE}\ SFC_{AE} - \left(\sum_{i=1}^{neff} f_{eff}\ P_{eff}\ C_{FMEi}\ SFC_{MEi}\right)$$

Appropriate adjustment for energy recovery devices

40 There are many cases where no auxiliary engine (generator) is used during normal seagoing because of the use of energy recovery devices such as shaft generators, power turbine generators or turbo generators. In particular, most steam turbine ships, usually do not use auxiliary engines (diesel generators) during normal seagoing as the power requirement is covered by steam turbine generators.

41 The Interim Guidelines stipulates that the effect of energy recovery devices on board is to be deducted from the total CO_2 emissions from the vessel; however it may happen that the effect of such devices (the power that can be recovered) could be larger than the power of shaft motors and auxiliary engines. This is illustrated in figure 3(b).



(a) $P_{AE} + \Sigma P_{PTIi} - \Sigma P_{ERi} > 0$ (b) $P_{AE} + \Sigma P_{PTIi} - \Sigma P_{ERi} < 0$

Figure 3 – Consideration of the effect of energy recovery devices

42 If the "excess" energy as shown in figure 3(b) is left in the numerator of the EEDI formula, it would unreasonably lower the EEDI, because such "minus" value in $\{(P_{AE} + \Sigma P_{PTIi} - \Sigma P_{ERi})*C_{FAE}*SFC_{AE}\}$ would be deducted from other parts of the numerator such as $(\Sigma C_{FMEi}*SFC_{MEi}*P_{MEi})$. This would contradict an actual situation on board where no auxiliary engines are used, but main engines are unaffected. Therefore, it is necessary to reset, $\{(P_{AE} + \Sigma P_{PTIi} - \Sigma P_{ERi})*C_{FAE}*SFC_{AE}\} = 0$, if $\{(P_{AE} + \Sigma P_{PTIi} - \Sigma P_{ERi})*C_{FAE}*SFC_{AE}\}$ is less than zero. Also, in cases where it is clear from the electric power table that neither auxiliary engines nor shaft motors are used during normal seagoing, such as steam turbine ships, the parts of the auxiliary engines, the shaft motors and the energy recovery, i.e. $\{(P_{AE} + \Sigma P_{PTIi} - \Sigma P_{ERi})*C_{FAE}*SFC_{AE}\}$ could be set to zero without calculation.

43 It is therefore suggested to add a new paragraph after paragraph 7, as follows:

7bis In cases where CO_2 emissions of energy recovery devices becomes larger than the total CO_2 emission of the auxiliary and shaft motors parts, i.e.

$$\left(P_{AE} + \sum_{i=1}^{nPTI} P_{PTIi} - \sum_{i=1}^{nER} P_{ERi} \right) C_{FAE}\ SFC_{AE} < 0 ,$$

or in cases where it is clear from the electric power table that neither auxiliary engines nor shaft motors are used during normal seagoing because of the use of energy recovery devices such as shaft generators, power turbine generators or turbo generators,

$$\left(P_{AE} + \sum_{i=1}^{nPTI} P_{PTIi} - \sum_{i=1}^{nER} P_{ERi} \right) C_{FAE}\ SFC_{AE} = 0$$

***SFC_{ME}* for steam turbine ships**

44 For all diesel engines being installed on board a ship, engine output power and specific fuel consumption are measured during factory acceptance tests and the results are documented in the technical file of the EIAPPC. For steam turbine engines, however, there is no official documents showing such information, and it is impossible in case of turbine plants to determine SFC_{ME} at the engines 75% of MCR power at a shop test because a boiler and a main turbine are tested separately on land and SFC is measured as one integrated turbine plant (boilers and turbine generators) by on board testing. On the other hand, while SFC of a diesel auxiliary engine (generator) is the specific fuel consumption of the diesel engine itself and does not include the loss in the generator.

45 It is therefore necessary to define SFC_{ME} for steam turbine ships, and it is proposed to add the following paragraph after paragraph 7:

7ter For steam turbine ships, $SFC_{ME(i)}$ is calculated by pro rata allocation of the turbine plant SFC by the steam volume with a heat balance diagram at 75% of the rated installed power, as follows:

$SFC_{ME(i)}$ = turbine plant FOC × (steam consumption volume of main turbine/total steam consumption volume)

EEDI of ships that can use more than one type of fuel

46 For ships that can use more than one type of fuel, e.g., steam turbine ships and ships with a Dual Fuel Engine (DFE), the EEDI could vary depending on the fuel, as an example shown in table 6.

Table 6 – An example of a steam turbine-LNG carrier

(80,229 DWT, 17 knot, MCR of main engine = 22,930 kW)

fuel type	SFC_{ME} (g/kWh)	EEDI (g-CO_2/ton-mile)
Oil (RFO)	293.9	11.54
Gas (LNG)	249.2	9.21

47 A DFE for bio-fuel will also be used in the future and the EEDI varies greatly when using the bio fuel. Therefore, the EEDI should be recorded for each fuel in cases of a ship that can use more than one type of fuel. It is thus proposed to add the following notation in the end of the Interim Guidelines:

> *NOTE: In cases of a ship that can use more than one type of fuel, the EEDI should be calculated and recorded for each fuel.*

Action requested of the Intersessional Meeting

48 The Intersessional Meeting is invited to consider the points addressed and the proposals presented in this document and take action as appropriate.

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