International Standard

ISO 8933-2

First edition
2024-08

Ships and marine technology — Energy efficiency —

Part 2:
Energy efficiency of maritime functional systems

Navires et technologie maritime — Efficacité énergétique —

Partie 2: Efficacité énergétique des systèmes fonctionnels maritimes

Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*.

A list of all parts in the ISO 8933 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Environmental concerns, emission regulations, fuel prices and emission taxes are increasing the demand for greater energy efficiency in the shipping industry. In 2013, the International Maritime Organization (IMO) adopted the Ship Energy Efficiency Management Plan (SEEMP)[10] to significantly decrease the amount of carbon dioxide (CO_2) emissions by 10 % to 50 % per transport work in international shipping. This strategy refers to a pathway of CO_2 emission reduction which is consistent with the goals of the Paris Agreement[13], alongside the United Nations 2030 Agenda for Sustainable Development[14].

Standardizing methods to evaluate energy efficiency in the maritime sector interface is valuable for a range of different stakeholders, including:

— shipowners who are looking to buy maritime systems to comply with IMO SEEMP initiatives;

— maritime equipment and engine manufacturers who are responsible for the design and production of ship systems;

— governments that are committed to environmental regulations and environmental targets such as the "levels of ambition" adopted by the IMO.

The purpose of this document is to improve energy efficiency in ships by providing more energy-efficient options that can be considered when replacing malfunctioning components throughout the ship's lifetime.

This document allows shipowners and shipyard workers to objectively identify the most energy-efficient components, systems and solutions for retrofits, as well as new-builds.

This document provides a method for comparing energy performance on an objective basis to prevent energy loss and to improve cost-efficiency and environmental conditions during maritime transport. This document makes it possible for users to compare the energy efficiency of different individual maritime components or functional units based on a standardized method to measure and calculate the values.

It is widely established that the usual combination of the most efficient single systems on board do not lead in sum to the most efficient ship. It is common practice that owners instruct shipyards to meet the criteria for an optimized operating point of the respective ship system during the design phase (new-build or reconstruction).

Accordingly, a shipyard checks before installation that each single system or component meets good energy efficiency values. It is not possible to calculate the ship's overall efficiency if the operating conditions are not standardized.

An example of a system or component where the efficiency depends on the operational conditions is an engine room ventilation without a given fan speed control system. If the fan is designed and optimized for the tropical zone and the ship is operated under North Atlantic conditions, less power is necessary during winter times. Owing to the absence of a controller, the fan rotation speed cannot be adjusted. In sum, every single fan can operate efficiently on a test bed (value given by manufacturer). An efficient performance is questionable if the ship sails under different operational conditions than what it is designed for.

To raise the overall operational energy efficiency of a ship in different operational conditions, the overall ship-individual combined system efficiency check should be performed. In addition, manufacturers and operators should take into account the possible variations between test bed conditions and onboard test conditions when developing individual components and systems.

Ships and marine technology — Energy efficiency —

Part 2:
Energy efficiency of maritime functional systems

1 Scope

This document specifies generic measuring and calculation methods to evaluate the energy efficiency of multiple components connected in a functional system installed on board ships, vessels for inland navigation and offshore structures.

A maritime functional system consists of multiple components integrating multiple functions, working together to achieve an overall goal.

The purpose of this document is to show how the energy efficiency of various functional systems correspond to the other installations on board of same functionality, thus ensuring that efficient design is rewarded.

Maritime systems are grouped according to their functionality, to compare the energy efficiency of functional systems which can fulfil the same task on board a ship.

This document is applicable to only the functional systems for which a unit output can be clearly defined, and which require energy to function.

This document is applicable to energy consuming functional systems. It does not provide a life cycle assessment (LCA).

NOTE   An LCA can prove useful when considering systems which consume substances, and which would not meet the functional requirements without the use of these substances. An example is a ballast water management system (BWMS) using active substances (these types are not considered in this document).

This document is applicable to the following five types of functional systems:

a)   pressure and flow;

b)   lighting;

c)   heating and cooling;

d)   mechanical;

e)   propulsion.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
energy efficiency
ratio or other quantitative relationship between an *output* (3.6) of performance, service, goods or energy, and an *input* (3.5) of energy

EXAMPLE   Efficiency conversion energy; energy required/energy used; output/input; theoretical energy used to operate/energy used to operate.

Note 1 to entry: Both input and output shall be clearly specified in quantity and be measurable.

[SOURCE: ISO/IEC 13273-1:2015, 3.4.1, modified — "and quality" deleted in Note 1 to entry.]

3.2
component
element performing only one *function* (3.4) and whose efficiency is defined by the ratio between *input* (3.5) and *output* (3.6)

EXAMPLE   Electric motor, water pump.

3.3
functional system
collection of *components* (3.2) creating a system which performs a well-defined *function* (3.4)

Note 1 to entry: The components included in the functional system can be energy consuming or passive components. A functional system can also contain a system, controlling the operation of the components.

Note 2 to entry: The energy consumption of a functional system is not only defined by the efficiency of the individual components but is also influenced by the design of the integration between these components.

Note 3 to entry: A functional system is supplied by a single supplier who is responsible for the integration of the components, and the function and performance of the unit based on a set of boundary conditions defining the quality/amount of *input* (3.5) and *output* (3.6).

3.4
function
operation that is performed by the system

Note 1 to entry: The function will have an *output* (3.6) characterized by the type and amount of output, i.e. treated volume/force/energy, and an *input* (3.5) in the form of consumed energy.

3.5
input
product, material or energy flow that enters a unit process

Note 1 to entry: Products and materials include raw materials, intermediate products and co-products.

3.6
output
product, material or energy flow that leaves a unit process

Note 1 to entry: Products and materials include raw materials, intermediate products, co-products and releases.

3.7
system boundary
boundary based on a set of criteria specifying which unit processes are part of the system under study

4   Symbols and abbreviated terms

The following symbols and abbreviated terms are used throughout the document.

η	efficiency ratio	dimensionless
EER	efficiency ratio used in the heating/cooling industry	non-dimensionless
COP	performance coefficient used in the air-conditioning industry	dimensionless
TPI	thermal power index used in the air-conditioning industry	dimensionless
ECI	energy consumption index used in the ship cargo industry	non-dimensionless
E	energy consumption	J
P	power consumption	W
Q	thermal energy	J
q_V	volume flow rate	m^3/s
q_m	mass flow rate	kg/s
ρ	density of water	kg/m^3
c_v	heat capacity of water	kJ/kg K
h	enthalpy	J/kg
T	temperature	K or °C
V	volume	m^3

5   Methods to evaluate the energy efficiency of maritime functional systems

Maritime functional systems are grouped according to their functionality. This makes it easier to compare the energy efficiency of functional systems which can solve the same task on board a vessel.

This document examines functional systems divided into following topical areas:

a)   pressure and flow functional systems (see Clause 6);

b)   lighting functional systems (see Clause 7);

c)   heating and cooling functional systems (see Clause 8);

d)   mechanical functional systems (see Clause 9);

e)   propulsion functional systems (see Clause 10).

The energy efficiency of the system is evaluated based on its expected operational purpose on board the ship and during its expected process operating window. This means that the boundary conditions on which the system is evaluated are defined to represent the normal operational pattern. This can include the variations in ambient conditions or variations in the ship's operational pattern. This is defined for each functional system.

The basic terminology of a maritime functional system is illustrated in Figure 5.1.
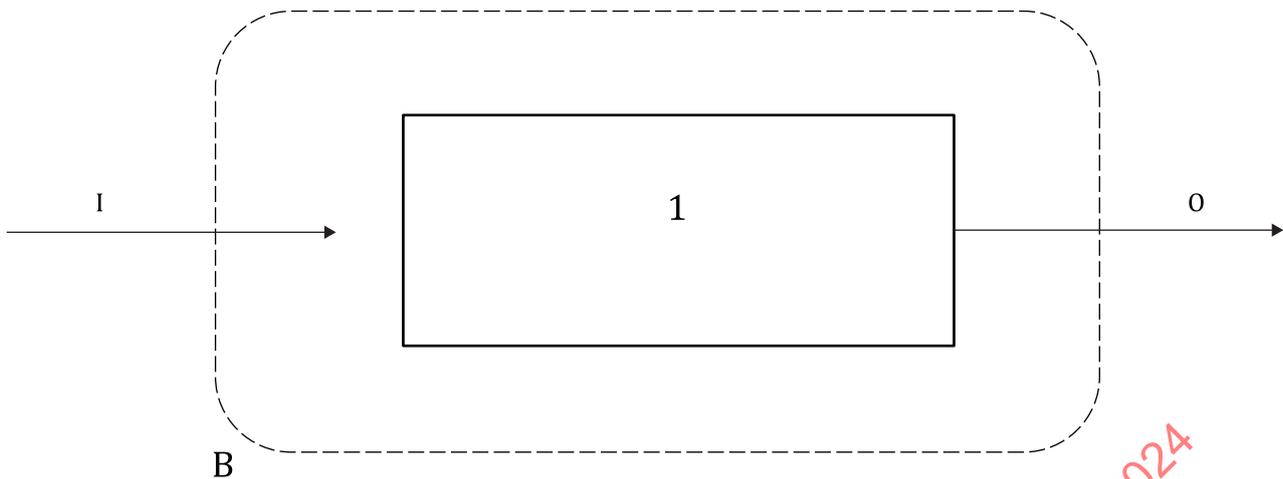
Key

B   boundary
1   functional system
I   input (energy, temperature, pressure, flow, concentration, force, velocity, torque, electricity, etc.)
O   output (energy, temperature, pressure, flow, concentration, force, velocity, torque, electricity, etc.)

Figure 5.1 — Basic terminology of a maritime functional system

6   Pressure and flow functional systems

6.1   General

A pressure-driven functional system consists of several components and connections between those components. The combined key functionality of these components (and the connections between them) changes the pressure or flow in a fluid.

The systems under this category include:

— ballast water management system (BWMS) (see 6.2), including:

  — ultraviolet (UV) light technology;

  — electro-chlorination (EC) technology;

— freshwater generator (see 6.3);

— sea water cooling system (see 6.4);

— freshwater cooling system (see 6.5);

— engine lube oil system (see 6.6);

— steam boiler system, thermal fluid system and hot water system (see 6.7);

— cargo pump system (see 6.8);

— cargo heating system (see 6.9);

— volatile organic compound (VOC) recovery system (see 6.10);

— separator system (see 6.11).

6.2 Ballast water management system

6.2.1 General

A BWMS[6] processes ballast water so that the water discharged (the treated water) meets the specified performance requirements for eliminating, inactivating or reducing an aquatic organism to prevent the problem of invasive species.

The energy efficiency calculation should be made based on an "output" treated water quality, meeting at least the D-2 standard of the IMO's Ballast Water Management (BWM) Convention.[6] If it is based on a stricter quality standard, this should be stated.

The BWM Convention requires BWMS to undergo type approval testing as described in the BWMS Code. [6][11] The data from the type approval test are needed for the establishment of the energy efficiency ratio (EER). A BWMS must be type approved for operation in:

— fresh water (< 1 PSU);

— brackish water (10 PSU to 20 PSU);

— marine water (28 PSU to 36 PSU).

NOTE 1   PSU = practical salinity unit.

The energy consumption of a BWMS can vary with the water type and therefore this must be considered when calculating the energy efficiency.

NOTE 2   If a system has not been part of a type approval, it must undergo testing under the same requirements as described in the BWMS Code to obtain the needed data to be able to compare systems on EER on a level basis.

The energy required to pump the water to the BWMS is not considered for several reasons, including:

— the pump(s) is normally out of the scope of the delivered BWMS;

— the pump(s) can have shared services on board the ship and is thus not necessarily dimensioned to fit the installed BWMS;

— the sizing of the pump(s) is dependent upon the location of the tanks and BWMS.

Hence, the pressure drop in the piping system from the pump(s) to the BWMS is also not considered.

Both UV and EC systems may deploy mechanical separation (filter, hydro-cyclone, etc.) to eliminate larger algae and organisms. For systems which are dependent on separation to comply with the BWM Convention, the separation units form part of the testing for type approval. The power needed for operation of separation under the approval conditions should be included in the EER consideration.

The energy efficiency of the BWMS is expressed through an EER as energy/volume. Since there are numerous parameter dependencies on the energy efficiency of BWMS, this document shows two EERs calculated for each water type, as applicable:

— one for nominal operation conditions: EER_{nom};

— one for the combination of high or low range values of any given parameter which will provide the highest index: EER_{max}.

NOTE 3   The higher the EER, the lower the energy efficiency.

Along with results of the EERs, it is necessary to present information on the treatment rated capacity, the water type (as applicable) and the system design limitation, including the holding time. However, if these data are available from the type approval certificate (according to the BWMS Code), this certificate can be appended.

6.2.2 Ultraviolet treatment systems

6.2.2.1 General

The ballast water is treated prior to entering the ballast water tank(s). After a typical mechanical separation, the ballast water passes the UV reactor. Most systems can apply additional UV treatment when discharging the ballast water tank(s), which should also be reflected in the energy efficiency calculation.

6.2.2.2 Definition of input and output

The input and output of UV treatment systems consists of the following:

— Input: Electricity (UV treatment, mechanical separation (if applicable) and other auxiliary systems tested during the type approval) and untreated ballast water.

— Output: Treated ballast water compliant with at least the IMO D-2 discharge standard[6] (if another stricter standard is the output, this should be stated) and separated material.

6.2.2.3 Definitions of boundaries and media

The physical boundaries are defined to start from the inlet of the BWMS to the end at the outlet of the BWMS. Thus, any sampling ports, the ballast pump(s), and the piping to and from the BWMS are not included. Other electricity consumers, such as either a booster or backflushing pumps, should be included in the calculation if they are operated as part of the system-type approval. The cleaning in place (CIP) process is conducted independently of the treatment of ballast water and cannot be related to the functional unit. Therefore, the energy consumption of the CIP process is not included in the calculations.

The possible elements in a UV BWMS and the boundaries for the energy efficiency calculation are shown in Figure 6.1.

Key
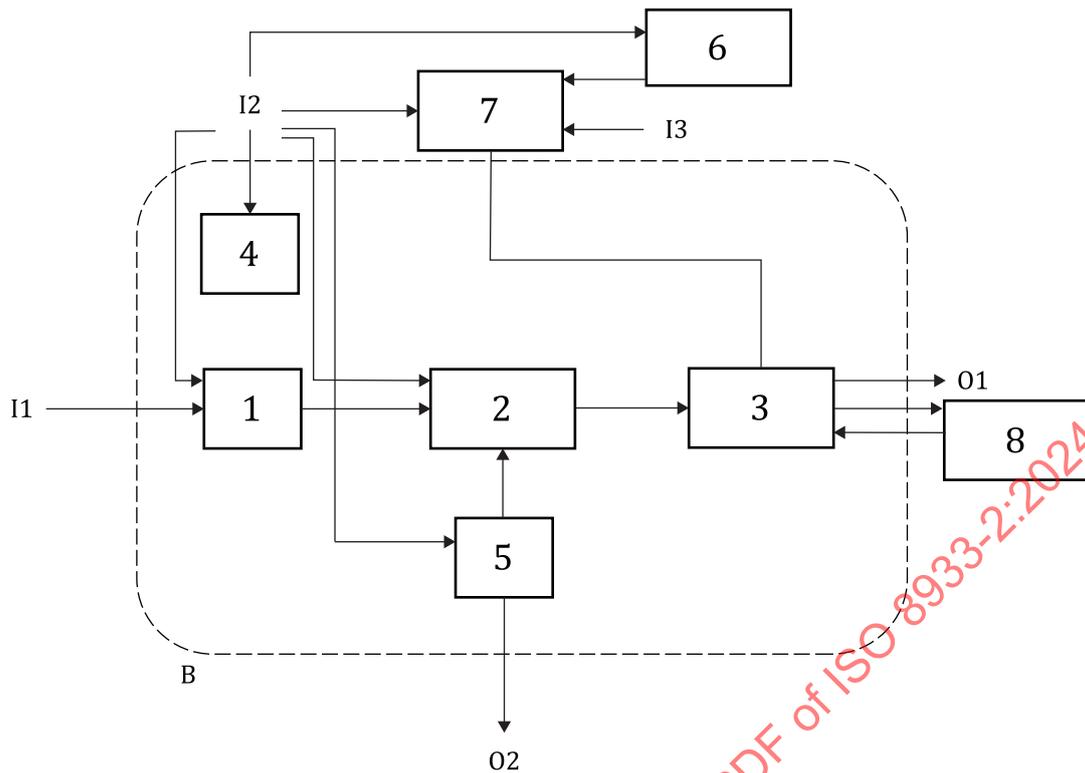
B	boundary	1	booster pump
I1	untreated ballast water	2	filter
I2	electric energy	3	UV reactor
I3	cleaning agent	4	control system
O1	compliant ballast water	5	backflush pump
O2	backflush material	6	fresh water
		7	cleaning in place unit
		8	ballast tank

Figure 6.1 — Possible components of a UV BWMS

6.2.2.4 Calculation method

Formula (6.1) shows how to calculate the average of *x* repetitive tests for energy consumption (measured by an energy meter) during a ballast operation and a de-ballast operation of minimum 100 m^3 of ballast water.

NOTE   Energy consumption is often lower during a de-ballast operation.

$$EER_{x,y} = \overline{\sum_{i=1}^{i} \left(E_{\text{UV,b},x,y} + E_{\text{UV,db},x,y} \right)_i} \tag{6.1}$$

where

$EER_{x,y}$ is the EER, expressed in kJ/100 m³ (1 kJ = $\frac{1}{3\,600}$ kWh), where x can be one of the two conditions nominal (nom) or maximum (max) and y is the water type fresh, brackish or sea;

i is the test number per x and y;

$E_{UV,b,\,x,y}$ is the energy consumption measured during ballasting, expressed in kJ/100 m³ (1 kJ = $\frac{1}{3\,600}$ kWh) for the UV BWMS, where x can be one of the two conditions nominal (nom) or maximum (max) and y is the water type fresh, brackish or sea;

$E_{UV,db,x,y}$ is the energy consumption measured during de-ballasting, expressed in kJ/100 m³ (1 kJ = $\frac{1}{3\,600}$ kWh) for the UV BWMS, where x can be one of the two conditions nominal (nom) or maximum (max) and y is the water type fresh, brackish or sea.

Hence, the following values can be expected, dependent upon the system capabilities: $EER_{nom,fresh}$, $EER_{nom,brackish}$, $EER_{nom,sea}$, $EER_{max,fresh}$, $EER_{max,brackish}$ and $EER_{max,sea}$.

6.2.2.5 Measuring method

It is assumed that data for the calculation of the EER are available from the type approval test data.

The influent water should comply with the specification of the BWMS Code, MEPC.300(72)[11] with regards to dissolved organic carbon (DOC), particulate organic carbon (POC) or total suspended solids (TSS). Calculations should be done for all water types for which the BWTS have been type approved, e.g. fresh water (< 1 PSU), brackish water (10 PSU to 20 PSU) and marine water (28 PSU to 36 PSU), unless the manufacturer can document that the energy consumption is independent of the salinity. The temperature of the water does not affect the energy consumption of a UV BWMS.

For both the nominal operational condition (nom) and maximum operational condition (max), the data on the electricity consumed during ballast and the data on the electricity consumed during de-ballast is required.

The data should include influent water with both high (≥ 80 %) and low (≤ 55 %) UV transmittance (UV-T). The high UV transmittance reflects the nominal operation conditions and the low UV-T reflects the maximum operational conditions.

6.2.3 Electro-chlorination treatment systems

6.2.3.1 General

In this subclause, the treating of ballast water uses an EC treatment method. The full-flow ballast water may pass the EC reactor, or a substance is produced in a side stream by the EC reactor and dosed to the full flow ballast water.

6.2.3.2 Definition of input and output

The input and output of EC treatment systems consists of the following:

— Input: Electricity (electro-chlorination, mechanical separation (if applicable), neutralization, heating and other auxiliary systems tested during the type approval) and untreated ballast water.

— Output: Treated ballast water compliant with at least the IMO D-2 discharge standard[6] (if another stricter standard is the output, this should be stated) and separated material.

6.2.3.3 Definitions of boundaries and media

The physical boundaries are defined to start from the inlet of the BWMS to the end at the outlet of the BWMS. Thus, any sampling ports, the ballast pump(s), and piping to and from the BWMS are not included. Other pumps, such as booster and/or backflushing pumps, should be included in the calculation, as well as a degas unit, if they are integrated parts of the system.

The main elements of an EC BWMS are shown in Figure 6.2.

Key
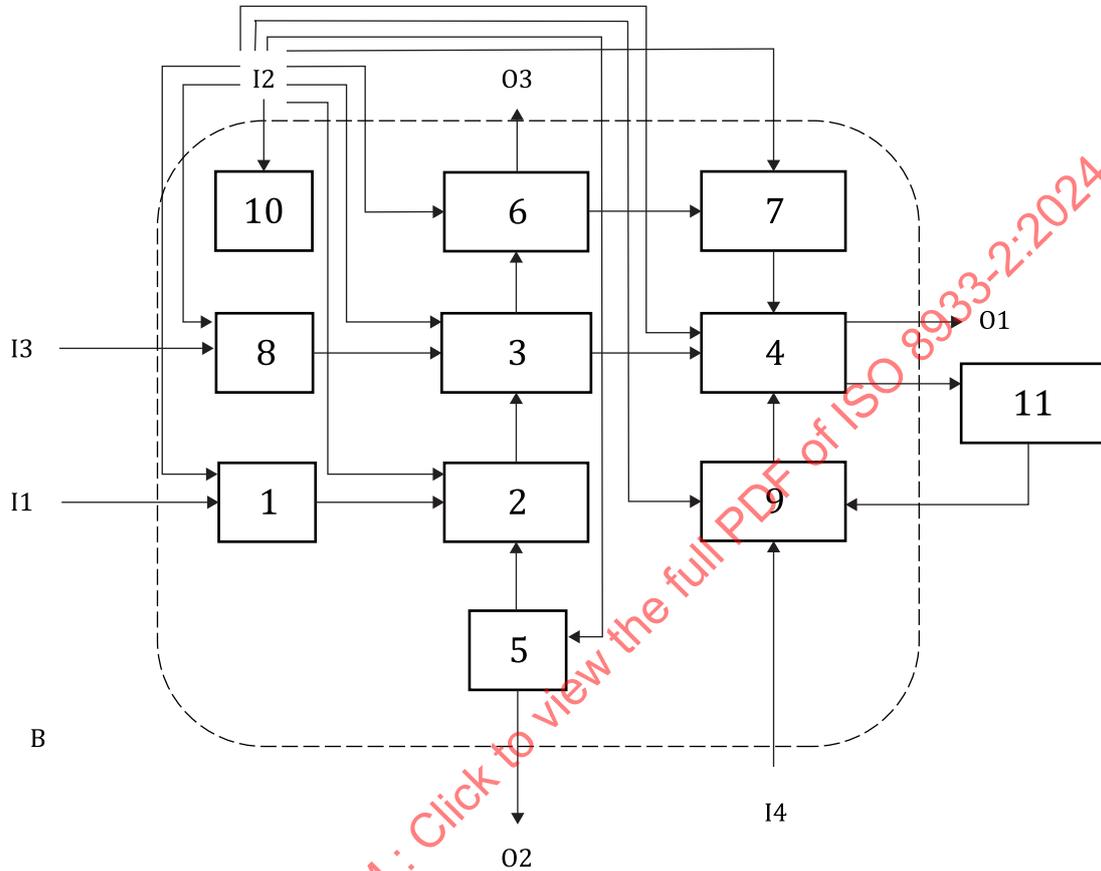
B	boundary	1	booster pump
I1	untreated ballast water	2	filter/strainer
I2	electric energy	3	electro chlorination unit
I3	salt water	4	TRO sensor
I4	neutralising agent	5	backflush pump
O1	compliant ballast water	6	degas/dosing unit
O2	backflush material	7	mixer unit
O3	hydrogen	8	side-stream pump
		9	neutralization unit
		10	control system
		11	ballast tank

NOTE 1   Some systems lead all the ballast water through the electrolyser.

NOTE 2   Other systems generate oxidants in a side stream flow and mix with the main ballast flow.

Figure 6.2 — Typical key components of an EC BWMS

6.2.3.4 Calculation method

Formula (6.2) shows how to calculate the average of x repetitive tests for energy consumption (measured by an energy meter) during a ballast operation and a de-ballast operation of minimum 100 m³ of ballast water.

NOTE   Energy consumption is often lower during a de-ballast operation.

$$EER_{x,y} = \overline{\sum_{i=1}^{i}\left(E_{\text{EC,b},x,y} + E_{\text{EC,db},x,y}\right)_i} \tag{6.2}$$

where

$EER_{x,y}$ is the EER, expressed in kJ/100 m³ (1 kJ = $\dfrac{1}{3\,600}$ kWh), where x can be one of the two conditions nominal (nom) or maximum (max) and y is the water type fresh, brackish or sea;

i is the test number per x and y;

$E_{\text{EC,b},\,x,y}$ is the energy consumption measured, expressed in kJ/100 m³ (1 kJ = $\dfrac{1}{3\,600}$ kWh), during ballasting for the EC BWMS, where x can be one of the two conditions nominal (nom) or maximum (max) and y is the water type fresh, brackish or sea;

$E_{\text{EC,db},\,x,y}$ is the energy consumption, expressed in kJ/100 m³ (1 kJ = $\dfrac{1}{3\,600}$ kWh), measured during de-ballasting for the EC BWMS, where x can be one of the two conditions nominal (nom) or maximum (max) and y is the water type fresh, brackish or sea.

6.2.3.5 Measuring method

It is assumed that the data for the calculation of the EER is available from the type approval test data.

The influent water should comply with the specification of the BWMS Code, MEPC.300(72)[11] with regards to DOC, POC or TSS. Calculations should be done for all water types for which the BWTS have been type approved, e.g. fresh water (< 1 PSU), brackish water (10 PSU to 20 PSU) and marine water (28 PSU to 36 PSU), unless the manufacturer can document that the energy consumption is independent of the salinity.

For both the nominal operational condition (nom) and maximum operational condition (max), the energy consumed is measured during ballast and the energy consumed is measured during de-ballast.

The measurement should be done on influent water with both a low (≤ 8°) and a higher (≥ 20°) temperature. The high temperature will reflect the normal operation conditions and the low temperature will reflect the maximum operational conditions.

6.3 Freshwater generator

6.3.1 General

The crew on board large ocean-going ships require freshwater for drinking, cooking, showering etc., and some equipment on board the ship can require technical freshwater. Installing a freshwater generator as an alternative to bunkering freshwater is the primary choice for larger ships.

The system consists of pumps and two or more heat exchangers in a vacuum vessel, enabling the evaporation of sea water at low temperature, and subsequent condensation of the distillate/freshwater.

The freshwater generators described in 6.3.3 require a heat source, which is often waste heat from an engine, but steam from boilers can also be a chosen thermal heat source. Freshwater generators that operate only on electricity are used mainly in the offshore industry and are not covered in this document.

Depending on the integration of the systems on board the ship, a system can include a feedwater pump(s), freshwater pump(s) and/or ejector pump, if applicable. Hence, for comparison purposes, this document prescribes specific test conditions under which the system is to be tested.

Freshwater generators are typically operated periodically, and the produced freshwater is stored in tanks.

6.3.2   Definition of input and output

The input and output of a freshwater generator consists of the following:

— Input: Heat energy, electrical energy and sea water.

— Output: Distillate/freshwater, brine and heat loss (heating media and cooling water returns).

6.3.3   Definitions of boundaries and media

A freshwater generator requires an electrical supply and connections for the heat energy source (water or steam), seawater and freshwater. The boundaries are shown in Figure 6.3.

Key
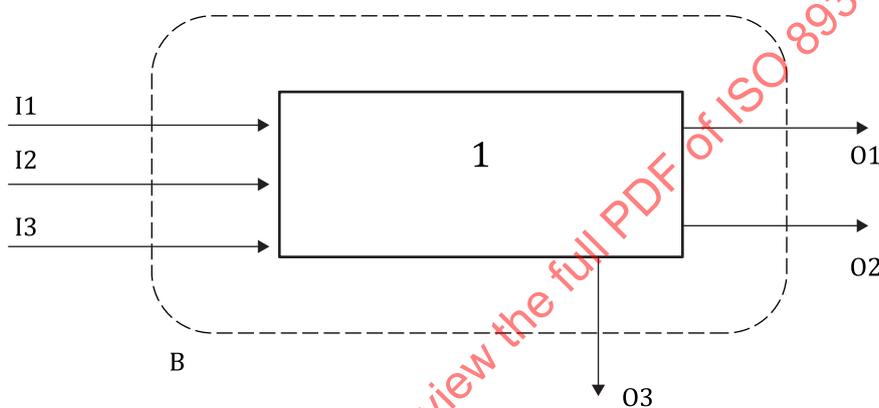
B   boundary
I1   electricity
I2   seawater, used both as feed water and cooling water
I3   thermal heat source (steam /hot water)
O1   freshwater
O2   brine
O3   heat loss (cooling water and outlet thermal heat source)

1   freshwater generator system

Figure 6.3 — Boundaries and input/output for a freshwater generator

6.3.4   Calculation method

6.3.4.1   General

The energy efficiency of a freshwater generator is determined by how much energy is used per kilo mass of produced fresh water. An energy rating requires an index ratio for the electrical efficiency as well as an index ratio for the thermal efficiency.

The method covers both the tubular type and the plate type fresh water generator.

6.3.4.2 Electrical efficiency

Calculating the electrical EER (EER_{el}) is done by measuring the power consumption of specified electrical consumers, $\sum P_{el}$, while producing freshwater at its design mass flow rate, $q_{m\ design}$ and is hence expressed as shown in Formula (6.3):

$$EER_{el} = \frac{\sum P_{el}}{q_{m\ design}} \tag{6.3}$$

where

EER_{el} is the electrical EER at design flow, expressed in kJ/kg;

P_{el} is the power consumption as specified in Formula (6.4), expressed in kJ;

$q_{m\ design}$ is the design mass flow rate as specified in Formula (6.5), expressed in kg/s.

The main electricity consumers are pumps. The electricity consumption of a control system and associated valves will generally be insignificant and can be ignored in this document. In order to compare the EER_{el} among suppliers of freshwater generator systems, the following consumptions should be accounted for in Formula (6.4):

$$\sum P_{el} = P_{feedwater} + P_{cooling} + P_{ejecting} \tag{6.4}$$

where

$P_{feedwater}$ is the power consumed to provide feedwater to the system, expressed in kJ (1 kJ = $\frac{1}{3\,600}$ kWh);

$P_{cooling}$ is the power consumed to provide cooling water to condense the generated freshwater to a given temperature, expressed in kJ (1 kJ = $\frac{1}{3\,600}$ kWh);

$P_{ejecting}$ is the power consumed to eject/discharge brine, etc. from the system, expressed in kJ (1 kJ = $\frac{1}{3\,600}$ kWh).

Often the above functions are provided by one pump only, but to keep this document generic, Formula (6.4) has been provided. Even though pump(s) can be shared services on board the ship, the pump(s) should be accounted for in full to properly reflect the pressure loss of the system. The energy needed to pump the produced freshwater to its destination shall not be considered. It is also assumed that any pumping required to circulate the heating media is provided by existing systems on board the ship, and hence shall not be accounted for. In cases where these directions cannot be followed, it shall be stated that the EER_{el} result does not follow this document and a non-compliant EER_{el} shall be accompanied with information on which consumers have been accounted for.

The freshwater production capacity of a system is typically given in kilo per day (24 h). If a range is given, it should be the highest amount that forms the basis for determining $q_{m\ design}$. A freshwater generator does not normally operate on a continuous basis, but it should be able to deliver the amount promised and hence the mass flow for the calculation is established based on this promise.

$$q_{m\ design} = x \cdot \frac{1}{86,4} \tag{6.5}$$

where x is the maximum capacity for the given system, expressed in ton/day.

NOTE 1   1 ton = 1 000 kg.

NOTE 2   1 day = 86 400 s.

It should be noted that if the capacity is given in cubic metres per day, the density of the produced freshwater, expressed in degrees Celsius shall be considered in the above establishment of $q_{m\,\text{design}}$.

As an alternative, the EER in general can be reflected in kWh/ton, by using Formula (6.6):

$$EER_{\text{alt}} = y \cdot \frac{1}{3,6} \tag{6.6}$$

where

EER_{alt} is the EER, expressed in kWh/ton;

y is the EER at design flow, expressed in kJ/kg.

NOTE 3   1 ton = 1 000 kg.

NOTE 4   1 kWh = 3 600 kJ.

6.3.4.3 Thermal efficiency

The thermal EER (EER_{th}) is calculated by measuring the heat consumed by the freshwater generator, $\dot{Q}_{\text{heat}}$, while it is producing freshwater at its design mass flow, $q_{m\,\text{design}}$, as defined by Formula (6.7):

$$EER_{\text{th}} = \frac{\dot{Q}_{\text{heat}}}{q_{\text{m design}}} \tag{6.7}$$

where

EER_{th} is the thermal EER at design flow, expressed in kJ/kg (as an alternative, EER_{th} can be expressed in kWh/ton, see Formula (6.6));

$\dot{Q}_{\text{heat}}$ is the heat consumed by the freshwater generator, expressed in kW.

The heat consumed is calculated as shown in Formula (6.8):

$$\dot{Q}_{\text{heat}} = q_{\text{m h}} \cdot c_{\text{p}} \cdot \Delta T_{\text{h}} \tag{6.8}$$

where

$q_{m\,\text{h}}$ is the mass flow of heat source, expressed in kg/s;

c_{p} is the heat capacity of the heat source at constant pressure, expressed in kJ/kg K;

ΔT_{h} is the temperature difference of the heat source between the inlet and the outlet.

The product of $q_{m\,\text{h}}$ and c_{p}, and the inlet and outlet temperatures above, shall be registered along with EER_{th}.

6.3.5 Measuring method

The parameter measurements required to calculate the EERs shall be performed while the freshwater generator is producing fresh water at the design mass flow rate, $q_{m\,\text{design}}$, as defined by Formula (6.5).

Additionally, the sea water temperature and the surrounding air should correspond to a common reference such as normal ambient operational conditions, so the ratios can be compared between freshwater generators. The sea water mass flow should be measured to ensure it is kept at the design value, and the temperature and the mass flow of the heat source should be typical and noted as part of the rating, as it affects the efficiency.

The following parameters shall be measured to establish the EERs:

— $\sum P_{\text{electrical}}$ is the power consumption, as defined in Formula (6.4), which is measured at each appropriate electrical consumer, preferably simultaneously, and summed up.

— $q_{m\,\text{h}}$ is the mass flow of the heat source, which is measured with a flow meter.

— $T_{\text{h,in}}$ is the temperature of the heat source at the inlet.

— $T_{\text{h,out}}$ is the temperature of the heat source at the outlet.

The following parameter shall be measured to ensure the standard reference is achieved:

— $T_{\text{sw,in}}$ is the seawater inlet temperature.

6.3.6 Example of measuring and calculations

This example applies to a freshwater generator designed for producing 29 500 kg (29,5 ton) of freshwater per day using hot water at 90 °C.

The design mass flow maintained throughout the testing is therefore in accordance with Formula (6.5):

$$q_{\text{m design}} = 29,5 \cdot \frac{1}{86,4} = 0,341 \text{ kg/s}$$

Under normal operational conditions, both the electrical consumptions have been registered:

$$\sum P_{\text{el}} = P_{\text{feedwater}} + P_{\text{cooling,ejecting}} = 5,62 + 0,87 = 6,49 \text{ kW}$$

In accordance with Formula (6.3):

$$EER_{\text{el}} = \frac{\sum P_{\text{el}}}{q_{\text{m design}}} = \frac{6,49}{0,341} = 19 \text{ kJ/kg}$$

In accordance with Formula (6.6), an alternative $EER_{\text{el,alt}}$ can be established:

$$EER_{\text{el,alt}} = 19 \cdot \frac{1}{3,6} = 5,28 \text{ kWh/ton}$$

NOTE 1   1 ton = 1 000 kg.

NOTE 2   1 kWH = 3 600 kJ.

$q_{m\,\text{h}}$ has been measured and averaged in the testing period at stable $q_{m\,\text{design}}$ to be 18 kg/s.

Inlet temperature is 90 °C and outlet temperature is 78,4 °C, giving a difference between inlet and outlet of $\Delta T_{\text{h}} = 11,6$ K.

Using Formula (6.8):

$$\dot{Q}_{\text{h}} = 18 \cdot \bar{c}_p \cdot 11,6 = 810 \text{ kW}$$

Using $\bar{c}_{\text{p}}$ = 3,88 kJ/kg·K, for freshwater at 80 °C.

In accordance with Formula (6.7):

$$EER_{th} = \frac{810}{0,341} = 2\,370 \text{ kJ} / \text{kg}$$

In accordance with Formula (6.6), an alternative $EER_{th,alt}$ can be established:

$$EER_{th,alt} = 810 \cdot \frac{1}{3,6} = 225 \text{ kWh} / \text{ton}$$

NOTE 3   1 ton = 1 000 kg.

NOTE 4   1 kWh = 3 600 kJ.

6.4   Seawater cooling system

6.4.1   General

The seawater cooling system consists of a cooling circuit where seawater is pumped continuously from the sea chest through a freshwater heat exchanger before it is discharged back to the sea.

The freshwater heat exchanger is the common component for both the seawater cooling system (see 6.4.2 to 6.4.6) and the freshwater cooling system (see 6.5).

6.4.2   Definition of input and output

The input and output of a seawater cooling system consists of the following:

— Input: Cold seawater and hot freshwater and electricity.

— Output: Hot seawater and cold freshwater.

6.4.3   Definitions of boundaries and media

The sea water cooling system and its boundaries are defined in Figure 6.4. This document describes the method for this 1:1 system (one pump:one cooler). In cases where any additional component is connected to the seawater pump, this component shall be deducted in the efficiency calculation.
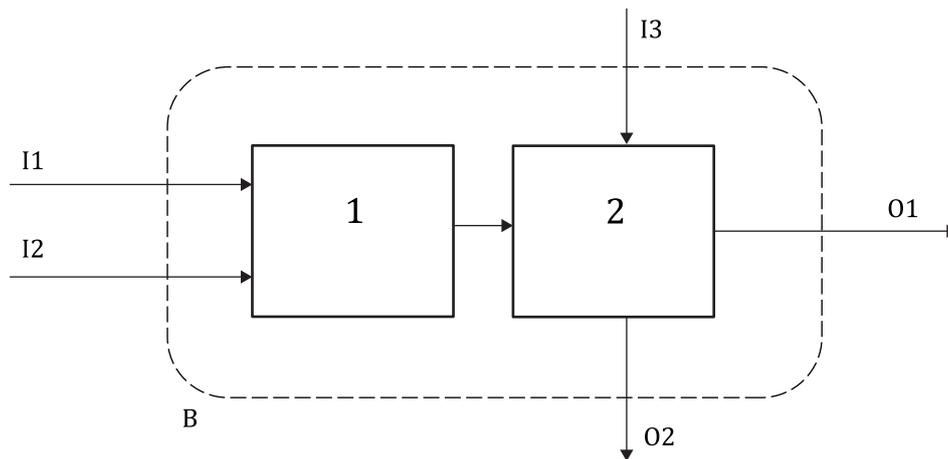
Key

B	boundary	1	seawater pump
I1	electricity	2	freshwater heat exchanger
I2	cold seawater		
I3	hot freshwater		
O1	hot seawater		
O2	cold freshwater		

Figure 6.4 — Definitions of boundaries for the seawater cooling system

6.4.4 Calculation method

The energy efficiency of the seawater cooling system is calculated as a ratio, EER_s, as shown in Formula (6.9):

$$EER_s = \frac{\dot{Q}_{s,out}}{P_{s,Actual}} \tag{6.9}$$

where

$\dot{Q}_{s,out}$ is the change in thermal energy after the cooling seawater passes through the heat exchanger, see Formula (6.10);

$P_{s,Actual}$ is the actual electrical power needed for pumping cooling seawater.

$$\dot{Q}_{s,out} = c_{p,s} \cdot q_{m\,s} \cdot \Delta T_s = c_{p,s} \cdot q_{m\,s} \cdot \left(T_{s,out} - T_{s,in} \right) \tag{6.10}$$

where

$c_{p,s}$ is the specific heat capacity (at constant pressure) of the cooling seawater, 20 °C and salinity 35 ‰, expressed in kJ/kg K;

$q_{m\,s}$ is the mass flow rate of the cooling seawater, expressed in kg/s;

$T_{s,out}$ is the temperature when the cooling seawater leaves the freshwater heat exchanger, expressed in °C;

$T_{s,in}$ is the temperature when the cooling seawater enters the freshwater heat exchanger, expressed in °C.

$q_{m\,s}$, $T_{s,out}$ and $T_{s,in}$ can be obtained by installing a flow sensor and a temperature sensor in the system.

An alternative method to evaluate the energy performance of the system is to compare the actual power required by the seawater pump with the rated power for the seawater pump using a power ratio, η_{PR}, defined in Formula (6.11). The advantage of this method is that it requires fewer instruments to measure and is easy to calculate.

$$\eta_{PR} = \frac{P_{s,Actual}}{P_{s,Rated}}$$ (6.11)

where

$P_{s,Actual}$ is the actual electrical power needed for pumping cooling seawater;

$P_{s,Rated}$ is the rated power required for the seawater pump taken from the ship's "Electrical power table for EEDI" based on MEPC.364(79).[12]

The restriction of this method is that it is specific for the actual ship and can only be used to verify or evaluate the improvements of the ship itself.

6.4.5 Measuring method

The necessary measurements for this method are as follows:

— $q_{m\,s}$ is the mass flow rate of the cooling seawater, expressed in kg/s. This requires a flow meter in the seawater pipe. A temporary clamp-on flow meter may also be used.

— $T_{s,out}$ is the temperature when the cooling seawater leaves the heat exchange, expressed in °C. It is measured close to the heat exchanger outlet flange.

— $T_{s,in}$ is the temperature when the cooling seawater enters the cooler, expressed in °C. It is measured close to the heat exchanger inlet flange.

— $P_{s,Actual}$ is the actual power of the seawater pump by using a power meter mounted in the switchboard or a hand-held clamp meter for that specific power line, expressed in kW.

For the alternative method, the only measurement required is $P_{sActual}$.

6.4.6 Example of measuring and calculation

Measure and calculate $\dot{Q}_{s,out}$ by using Formula (6.10).

The specific heat capacity for seawater is found from conventional engineering tables: $c_{p,s}$ = 4,007 kJ/kgK.

The mass flow rate of seawater is measured: $q_{m\,s}$ = 103 kg/s (equal to 360 m³/h with a density of 1 030 kg/m³).

The seawater outlet temperature is measured: $T_{s,out}$ = 25 °C.

The seawater inlet temperature is measured: $T_{s,in}$ = 15 °C.

$$\dot{Q}_{s,out} = 4,007 \text{ kJ/kgK} \cdot 103 \text{ kg/s} \cdot (25 \text{ °C} - 15 \text{ °C}) = 4\,127 \text{ kW}$$

$P_{s,Actual}$ is retrieved by reading the power from the seawater cooling pump by using a power meter: $P_{s,Actual}$ = 35 kW.

The EER of the seawater cooling system can be calculated by using [Formula (6.9)](#):

$$EER_s = \frac{4\,127 \text{ kW}}{35 \text{ kW}} = 117,9$$

For the alternative method, $P_{s,Actual}$ is measured as 35 kW and $P_{s,Rated}$ is found from the "Electrical power table for EEDI" based on MEPC.364(79)[12] at 38 kW:

$$\eta_{PR} = \frac{P_{s,Actual}}{P_{s,Rated}} = \frac{35 \text{ kW}}{38 \text{ kW}} = 0,92$$

6.5   Freshwater cooling system

6.5.1   General

The freshwater cooling system is a cooling circuit where freshwater is continuously pumped in a closed loop to cool engine room machinery, fan coils, etc. When the freshwater is returning from the machinery, it is cooled down again by the freshwater heat exchangers.

The machinery refers to a set of different machines and equipment that require cooling.

The freshwater heat exchanger is the common component for both the freshwater cooling system, which is described in [6.5.2](#) to [6.5.6](#), and the seawater cooling system described in [6.4](#).

### 6.5.2   Definition of input and output

The input and output of a freshwater cooling system consists of the following:

—   Input: Seawater and electricity.

—   Output: Hot seawater.

6.5.3   Definitions of boundaries and media

The freshwater cooling system and its boundaries are defined in [Figure 6.5](#).
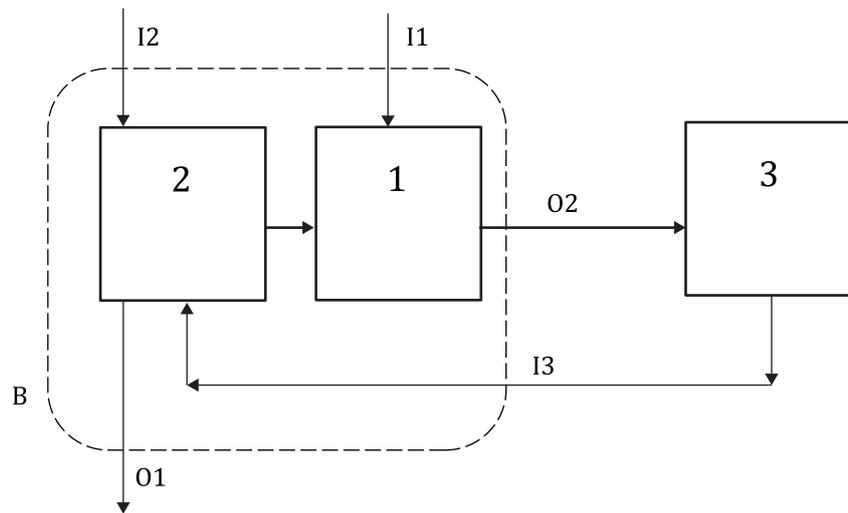
Key

B	boundary	1	seawater pump
I1	electricity	2	freshwater heat exchanger
I2	cold seawater	3	engine room machinery, fan coils, etc. (to be cooled)
I3	hot freshwater		
O1	hot seawater		
O2	cold freshwater		

Figure 6.5 — Definitions of boundaries for the freshwater cooling system

6.5.4 Calculation method

The energy efficiency of the freshwater cooling system is calculated as a ratio, EER_f, as shown in Formula (6.12):

$$EER_f = \frac{\dot{Q}_{f,out}}{P_{f,Actual}} \tag{6.12}$$

where

$\dot{Q}_{f,out}$ is the change in thermal energy after the cooling freshwater passes through the engine room machinery, see Formula (6.13);

$P_{f,Actual}$ is the actual electrical power needed for pumping cooling freshwater.

$$\dot{Q}_{f,out} = c_{p,f} \cdot q_{m\,f} \cdot \Delta T_f = c_{p,f} \cdot q_{m\,f} \cdot \left(T_{f,out} - T_{f,in} \right) \tag{6.13}$$

where

$c_{p,f}$ is the specific heat capacity (at constant pressure) of the cooling freshwater, 20 °C, expressed in kJ/kg K;

$q_{m\,f}$ is the mass flow rate of the cooling freshwater, expressed in kg/s;

$T_{f,out}$ is the temperature when the cooling freshwater leaves the engine room machinery, expressed in °C;

$T_{s,in}$ is the temperature when the cooling freshwater enters the engine room machinery, expressed in °C.

$q_{m\,f}$, $T_{f,out}$ and $T_{f,in}$ can be obtained by installing a flow sensor and a temperature sensor in the system.

An alternative method to evaluate the energy performance of the system is to compare the actual power required by the fresh water pump with the rated power for the fresh water pump using a power ratio, η_{PR}, defined in Formula (6.14). The advantage of this method is that it requires fewer instruments to measure and is easy to calculate.

$$\eta_{PR\,f} = \frac{P_{f,Actual}}{P_{f,Rated}} \tag{6.14}$$

where

$P_{f,Actual}$ is the actual electrical power needed for pumping cooling freshwater;

$P_{f,Rated}$ is the rated power required for the freshwater cooling pump taken from the ship's "Electrical power table for EEDI" based on MEPC.364(79).[12]

The restriction of this method is that it is specific for the actual ship and can only be used to verify or evaluate the improvements of the ship itself.

6.5.5 Measuring method

The necessary measurements for this method are as follows:

— $q_{m\,f}$ is the mass flow rate of the cooling freshwater, expressed in kg/s. This requires a flow meter in the freshwater pipe. A temporary clamp-on flow meter may also be used.

— $T_{f,out}$ is the temperature when the cooling freshwater leaves the engine room machinery, expressed in °C. It is measured on the common pipe manifold upstream the freshwater pump.

— $T_{f,in}$ is the temperature when the cooling freshwater enters the engine room machinery, expressed in °C. It is measured on the common pipe manifold downstream the freshwater pump.

— $P_{f,Actual}$ is the actual power of the freshwater pump by using a power meter mounted in the switchboard or a hand-held clamp meter for that specific power line, expressed in kW.

For the alternative method, the only measurement required is $P_{fActual}$.

6.5.6 Example of measuring and calculation

Measure and calculate $\dot{Q}_{f,out}$ by using Formula (6.13).

The specific heat capacity for freshwater is found from a recognized engineering table: $c_{p,f}$ = 4,184 kJ/kgK.

The mass flow rate of freshwater is measured: $q_{m\,f}$ = 250 kg/s (equal to 900 m^3/h with a density of 1 000 kg/m^3).

The freshwater outlet temperature is measured: $T_{f,out}$ = 41 °C.

The freshwater inlet temperature is measured: $T_{f,in}$ = 36 °C.

$Q_{f,out}$ = 4,184 kJ/kgK · 250 kg/s · (41 °C – 36 °C) = 5 230 kW

$P_{f,Actual}$ is retrieved by reading the power from the freshwater cooling pump by using a power meter: $P_{f,Actual}$ = 78 kW.

The EER of the freshwater cooling system can be calculated by using Formula (6.12):

$$EER_f = \frac{5\,230\,\text{kW}}{78\,\text{kW}} = 67,05$$

For the alternative method, $P_{f,\text{Actual}}$ is measured as 78 kW and $P_{f,\text{Rated}}$ is found from the "Electrical power table for EEDI" based on MEPC.364(79)[12] at 90 kW:

$$\eta_{\text{PR}\,f} = \frac{P_{f,\text{Actual}}}{P_{f,\text{Rated}}} = \frac{78\,\text{kW}}{90\,\text{kW}} = 0,867$$

6.6 Engine lube oil system

6.6.1 General

The design of the main engine lube oil system is different in two-stroke and four-stroke marine engines:

— in a two-stroke engine, the main engine lube oil system consists of two individual systems: a cylinder lube oil system and a crankcase lubrication system;

— in a four-stroke engine, the main lube oil system is a common lubrication system for both cylinder lubrication and crankcase lubrication.

This document focuses on the crankcase lubrication.

The main lube oil system consists of six main elements: sump/drain tank, strainer, lube oil pump, filter, lube oil cooler and distribution manifold. In some engines, there is added a crosshead lube oil pump to boost the pressure for crosshead lubrication.

In a typical design, the main lube oil pump takes suction from the drain sump through a strainer and pumps the lube oil to the cooler and a lube oil filter. From the lube oil filter, the lube oil is distributed in the engine.

Engine driven lube oil pumps are excluded from this document, as it is practically impossible to measure the pump power. Many four-stroke engines have a main lube oil pump that is engine driven.

6.6.2 Definition of input and output

The input and output of an engine lube oil system consists of the following:

— Input: Cold freshwater and electricity.

— Output: Hot freshwater and heat loss.

6.6.3 Definitions of boundaries and media

The boundary of the main engine lube oil system encloses the six main elements: the sump/drain tank, strainer, lubricating pumps, filter, lube oil cooler and distribution manifold (see Figure 6.6). The cylinder lube oil system is excluded.
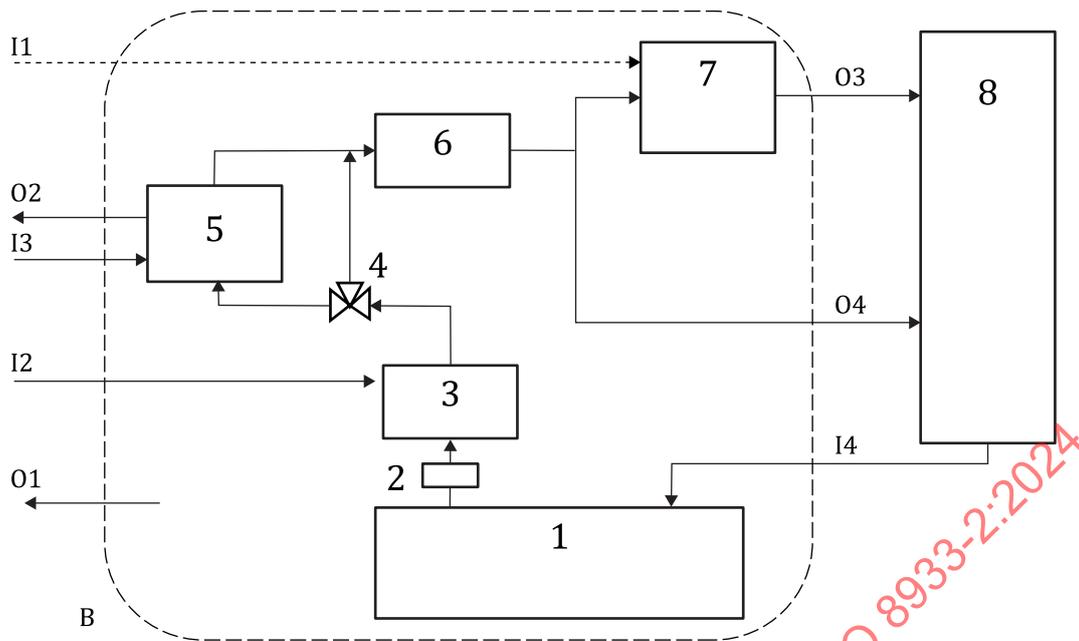
Key

B	boundary	1	lube oil tank
I1	electricity	2	strainer
I2	electricity	3	main lube oil pump
I3	cold seawater	4	shunt valve
I4	lube oil return	5	main engine lube oil cooler
O1	heat loss	6	lube oil filter
O2	hot freshwater	7	crosshead lube oil pump
O3	crosshead lube oil injection	8	main engine
O4	crankcase lube oil injection		

Figure 6.6 — Boundaries of the main engine lube oil system

6.6.4 Calculation method

The energy efficiency of the main engine lube oil system is calculated as a ratio, EER_{LO}, as shown in Formula (6.15):

$$EER_{LO} = \frac{\dot{Q}_{LO,out}}{P_{LO,Actual}} \tag{6.15}$$

where $\dot{Q}_{LO,out}$ is the change in thermal energy when the cooling freshwater passes through the main engine lube oil cooler, plus the heat lost in the machinery.

However, since this document considers the efficiency of the system, the heat loss shall be disregarded, and the expression can be written as shown in Formula (6.16):

$$\dot{Q}_{LO,out} = \dot{Q}_{LO,cooler,out} \tag{6.16}$$

where

$$\dot{Q}_{LO,cooler,out} = c_{p,f} \cdot q_{mf} \cdot \Delta t_f = c_{p,f} \cdot q_{mf} \cdot \left(T_{f,out} - T_{f,in}\right)$$

where

$c_{p,f}$ is the specific heat capacity (at constant pressure) of the cooling freshwater, 20 °C, expressed in kJ/kgK;

$q_{m\,f}$ is the mass flow rate of the cooling freshwater, expressed in kg/s;

$T_{f,out}$ is the temperature when the cooling freshwater leaves the main engine lube oil cooler, expressed in °C;

$T_{f,in}$ is the temperature when the cooling freshwater enters the main engine lube oil cooler, expressed in °C.

$q_{m\,f}$, $T_{f,out}$ and $T_{f,in}$ can be obtained by installing a flow sensor and a temperature sensor in the system.

$P_{LO,Actual}$ is the actual electrical power required for pumping the lube oil. As some engines can have two pumps (the main lube oil pump and the crosshead lube oil pump), the actual electrical power needed can be written as shown in Formula (6.17):

$$P_{LO,Actual} = P_{LO,main,Actual} + P_{.LO,crosshead,Actual} \tag{6.17}$$

where

$P_{Main.LO,Actual}$ is the actual electrical power needed for the main lube oil pump, expressed in kW;

$P_{Crosshead.LO,Actual}$ is the actual electrical power needed for the crosshead lube oil pump, expressed in kW.

An alternative method to evaluate the energy performance of the system is to compare the actual power required by the lube oil pumps with the rated power for the lube oil pumps using a power ratio, η_{PR}, defined in Formula (6.18). The advantage of this method is that it requires fewer instruments to measure and is easy to calculate.

$$\eta_{PR\,LO} = \frac{P_{LO,Actual}}{P_{LO,Rated}} \tag{6.18}$$

where

$P_{LO,Actual}$ is the actual electrical power required for pumping lube oil and is described in Formula (6.17);

$P_{LO,Rated}$ is the rated power required for the lube oil pumps taken from the ship's "Electrical power table for EEDI" based on MEPC.364(79).[12]

The restriction of this method is that it is specific for the actual ship and can only be used to verify or evaluate the improvements of the ship itself.

6.6.5 Measuring method

The necessary measurements for this method are:

— $q_{m\,f}$ is the mass flow rate of the cooling freshwater, expressed in kg/s. This requires a flow meter in the freshwater pipe.

— $T_{f,out}$ is the temperature when the cooling freshwater leaves the main engine lube oil cooler, measured on the freshwater pipe, expressed in °C.

— $T_{f,in}$ is the temperature when the cooling freshwater enters the main engine lube oil cooler, measured on the freshwater pipe, expressed in °C.

— $P_{LO,Actual}$ is the actual power of the main lube oil pump and eventually the crosshead lube oil pump by using a power meter mounted in the switchboard or a hand-held clamp meter for that specific power line, expressed in kW.

For the alternative method, the only measurement required is $P_{LO,Actual}$.

6.6.6 Example of measuring and calculation

Measure and calculate $\dot{Q}_{LO,out}$ by using Formula (6.16).

The specific heat capacity for freshwater is found from a recognized engineering table: $c_{p,f}$ = 4,184 kJ/kgK.

The mass flow rate of cooling freshwater is measured: $q_{m\,f}$ = 20,8 kg/s (equal to 75 m^3/h with a density of 1 000 kg/m^3).

The freshwater outlet temperature is measured: $T_{f,out}$ = 46 °C.

The freshwater inlet temperature is measured: $T_{f,in}$ = 36 °C.

$$\dot{Q}_{LO,cooler,out} = 4{,}184 \text{ kJ/kgK} \cdot 20{,}8 \text{ kg/s} \cdot (46\,°C - 36\,°C) = 870{,}3 \text{ kW}$$

Then use Formula (6.16) and calculate: $\dot{Q}_{LO,out}$ = 870,3 kW.

$P_{LO,Actual}$ is retrieved by reading the power from the main lube oil pump and crosshead lube oil pump by using a power meter:

— $P_{Main.LO,Actual}$ = 52 kW

— $P_{Crosshead.LO,Actual}$ = 5 kW

Then use Formula (6.17) and calculate:

$$P_{L.O,Actual} = 52 \text{ kW} + 5 \text{ kW} = 57 \text{ kW}$$

The EER of the main engine lube oil system can be calculated by using Formula (6.14):

$$EER_{LO} = \frac{870{,}3\,\text{kW}}{57\,\text{kW}} = 15{,}27$$

For the alternative method, $P_{LO,Actual}$ is measured as 57 kW and $P_{LO,Rated}$ is found from the "Electrical power table for EEDI" based on MEPC.364(79)[12] at 61 kW:

$$\eta_{PR\,LO} = \frac{P_{LO,Actual}}{P_{LO,Rated}} = \frac{57\,\text{kW}}{61\,\text{kW}} = 0{,}934$$

6.7 Steam boiler system, thermal fluid system and hot water system

6.7.1 General

This subclause covers systems that produce steam, hot thermal oil or hot water. Such systems are mostly designed according to a yard and/or shipowner specification and hence deviate widely in size and configuration. Since the scope of the subclause is wide, it should remain as generic as possible.

6.7.2 Definition of input and output

The input and output of a steam boiler system, thermal fluid system and hot water system consists of the following:

— Input: Heat source (fuel and air, and/or exhaust gas and/or other appropriate heat source), electricity and feed medium.

— Output: Medium output, heat loss, exhaust gas and/or flue gas.

6.7.3 Definitions of boundaries and media

The complexity of the systems varies. The main component in a system is the boiler or heater (non-boiling). The typical components required to support the system are:

— feed pump;

— fuel pump;

— forced draft fan;

— burner.

An exhaust gas boiler does not have a fuel system; hence, fuel pumps, forced draft fans and burners are not necessary. For a boiler with pre-heater, an additional circulation pump besides the pre-heater is required.

Due to the possible number of system variations, this document does not describe in detail what components, functionalities or subsystems to include within the boundaries. However, it is assumed that an actual system to be considered is a full standalone functional system. Hence, a system can be described very generically as reflected in Figure 6.7.

Key
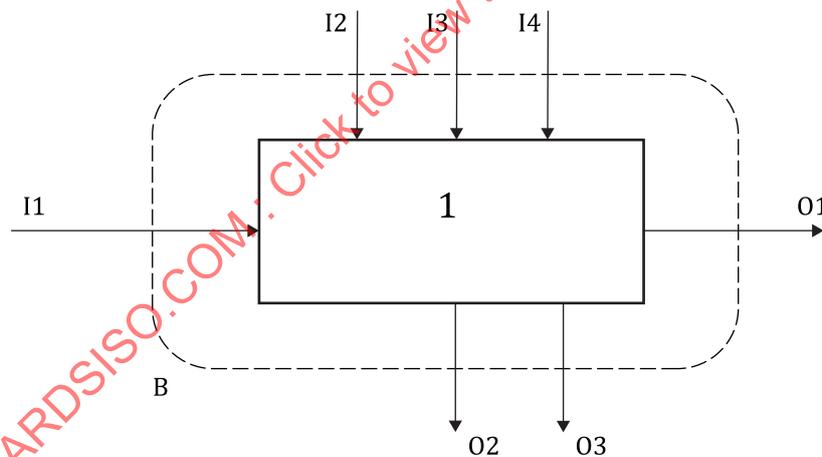
B   boundary

I1   feed media – inlet

I2   fuel, if applicable

I3   exhaust gas, if applicable (or other heat source), inlet

I4   electricity

O1   feed media outlet (steam, thermal-oil, hot water)

O2   flue gas and/or exhaust gas, outlet

O3   heat loss cooling water and outlet thermal heat source)

1   steam boiler system

Figure 6.7 — Steam boiler system, thermal fluid system or hot water system and its boundaries

6.7.4 Calculation method

6.7.4.1 General

The energy efficiency of the steam boiler system/thermal fluid system/hot water system is defined as the flow of heat leaving the system per net flow of heat and power entering the system, as shown in Formula (6.19):

$$\eta = \left(\frac{\dot{Q}_{\text{output}}}{\dot{Q}_{\text{net input}}} \right) \tag{6.19}$$

where

$\dot{Q}_{\text{net input}}$ is the net energy entering the system as defined by Formula (6.20), expressed in kW;

$\dot{Q}_{\text{output}}$ is the heat output as defined by Formula (6.24), expressed in kW.

6.7.4.2 Energy input

The net energy entering the system is found from Formula (6.20):

$$\dot{Q}_{\text{net input}} = \dot{Q}_{\text{fuel}} + \dot{Q}_{\text{ex}} + P \tag{6.20}$$

where

$\dot{Q}_{\text{fuel}}$ is, if applicable, the energy input of the combusted fuel or fuels, as defined by Formula (6.21), expressed in kW;

$\dot{Q}_{\text{ex}}$ is, if applicable, the sum of additional net heat input from other sources, as defined by Formula (6.22), expressed in kW;

P is, as applicable, the sum of power needed to operate electrical power consumers, as defined by Formula (6.23), expressed in kW.

$$\dot{Q}_{\text{fuel}} = \Sigma (q_{\text{m fuel}} \cdot H_{\text{n}})_i \tag{6.21}$$

where

i is the specific fuel type used in case of mixtures; i can be ignored when only one type of fuel is combusted;

$q_{m\ \text{fuel}}$ is fuel mass flow of the specific fuel type, expressed in kg/s;

H_{n} is the net or lower calorific value of the specific fuel type, expressed in kJ/kg.

As the normal ambient operational test conditions are used, $\dot{Q}_{\text{fuel}}$ is not corrected for losses heating up combustion air.

Sources of heat contributing to the system (e.g. exhaust gas from an engine, heat from jacket water) are expressed shown in Formula (6.22):

$$\dot{Q}_{\text{ex}} = \Sigma [q_{\text{m}} \cdot (h_{\text{in}} - h_{\text{out}})]_i \tag{6.22}$$

where

    i   denotes, in case an additional heat source(s) is utilized, the specific source;

    q_m is the mass flow of the heat source, expressed in kg/s;

    h_{in} is the specific enthalpy of the heat source, expressed in kJ/kg;

    h_{out} is the specific enthalpy of the heat source out, expressed in kJ/kg.

Since the description considers a complete system, various electricity consumers should be accounted for (e.g. thermal-oil pumps, feedwater pumps, circulation pumps, forced draft fans, fuel pumps). Electricity required for the control system including valves, frequency drivers, etc. should not be taken into account, as these aspects only have impact from a lifetime perspective and are very operation dependent. See Formula (6.23):

$$P = \sum P_i \tag{6.23}$$

where

    i   denotes the ith electrical consumer;

    P   is the power needed by the electrical consumer at system design condition, expressed in kW.

6.7.4.3 Energy output

In this document, the net flow of heat output is not considered, since the net value depends on the utility for which the hot media is intended on board. Hence, the total flow of heat is considered as a reference point for the energy efficiency calculation. This makes it possible to compare systems independent of the utility on board. It should be noted that this does not mean that the size, pressure level or media used, etc. can be disregarded in a comparison.

The total flow of output can be expressed as shown in Formula (6.24):

$$\dot{Q}_{\text{output}} = \sum \left(q_{m\,\text{output}} \cdot h \right)_i \tag{6.24}$$

where

    i   denotes the ith source of flow of heat output;

    $q_{m\,\text{output}}$ is the mass flow of the output, expressed in kg/s;

    h   is the specific enthalpy at output temperature and pressure, expressed in kJ/kg.

Since it can be challenging to monitor steam mass flows and exhaust gas mass flows, the so-called "indirect method" can be used, which considers the heat losses of the system. In order to establish the parameters required for the indirect method, gas analysing sensors are necessary to establish the level of CO_2, CO, O_2 and moisture content. If it is necessary to deploy an indirect method, reference should be made to EN 12952-15. In EN 12952-15, it is viable to assume that the mass flow of the feedwater going into the system is equal to the steam mass flow leaving the system, unless, of course, there are interjections of this main flow. If such interjections can be accounted for, it is still considered a valid equivalent method.

6.7.5 Measuring method

All parameters will be measured at the functional system boundaries.

The load of the system while testing shall be at the system-defined nominal/design load.

Testing and monitoring shall have a duration of not less than 2 h while ensuring stable fuel flow, and/or exhaust gas flow, and feed media flow. The gathered data are averaged over the testing period.

The normal operational ambient conditions are used, except for the temperature of air and fuel, which should be 25 °C. If this is not achievable, the measurements made shall be corrected for temperature, relative moisture content and ambient air pressure.

$q_{m\,\text{fuel}}$, q_m and $q_{m\,\text{output}}$ are measured by flowmeters every 3 min; however, if the output flow is steam, the feedwater flow to the system can be used as an equivalent parameter.

The H_n of the fuels used should be provided by certified documentation.

The temperature measurements of the output media, and if applicable, input and output temperatures of the heating source(s), are monitored by thermometers every 10 min.

The pressure of the output media and the external heat source(s) media, as applicable, are monitored by pressure gauges or transducers every 10 min.

The power required by the various electrical consumers (which are included or excluded as described in 6.7.3) should be monitored by power meters every 3 min.

6.7.6 Example of measuring and calculation

A calculation example is provided considering a steam boiler system.

The calculations are based on a boiler size of 5 500 kg (5,5 tons) steam per hour at 0,8 MPa (8 bar).

Measurements and engineering table values related to fuel:

— $q_{m\,\text{fuel}}$ = 0,111 7 kg/s

— H_n = 42 200 kJ/kg

Measurements and engineering table values related to the saturated steam output:

— $q_{m\,\text{output}}$ = 1,527 8 kg/s

— output pressure = 0,8 MPa

— T_{out} = 444 K (170 °C)

— h = 2 769 kJ/kg

Measurements of the power consumers:

$$P = P_{\text{fuel}} + P_{\text{fan}} + P_{\text{feedwater}} = 50 \text{ kW}$$

The energy input of the combusted fuel, following Formula (6.21), is:

$$\dot{Q}_{\text{fuel}} = 0,111\,7\,\frac{\text{kg}}{\text{s}} \cdot 42\,200\,\frac{\text{kJ}}{\text{kg}} = 4\,714\,\text{kW}$$

Hence, the net energy input can be calculated, following Formula (6.20), as:

$$\dot{Q}_{\text{net input}} = \dot{Q}_{\text{fuel}} + P = 4\,714\,\text{kW} + 50\,\text{kW} = 4\,764\,\text{kW}$$

Energy output can be calculated, following Formula (6.24), as:

$$\dot{Q}_{\text{output}} = q_{m\,\text{output}} \cdot h = 1,527\,\frac{\text{kg}}{\text{s}} \cdot 2\,769\,\frac{\text{kJ}}{\text{kg}} = 4\,228\,\text{kW}$$

Energy efficiency for the steam boiler system is therefore in accordance with Formula (6.19):

$$\eta = \left(\frac{\dot{Q}_{\text{output}}}{\dot{Q}_{\text{net input}}} \right) = \frac{4\,228\,\text{kW}}{4\,764\,\text{kW}} = 0{,}89$$

6.8 Cargo pump system

6.8.1 General

The cargo pump system consists of a set of pumps to empty the cargo tanks on board the ship.

The aim of the system is to empty the tank as much as possible at a certain flow rate. This flow rate varies from port to port, and therefore the number of pumps in use also depends on the port where the cargo is being discharged.

Cargo pump systems vary in design and fitted equipment, depending on the ship type and the manufacturer of the cargo pump system.

The energy sources, energy control and equipment set-up can have various configurations. Therefore, the description is generalized, but the calculation is made specific for the actual configuration.

The energy sources can be electrical, fuel or steam.

The energy control can be direct electrical, direct steam, by hydraulic power unit (HPU) or by steam turbine.

6.8.2 Definition of input and output

The input and output of cargo pump systems consists of the following:

— Input: Electricity and steam. If there is an HPU, it may be fuel (diesel engine on an HPU).

— Output: One batch of cargo and one batch of slop.

6.8.3 Definitions of boundaries and media

The boundary of the cargo pump system encompasses the cargo pumps, cargo stripping pumps and the HPU, as applicable, plus tank cleaning and slop handling.

The boundaries of the system are defined four operational steps during one cargo-tank-emptying sequence. The tank-emptying sequence begins when starting the cargo pumps and lasts until the tanks are cleaned and ready to be filled again. One batch of cargo is defined as the total volume of cargo and stripping. One batch of slop is defined as the total volume from tank cleaning and slop handling.

The boundaries are shown in Figure 6.8.
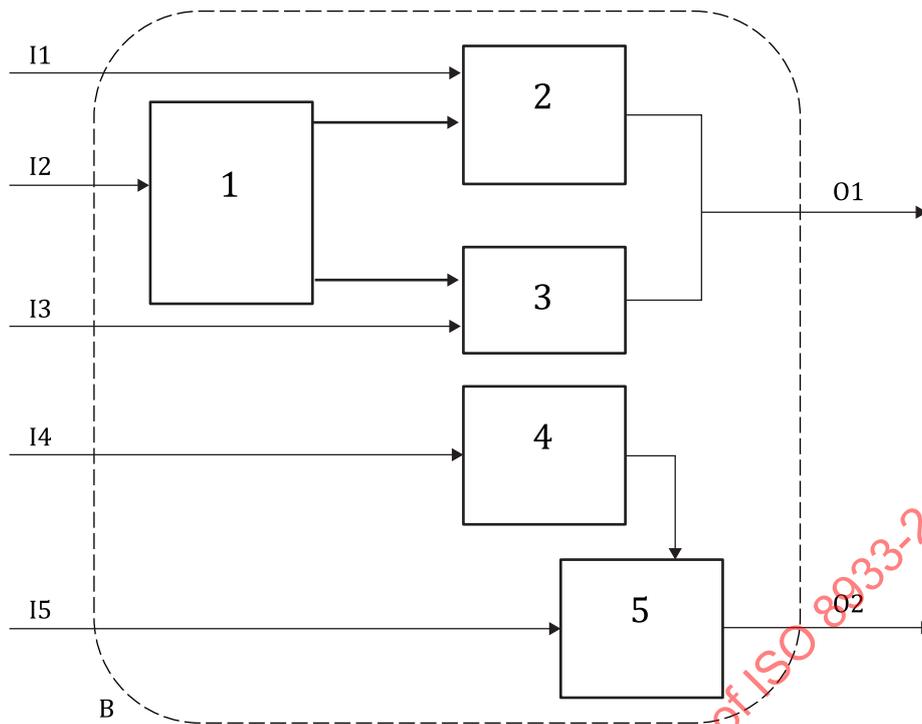
Key

B	boundary	1	steam boiler system
I1	electricity or I2	2	hydraulic power unit or steam turbine
I2	electricity, fuel or steam	3	step 1, cargo pumping
I3	electricity or I2	4	step 2, stripping
I4	steam	5	step 3, tank cleaning
I5	electricity	6	step 4, slop handling
O1	one batch of cargo		
O2	one batch of slop		

Figure 6.8 — Cargo pump system and its boundaries

6.8.4 Calculation method

The energy efficiency of the cargo pump system is calculated as an energy consumption index (ECI), ECI_{CPS}, as shown in Formula (6.25). The ECI evaluates the amount of energy which is consumed during one cargo tank emptying sequence per cubic meter cargo.

$$ECI_{CPS} = \frac{E_{Cargo}/SG_{Cargo} + E_{Stripping}/SG_{Cargo} + E_{Clean} + E_{Slop}}{V_{Cargo}} \tag{6.25}$$

where

E_{Cargo} is the energy used to discharge one batch of cargo, expressed in kJ;

$E_{\text{Stripping}}$ is the energy used during the stripping of one batch of cargo, expressed in kJ;

E_{Clean} is the energy used for cleaning during one batch of slop, expressed in kJ;

E_{slop} is the energy used by the slop handling during one batch of slop, expressed in kJ;

V_{Cargo} is the volume of one batch of cargo, expressed in m^3;

SG_{Cargo} is the specific gravity, a dimensionless property for the cargo fluid.

6.8.5   Measuring method

The necessary measurements for this method are as follows:

— For direct electrical control or electrical-driven HPU, the energy used can be monitored by an energy meter.

— For fuel-driven HPU, the energy used can be obtained by gauging the fuel consumed (kg/batch) multiplied by the lower calorific value (kJ/kg) of the fuel used.

— Likewise, the energy consumed by steam can be obtained by gauging the fuel consumed (kg/batch) by the steam-producing unit and then multiplying it by the lower calorific value (kJ/kg) of the fuel used.

— The cargo volume can be obtained by a flow meter with a feature to gauge the total volume in the cargo pipe.

6.8.6   Example of measuring and calculation

A ship loads a total 50 000 m^3 of cargo with a specific gravity of 0,85.

Two cargo pumps run for 12 h, each with an electrical power of 935 kW.

One stripping pump runs thereafter with fuel-driven HPU, using 170 kg of fuel.

The cleaning is made by steaming for 2 h. The steam production consumes 50 kg of fuel and an electrical-driven pump runs with a power of 100 kW.

The slop handling is made in 1 h, with an electrical power of 500 kW.

The energy for cargo pump is calculated as follows:

$$E_{\text{Cargo}} = \frac{2 \cdot 935\,\text{kW} \cdot 12\,\text{h}}{0,85} = 26\,400\,\text{kWh}$$

$$E_{\text{Stripping}} = \frac{170\,\text{kg\_fuel}}{0,2\,\text{kg\_fuel} / \text{kWh} \cdot 0,85} = 1\,000\,\text{kWh}$$

$$E_{\text{Clean}} = \frac{50\,\text{kg\_fuel}}{0,2\,\text{kg\_fuel} / \text{kWh}} + 100\,\text{kW} \cdot 2\,\text{h} = 250\,\text{kWh} + 200\,\text{kWh} = 450\,\text{kWh}$$

$$E_{\text{Slop}} = 500\,\text{kW} \cdot 1\,\text{h} = 500\,\text{kWh}$$

NOTE 1   1 kWh = 3 600 kJ.

This is put into Formula (6.25) to find the ECI:

$$ECI_{\text{CPS}} = \frac{26,400\,\text{kWh} + 1\,000\,\text{kWh} + 450\,\text{kWh} + 500\,\text{kWh}}{50,000\,\text{m}^3} = 0,567\,\frac{\text{kWh}}{\text{m}^3}$$

NOTE 2   1 kWh = 3 600 kJ.

6.9   Cargo heating system

6.9.1   General

Highly viscous petroleum cargo, or cargo with a high pour point or wax content, requires heating during transit because heating reduces the viscosity of the cargo and enables it to flow better. Heating also leads to a constant circulation of cargo within the tank.

The system consists of heating devices for the cargo tanks which are either submerged heating coils or top-mounted heaters. The heat is taken from the steam system, using steam, hot water or thermal oil as the heating exchange medium.

The numbers of activated heating devices can vary in the different situations based on the driving parameter(s).

The control of the cargo fluid temperature is made by adjusting the input of the heating medium by means of control valves and/or other control devices.

6.9.2   Definition of input and output

The input and output of a cargo heat system consists of the following:

— Input: Hot heating medium.

— Output: Cold heating medium.

6.9.3   Definitions of boundaries and media

The cargo heating system and its boundaries are defined in Figure 6.9.
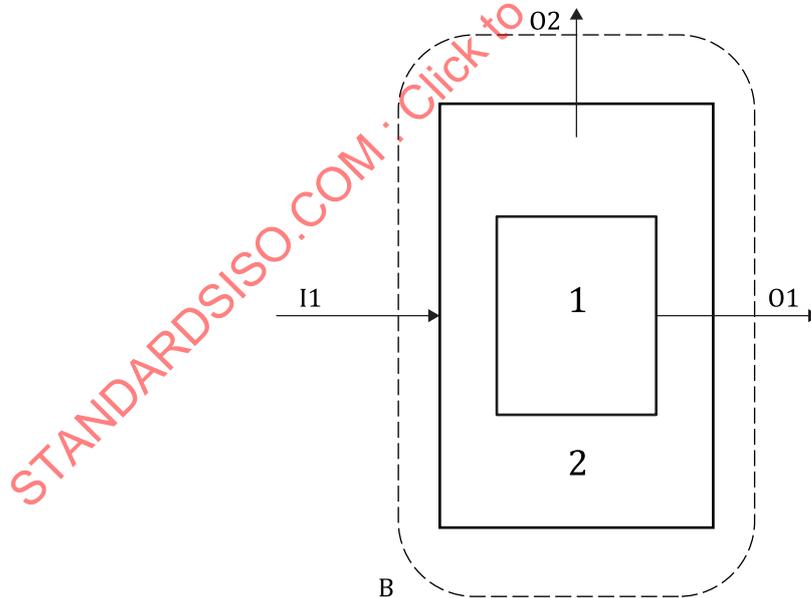
Key

B	boundary	1	heating devices (submerged coils or top mounted)
I1	hot heating medium (steam, hot water or thermal oil)	2	cargo tank
O1	old heating medium (steam, hot water or thermal oil)		
O2	heat loss		

Figure 6.9 — Cargo heat system and its boundaries

6.9.4 Calculation method

The cargo is loaded at temperature T_1 at port A and unloaded at temperature T_2 at port B.

To minimize heat loss, heating should start as late as practically possible, while still enabling the vessel to reach target temperature T_2 at port B. This minimizes the duration where there is a high temperature difference between the cargo and ambient temperature.

The energy efficiency of the cargo heat system is calculated as a thermal power index (TPI), TPI_{CHS}, as shown in Formula (6.26). It evaluates how much power is required for heating per volume of cargo.

$$TPI_{CHS} = \frac{\dot{Q}_{HM,out}}{V_{Cargo}} \tag{6.26}$$

where

$\dot{Q}_{HM,out}$ is the change in thermal energy after the heating medium passes through the heating device plus the heat lost from the tank;

V_{Cargo} is the volume of the cargo that is heated.

However, since this document considers the efficiency of the system, the heat loss shall be disregarded, and the expression can be written as shown in Formula (6.27). As the heating medium can be steam, thermal oil or hot water, the formula uses the general term "heating medium" to cover all three types.

$$\dot{Q}_{HM,out} = c_{p,HM} \cdot q_{m\,HV} \cdot \Delta t_{HM} = c_{p,HM} \cdot q_{m\,HV} \cdot \left(T_{HM,out} - T_{HM,in} \right) \tag{6.27}$$

where

$c_{p,HM}$ is the specific heat capacity (at constant pressure) of the actual heating medium at the actual temperature, expressed in kJ/kg K;

$q_{m\,HV}$ is the mass flow rate of the heating medium, expressed in kg/s;

$T_{HM,out}$ is the temperature when the heating medium leaves the heating device, expressed in °C;

$T_{HM,in}$ is the temperature when the heating medium enters the heating device, expressed in °C.

$q_{m\,HV}$ can be calculated as shown in Formula (6.28):

$$q_{m\,HV} = \rho_{HM} \cdot q_{v\,HM} \tag{6.28}$$

where

ρ_{HM} is the density of the heating medium, expressed in kg/m^3;

$q_{v\,HM}$ is the volume flow of the heating medium, expressed in m^3/s.

$q_{m\,HV}$, $T_{HM,out}$ and $T_{HM,in}$ can be obtained by installing a flow sensor and a temperature sensor in the system.

Typical values for $c_{p,HM}$ are as follows:

— Steam: $c_{p,HM}$ = 2,26 kJ/kg K at 1,0 MPa (10 bar) and temperature range 180 °C to 315°.

— Hot water: $c_{p,HM}$ = 4,20 kJ/kg K at 80 °C.

— Thermal oil: $c_{p,HM}$ = 2,35 kJ/kg K at 150 °C.

At other states of the heating medium, see other relevant engineering tables.

6.9.5 Measuring method

The necessary measurements for this method are as follows:

— $q_{m\,HV}$ is the mass flow rate of the heating, expressed in kg/s. This requires a flow meter in the heating medium pipe.

— $T_{HM,out}$ is the temperature when the heating medium leaves the heating devices, expressed in °C. It is measured on the common pipe manifold downstream the heating devices.

— $T_{HM,in}$ is the temperature when the heating medium enters the heating devices, expressed in °C. It is measured on the common pipe manifold upstream the heating devices.

— V_{Cargo} is the volume of the cargo that is filled on the tanks, expressed in m^3.

6.9.6 Example of measuring and calculation

50 000 m^3 of oil is transported by a ship that has a cargo heating system using steam as the heating medium. The steam is delivered at 1,0 MPa (10 bar(g)) and 200 °C. The density of the steam can be found from a recognized engineering table as 5 382 kg/m^3.

The volume flow if steam is measured by a flow meter: $q_{v\,HM}$ = 10 000 m^3/h.

The steam outlet temperature is measured: $T_{HM,out}$ = 150 °C.

The steam inlet temperature is measured: $T_{HM,in}$ = 200 °C.

The mass flow is the calculated by using Formula (6.28):

$$q_{m\,HV} = 5{,}382 \text{ kg/m}^3 \cdot 10\,000 \text{ m}^3/\text{h} = 53{,}820 \text{ kg/h} = 14{,}95 \text{ kg/s}$$

Then Formula (6.27) is used:

$$\dot{Q}_{HM,out} = 2{,}26 \text{ kJ/kgK} \cdot 1{,}495 \text{ kg/s} \cdot (200 \text{ °C} - 150 \text{ °C}) = 169 \text{ kW}$$

The cargo heat system TPI is found by using Formula (6.26):

$$TPI_{CHS} = \frac{169 \text{ kW}}{50{,}000 \text{ m}^3} = 0{,}003\,4 \frac{\text{kW}}{\text{m}^3}$$

6.10 Volatile organic compound recovery system

6.10.1 General

VOCs are light components of crude oil, which evaporate during loading operations or during the carriage of high-volatility crude oil cargo.

After the VOCs are pre-treaded (cleaned), they are led into the VOC recovery system as gas, where they are compressed and thereafter condensed. The condensed VOC, named "LVOC" (i.e. liquid VOC), is either returned to cargo tank or used as fuel.

Within the system, there is a refrigerant loop that is used for the condensation, as well as a cooling water loop that is used for the condensation and cooling of the compressors.

6.10.2 Definition of input and output

The input and output of a VOC recovery system consists of the following:

— Input: Cold seawater and electricity and VOC.

— Output: Hot seawater and LVOC.

6.10.3 Definitions of boundaries and media

The boundary of the VOC recovery system encloses the VOC compressors, refrigerant compressor, VOC cooling water system, condensation unit and VOC cooling seawater pump (see Figure 6.10).
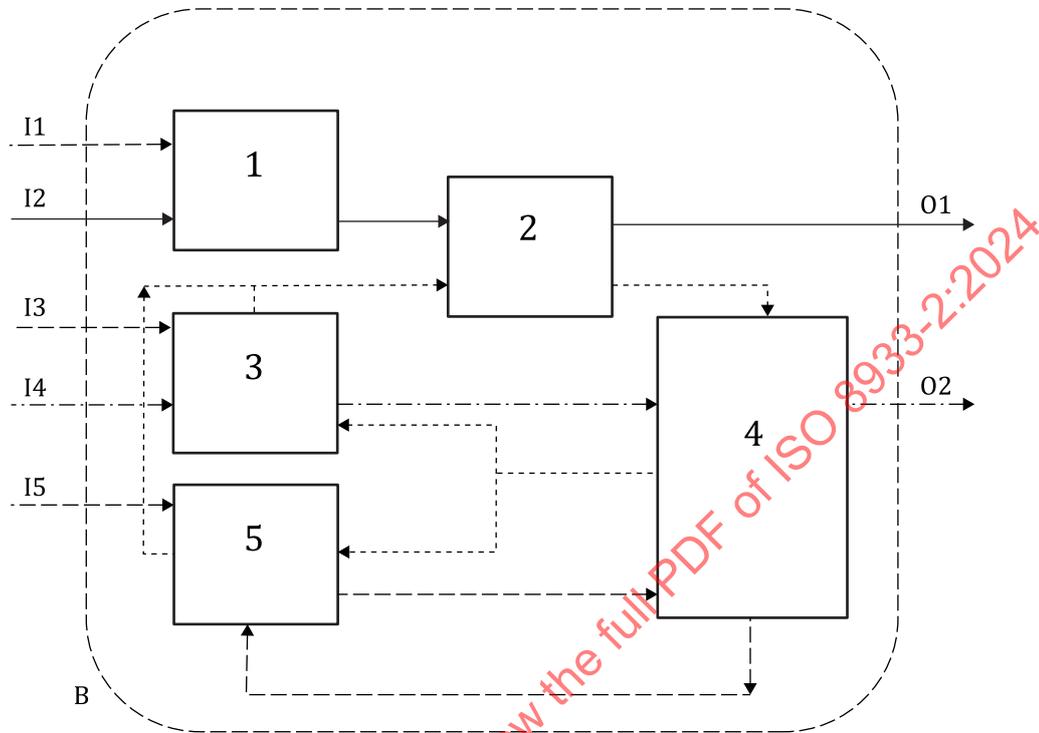
Key

B	boundary	1	VOC cooling seawater pump
I1	electricity	2	VOC cooling water system
I2	old seawater	3	VOC compressor
I3	electricity	4	condensation unit
I4	VOC	5	refrigeration compressor
I5	electricity	⟶	sea water
O1	hot seawater	┈┈➤	cooling water
O2	LVOC	┈·┈➤	VOC/LVOC
		┈ ┈➤	refrigerant

Figure 6.10 — VOC recovery system and its boundaries

6.10.4 Calculation method

The energy efficiency of the VOC recovery system is calculated as a ratio, EER_{VOC}, as shown in Formula (6.29):

$$EER_{VOC} = \frac{\dot{Q}_{s,out}}{P_{VOC,Actual}} \tag{6.29}$$

where $\dot{Q}_{s,out}$ is the change in thermal energy when the cooling seawater passes through the VOC cooling water system, see Formula (6.30):

$$\dot{Q}_{s,out} = c_{p,s} \cdot q_{ms} \cdot \Delta T_s = c_{p,s} \cdot q_{ms} \cdot \left(T_{s,out} - T_{s,in} \right) \tag{6.30}$$

where

$c_{p,s}$ is the specific heat capacity (at constant pressure) of the cooling seawater, at 20 °C and with salinity 35 ‰, expressed in kJ/kg K;

$q_{m\,s}$ is the mass flow rate of the cooling seawater, expressed in kg/s;

$T_{s,out}$ is the temperature when the cooling seawater leaves the VOC cooling seawater system, expressed in °C;

$T_{s,in}$ is the temperature when the cooling seawater enters the VOC cooling seawater system, expressed in °C.

$q_{m\,s}$, $T_{s,out}$ and $T_{s,in}$ can be obtained by installing a flow sensor and a temperature sensor in the seawater flowline.

$P_{VOC,Actual}$ is the actual electrical power required for the VOC cooling seawater pump, VOC compressor and refrigeration compressor. The actual electrical power required can be written as shown in Formula (6.31):

$$P_{VOC,Actual} = P_{Pump,Actual} + P_{VOC,compr,Actual} + P_{Refr,compr,Actual} \tag{6.31}$$

where

$P_{Pump,Actual}$ is the actual electrical power needed for the VOC cooling seawater pump, expressed in kW;

$P_{VOC,compr,Actual}$ is the actual electrical power needed for the VOC compressor, expressed in kW;

$P_{Refr,compr,Actual}$ is the actual electrical power needed for the refrigeration compressor, expressed in kW.

An alternative method to evaluate the energy performance of the system is to compare the actual power needed by the lube oil pumps with the rated power for the lube oil pumps using a power ratio, η_{PR}, defined in Formula (6.32). The advantage of this method is that it requires fewer instruments to measure and is easy to calculate.

$$\eta_{PR} = \frac{P_{VOC,Actual}}{P_{VOC,Rated}} \tag{6.32}$$

$P_{VOC,Actual}$ is the actual electrical power required for the VOC cooling seawater pump, VOC compressor and refrigeration compressor as described in Formula (6.31);

$P_{VOC,Rated}$ is the rated power required for the VOC cooling seawater pump, VOC compressor and refrigeration compressor taken from the ship's "Electrical power table for EEDI" based on MEPC.364(79).[12]

The restriction of this method is that it is specific for the actual ship and can only be used to verify or evaluate the improvements of the ship itself.

6.10.5 Measuring method

The necessary measurements for this method are as follows:

— $q_{m\,s}$ is the mass flow rate of the cooling seawater, expressed in kg/s. This requires a flow meter in the seawater pipe.

— $T_{s,out}$ is the temperature when the cooling seawater leaves the heat exchange, expressed in °C. It is measured close to the VOC cooling water system outlet flange.

— $T_{s,in}$ is the temperature when the cooling seawater enters the cooler, expressed in °C. It is measured close to the VOC cooling water system inlet flange.

— $P_{VOC,Actual}$ is the actual power of the VOC cooling seawater pump, VOC compressor and refrigeration compressor by using a power meter mounted in the switchboard or a hand-held clamp meter for that specific power line, expressed in kW.

For the alternative method, the only measurement required is $P_{VOC.Actual}$.

6.10.6 Example of measuring and calculation

Measure and calculate $\dot{Q}_{s,out}$ by using Formula (6.30).

The specific heat capacity for seawater is found from a table: $c_{p,s}$ = 4,007 kJ/kgK.

The mass flow rate of cooling seawater is measured: $q_{m\,s}$ = 228,9 kg/s (equal to 800 m^3/h with a density of 1 030 kg/m^3).

The seawater outlet temperature is measured: $T_{s,out}$ = 20 °C.

The seawater inlet temperature is measured: $T_{s,in}$ = 15 °C.

$$\dot{Q}_{s,out} = 4{,}007 \text{ kJ/kgK} \cdot 228{,}9 \text{ kg/s} \cdot (20 \text{ °C} - 15 \text{ °C}) = 4\,586 \text{ kW}$$

$P_{VOC,Actual}$ is retrieved by reading the power from the VOC cooling seawater pump, VOC compressor and refrigeration compressor by using a power meter:

— $P_{Pump,Actual}$ = 150 kW

— $P_{VOC,compr,Actual}$ = 150 kW

— $P_{Refr,compr,Actual}$ = 100 kW

By using Formula (6.31), it is possible to calculate:

$$P_{VOC,Actual} = 150 \text{ kW} + 150 \text{ kW} + 100 \text{ kW} = 450 \text{ kW}$$

The EER of the VOC recovery system can be calculated by using Formula (6.29):

$$EER_{VOC} = \frac{4\,586 \text{ kW}}{450 \text{ kW}} = 10{,}2$$

For the alternative method, $P_{VOC,Actual}$ is measured as 450 kW and $P_{VOC,Rated}$ is found from the "Electrical power table for EEDI" based on MEPC.364(79)[12] at 500 kW:

$$\eta_{PR\ VOC} = \frac{P_{VOC,Actual}}{P_{VOC,Rated}} = \frac{450 \text{ kW}}{500 \text{ kW}} = 0{,}9$$

6.11 Separator system

6.11.1 General

A separator system is a system that removes contaminants from a fluid. Examples on a ship can include a centrifugal separator or filter.

Performance is defined according to the specific application. In some cases, it can be defined as an efficiency comparing the contaminant concentration in the influent and effluent fluid.

In other cases, the system is more complex, where the efficiency varies over time, and with contaminant concentration that varies due to the changes of contaminant generation in the system.

Therefore, performance, in this case, is defined as a sufficient efficiency over time, thereby maintaining an acceptable level of contaminant concentration. The acceptable level can be defined in various ways,

depending on the actual application. The efficiency itself is not defined in this document, but the required efficiency is typically defined by, for example, equipment builders, equipment owners and by authorities.

6.11.2 Definition of input and output

The input and output of a separator consists of the following:

— Input: Total energy input needed for treating and pumping the fluid.

— Output: Treated flow.

6.11.3 Definition of boundaries and media

The boundaries and the input/output are shown in Figure 6.11.
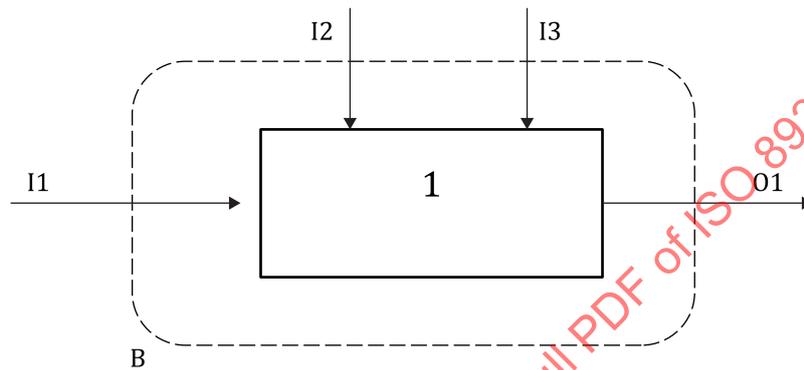
Key

B   boundary

I1   influent

I2   electricity

I3   steam

O1   effluent

1   separator (fluid conditioning, contaminant removal)

Figure 6.11 — Boundaries and input/output for a maritime separator

6.11.4 Calculation method

The energy consumption of the separator can be split into the following two categories:

a)   fluid conditioning;

   EXAMPLE   Heating or cooling of the fluid.

b)   contaminant removal, i.e. the part of the separator that separates the contaminant from the fluid.

Energy input is defined as the total energy input, in the form of thermal or electrical energy, which is delivered to the unit.

The energy input is related to the flow, thereby creating the energy efficiency, describing the necessary energy to treat one cubic metre of fluid.

The EER shall be calculated by using Formula (6.33):

$$EER = \frac{E}{q_m} \tag{6.33}$$

where

    E is the energy input, expressed in kJ;

    q_m is the mass flow rate, expressed in kg/s

The separator can add energy to the fluid in the form of thermal energy or pressure. This addition of energy cannot be subtracted from the energy input in the calculation.

7 Lighting systems

7.1 General

A lighting system consists of several components and connections between these components, which, when combined, provide the key functionality to give light. A typical lighting system consists of a number of electrical luminaires and a control system.

The main purpose of the lighting system is to provide the required minimum illuminance values, for a specific task area, set by maritime authorities. A lighting system should be designed to meet these requirements in an energy-efficient manner.

The correct illuminance value is crucial for safety as well as for the comfort and well-being of the crew members. It should not be compromised simply to reduce energy consumption. This is especially important for navigation lighting systems.

The quality of the light in lighting systems is very important for the safety and the well-being of the crew. Aspects such as flicker, glare and colour rendering should be considered. These aspects and minimum values are described in EN 12464-1. These aspects are especially important for light-emitting diode (LED) lighting, because the light quality in the LED chip can compromise the electrical efficiency of the LED chip. When changing luminaries to new models with much higher electrical efficiency, the lighting quality can decrease as a result.

7.2 Lighting of internal spaces

7.2.1 General

An electrical luminaire converts electrical energy into visual light and heat.

The function of a lighting system is to provide the required minimum illuminance values, for a specific task area, set by maritime authorities.

It is therefore necessary to review the lighting system with a number of luminaires in regard to the specific task area. The individual luminaire is produced with a specific lumen per watt (lm/W) design, as an indication of how much light the luminaire emits. The interesting aspect to observe is how much light is on the given task area. The total amount of light hitting the task area is the combination of the specific luminaire but also the reflection of the surrounding surfaces.

The true efficiency of a lighting system can only be determined by measuring the light on the task area with a lux meter, with the specific deck and bulkhead surface properties. The colour and reflection value of the deck and bulkhead directly contributes to the efficiency of the lightning system. This makes it possible to increase the lighting efficiency of the lighting system by changing the painting in the area as well as by keeping the surfaces clean.

Controlling the time period during which the luminaire is lit is an easy way to reduce energy consumption. In many areas of the ship, constant illumination is unnecessary. In areas with complex machinery such as the main engine room, the safety aspects of turning off the light should be considered. Dark areas create a safety hazard and shall be avoided. Using LED luminaires, it is possible to tone down the light output of the luminaires. Reducing the light to a low illumination level reduces the energy consumption dramatically, while maintaining a level of visual safety.

7.2.2 Definition of input and output

The input and output of an internal space lighting system consists of the following:

— Input: Total obtained electrical energy to the lighting system, in a task area.

— Output: Measured illumination on the task area surface measured in lux.

7.2.3 Definitions of boundaries and media

The lighting system can be spilt up into smaller areas and subsystems. The size of these areas can be defined by the task areas.

These areas can include a workshop, main engine room, auxiliary engine room, separator room, staircases or passages.

7.2.4 Calculation method

The energy efficiency of the lighting at internal spaces is defined in Formula (7.1):

$$\eta_{\text{lighting system}} = \frac{l_x}{P_{\text{electrical}}} \tag{7.1}$$

where

l_x is illuminance, or luminous flux per unit area, expressed in lux;

$P_{\text{electrical}}$ is electric power, expressed in W.

7.2.5 Measuring method

The luminance on the task area is measured with a lux meter, as illustrated in Figure 7.1. The measurement is done in the correct plane, according to the required illuminance level, as set by the classifications company.
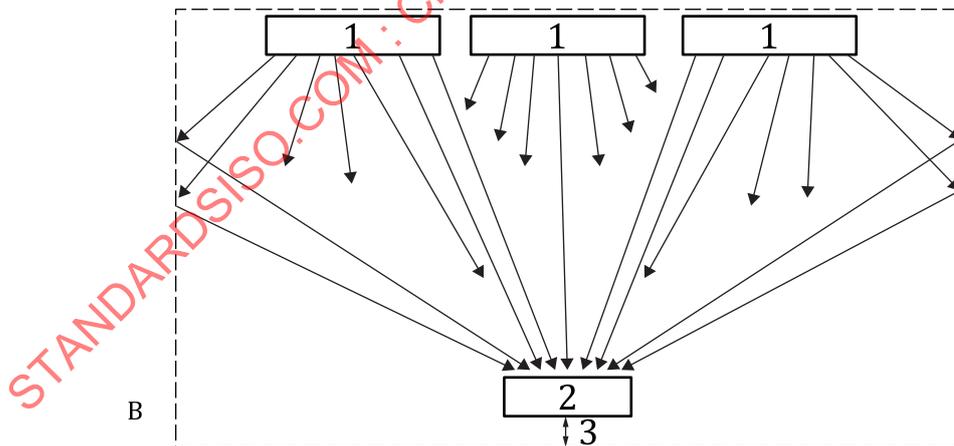
Key

B   boundary for a task area
1   luminaires
2   lux meter
3   measuring distance from deck

Figure 7.1 — Measurement of luminance for an area

The amount of energy consumed by the luminaire system is measured with a watt meter as illustrated in Figure 7.2.
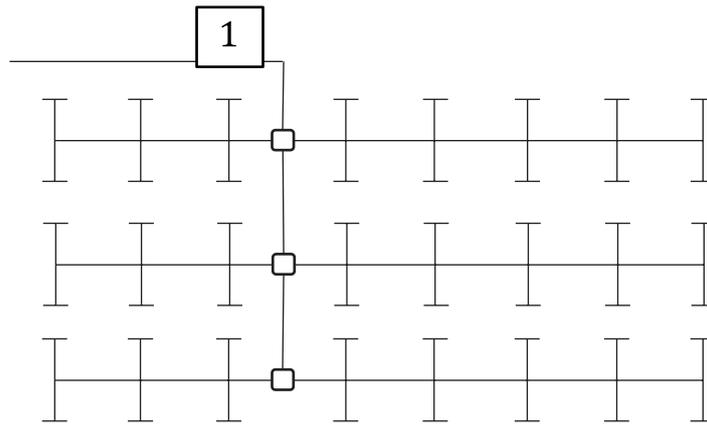
Key

1   watt meter

Figure 7.2 — Measurement of the electrical energy

The simplest way of achieving power savings on a lighting system is by changing the existing luminaires to more energy-efficient luminaires. This means changing to a product with a higher specific lm/W rating. As a guideline, a modern LED luminaire normally has a lm/W rating within the range of 150 lm/W to 160 lm/W. This is a significant improvement compared to fluorescent tubes, as the widely used T8 tube only has a total lm/W rating of approximately 80 lm/W maximum.

The following points should be considered in order to optimize the lighting system on board a ship:

a)   It is important to clarify the minimum value of illumination of the given task area. To verify the values of the illuminates, ensure that the measurements are taken in or using a lux meter. Start measuring the light after at least 15 min runtime on the luminaires to make sure that they are fully lit. At the same time, ensure that the area is properly cleaned. The colours and structures of the deck and bulkhead surfaces strongly impacts the illuminance level.

b)   Measure the power used by the given lighting system. This can involve finding a connecting box where the watt meter can be installed. The measurement should be done of a period of 15 min to 30 min.

c)   The measured light and power data are documented for later verification of power savings.

d)   The luminaires are changed to the new models.

e)   Steps a), b) and c) are repeated.

f)   The improvement of energy efficiency is complete and documented.

Power savings can also be obtained by additional lighting controls. It is especially important to maintain the correct illumination level in all task areas where people are working. However, there is no reason to illuminate areas where no one is working. EN 12464-1 defines the size of the task area and describes the possibility of lowering the lighting levels by dimming the light in the areas surrounding the task area. This allows for energy efficiency without turning off the light completely, thereby allowing a visual overview of larger areas.

A visual representation of a task area and its surroundings is shown in Figure 7.3.
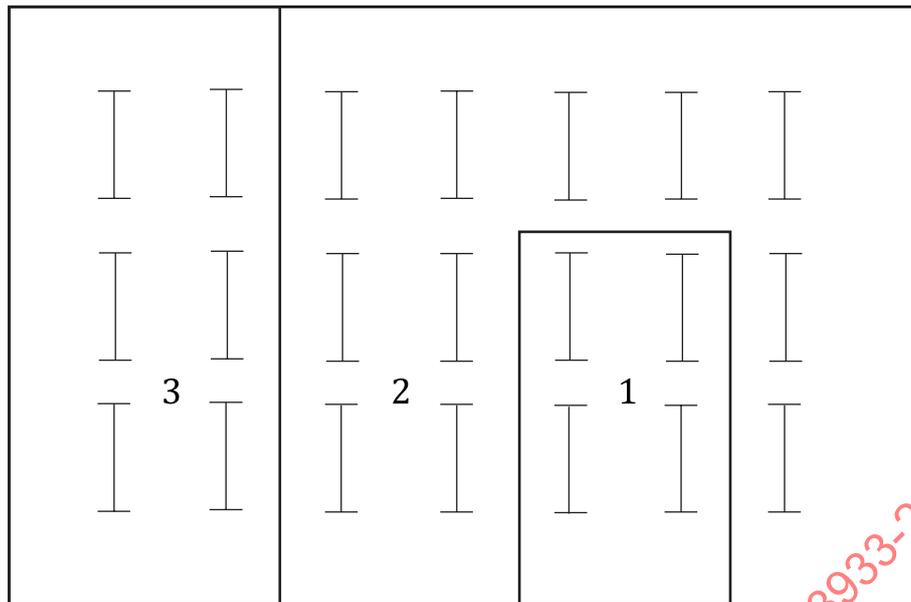
Key

1   task area

2   nearby surrounding area

3   surrounding area

Figure 7.3 — Task areas and surroundings

The area surrounding the task area is defined as nearby surroundings. This area shall be minimum 0,5 m wide. If there is a visual connection between the areas 1, 2 and 3 as shown in Figure 7.3, the minimum illumination levels specified in EN 12464-1 shall be used. But if there are no visual connections to the area marked with number 3, the light can be lowered to a minimum, or completely turned off.

There are many areas on board a ship where the lighting system can be operated with dimmed illumination or stand alone on/off controls, without compromising visual safety.

When dimming LEDs, the power consumption roughly follows the dimming level. If the illumination level is lowered by 50 %, the power consumption is equally lowered by 50 %. Normally, the dimming of LEDs is done by lowering the current flowing to the LED chip board. This is true for most types of LED. But when using Indium Gallium Phosphide (InGaP) LED chips, which is the most efficient type of LED at the moment, it is important to use pulse width modulation (PWM) drivers. Otherwise, the appearance of the emitted light and the emitted light will not be the same when dimming. This can cause problems with visual safety.

Another way of controlling the time in which the luminaires are lit is by turning them on and off with built-in motion sensors. By adjusting the sensitivity of these sensors and utilizing the built-in off-delay timer, it is possible to make standalone lighting controls. To provide some level of orientational illumination, a small built-in orientational lamp is lit in each luminaire.

7.2.6   Example of measuring and calculation

An example of power savings is illustrated in Table 7.1. Three different lighting solutions are compared. The three different lighting solutions give approximately the same lumen output.

Solution 1 is calculated based on 250 standard T8 fluorescent tubes without sensor control. This is compared to a system of 250 LED luminaires with built-in sensors (solution 2). The running hour of each luminaire is reduced from 24 h to 6 h per day.

The amount of energy saved is 234 kWh (1 kWh = 3 600 kJ) per day without built-in orientation lights. With an additional built-in orientation lamp, the energy saved is 213 kWh (1 kWh = 3 600 kJ) per day .

Table 7.1 — Example of power savings using motion sensors in an area

Parameter	Solution 1 Fluorescent tube T8 without sensor	Solution 2 LED luminaire with sensor	Solution 3 LED luminaire with sensor and orientation light
Number of luminaires	250	250	250
Power per luminaire (W)	36	18	18
Power per driver/ballast (W)	8	1	1
Power per sensor (W)		1	1
Power of orientation light (W)			2,5
Running h/d[a]	24	6	6
Total power consumption, in kWh[b]	11 000	5 000	5 000
Total power, orientation light, in Wh[c]			1 125
Total energy consumption, in kWh/d[d]	264	30	50,3
Power savings kWh/d[d]		234	213,8

[a] 1 h/d = 1/24.

[b] 1 kWh = 3 600 kJ.

[c] 1 h = 3 600 s.

[d] 1 kWh/d = $\dfrac{1}{24}$ kJ / s .

8 Heating/cooling functional systems

8.1 General

A heating/cooling functional system consists of several components and connections between those components, whose combined key functionality is to heat or cool something down.

Examples of these units on a ship include:

— air-conditioning system with compressor (see 8.2);

— air-conditioning system without compressor (see 8.3);

— absorption chiller system (see 8.4);

— compression-type water chilling system (see 8.5).

8.2 Air-conditioning system with compressor

8.2.1 General

An air-conditioning unit with compressor (hereinafter referred to as "the unit") is a functional system that ventilates, circulates, filters, cools, heats and humidifies the cabin air. The unit cools air directly with a steam compression refrigeration system.

8.2.2 Definition of input and output

The input and output of an air-conditioning system with compressor consists of the following:

— Input: Total consumed electric power.

— Output: Refrigerating capacity.

8.2.3 Definitions of boundaries and media

8.2.3.1 General

An air-conditioning unit with compressor consists of a condensing unit, air conditioner and other parts, as shown in Figure 8.1.

The unit boundaries are divided into environmental boundary conditions (see 8.2.3.2) and equipment boundary conditions (see 8.2.3.3).

Key

➡ air piping lines

→ refrigerant piping lines

1 condensing unit
2 air-conditioning unit
3 condenser
4 compressor
5 evaporator
6 heater
7 humidifier
8 fan
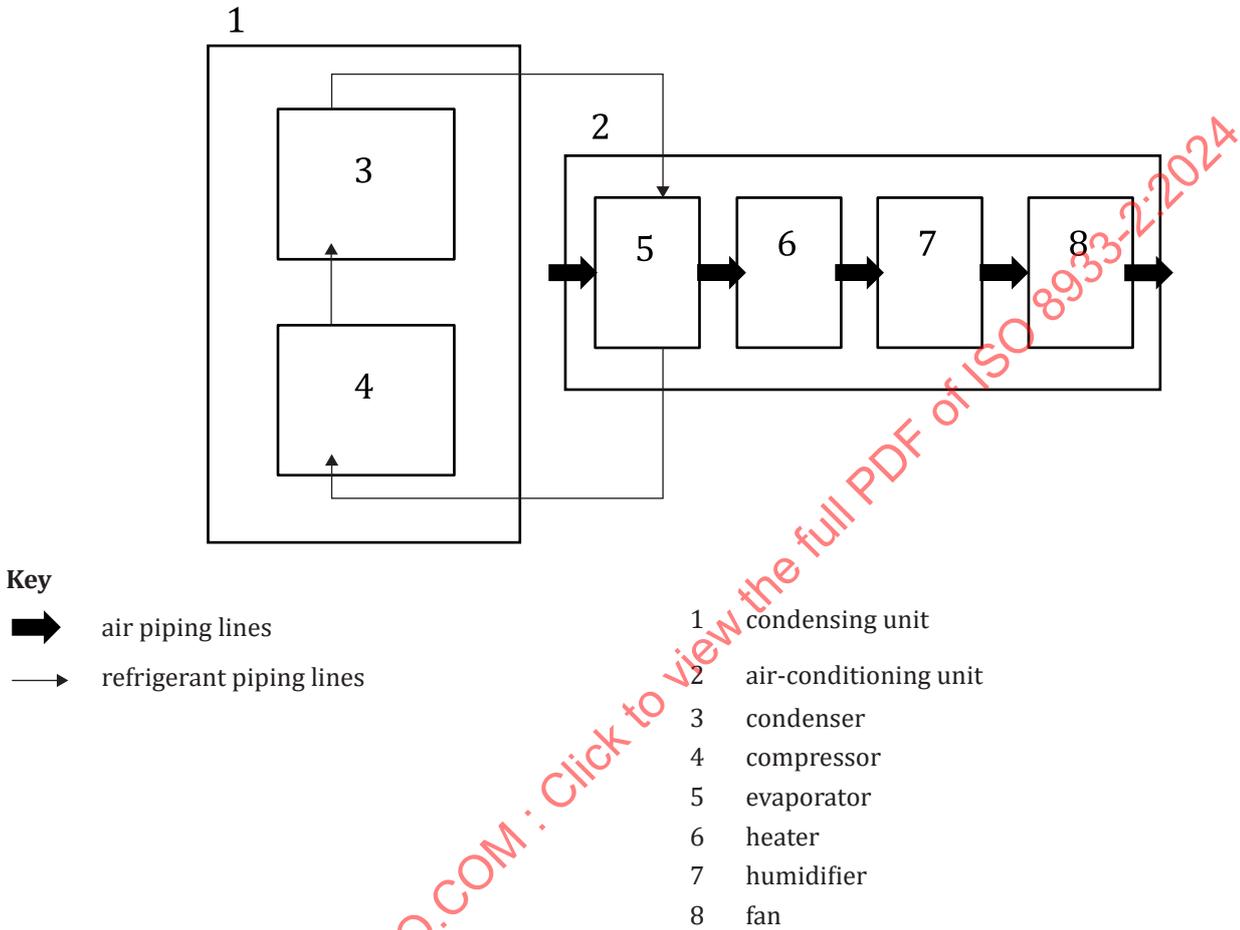
Figure 8.1 — Functional units for an air-conditioning unit with compressor

8.2.3.2 Environmental boundary conditions

Table 8.1 shows the unit temperature boundary under nominal working conditions.

Table 8.1 — Temperature boundary conditions under nominal working conditions for an air-conditioning unit with compressor

Items	Air side [a]		Cooling water side	
	Inlet dry bulb temperature °C	Inlet wet bulb temperature °C	Temperature at inlet °C	Cooling water flow m³/(h·kW)
Return air	27	19,5	32[c]/36[d]	0,268
Fresh air[b]	35	30		

[a] The air side inlet parameters are calculated according to the fresh air ratio in the contract.

[b] Fresh air ratio, 60 %.

[c] Cooling water is seawater at 32 °C.

[d] Cooling water is fresh water in the central cooling water system at 36 °C.

8.2.3.3 Equipment boundary conditions

According to the types of compressors, the units can be divided into piston type, scroll type and other types. The different compressors have different influences on the EER of the unit. This document mainly focuses on the units with piston type and scroll type compressors.

The boundary conditions are shown in Figures 8.2 and 8.3.

Key
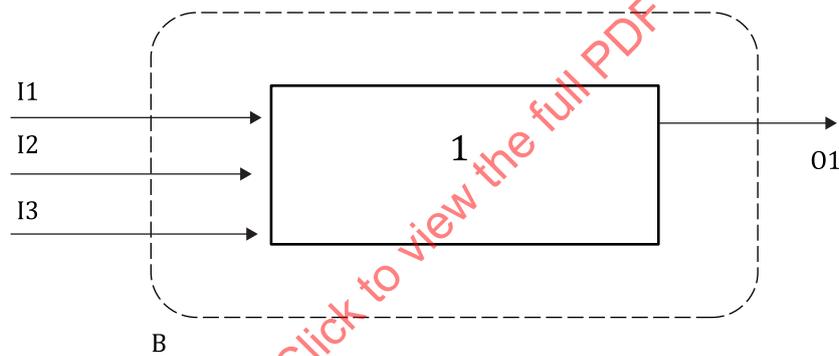
B   boundary

I1   electric power

I2   air to be cooled

I3   cooling water

O1   air after cooling

1   air-conditioning unit

Figure 8.2 — Boundary conditions when cooling

Key
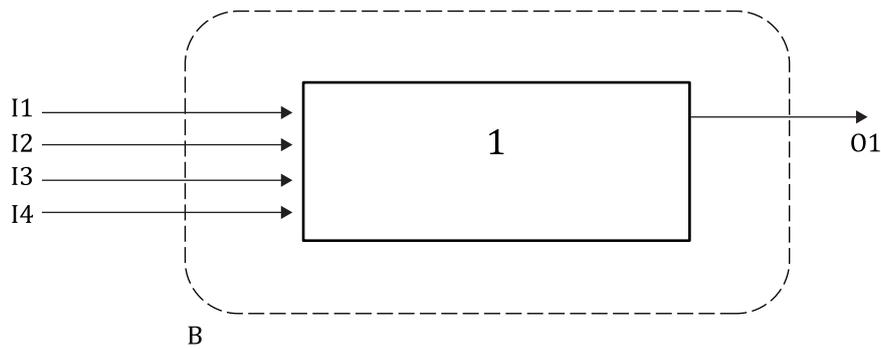
B   boundary
I1   electric power
I2   air to be heated
I3   fresh water for humidification
I4   heat medium water/vapour/electric
O1   air after heating

1   air-conditioning unit

Figure 8.3 — Boundary conditions when heating

8.2.4 Calculation method

The energy efficiency of the air-conditioning system with compressor is defined by the EER value which is used to represent the full-load performance coefficient of the unit under nominal working conditions. EER can be calculated as shown in Formulae (8.1), (8.2), (8.3) and (8.4):

$$EER = \frac{\dot{Q}_n}{P_0} \tag{8.1}$$

$$\dot{Q}_n = h_{in} \cdot q_{v,in} \cdot \rho_{in} - h_{out} \cdot q_{v,out} \cdot \rho_{out} \tag{8.2}$$

$$h = f_1(T_d, T_w) \tag{8.3}$$

$$\rho = f_2(T_d, T_w) \tag{8.4}$$

where

$\dot{Q}_n$ is the measured refrigerating capacity, expressed in kW;

P_0 is the total consumed power, expressed in kW;

T_d is the measured temperature of the dry-bulb, expressed in °C;

T_w is the measured temperature of the wet-bulb, expressed in °C;

q is the measured air flow, expressed in m³/h;

h is the enthalpy value, expressed in J/kg;

ρ is the density, expressed in kg/m³;

$f_1(T_d, T_w)$ is the enthalpy function value according to the dry-bulb temperature and the wet-bulb temperature;

$f_2(T_d, T_w)$ is the density function value according to the dry-bulb temperature and the wet-bulb temperature;

in is the descriptor index for mixed air of fresh air and return air;

out is the descriptor index for air after coil treatment.

$\dot{Q}_n$ is tested and calculated under the environmental conditions given in Table 8.1. P_0 is the total input of electric power from the compressor motor, operation control circuit (electric control box) and internal fan in the air conditioner. For an air-conditioning unit with a heating function, heat energy is transformed into electric energy before calculation.

8.2.5 Measurement method

It is recommended to make the measurements in a laboratory environment. The measuring points are shown in Figure 8.4.
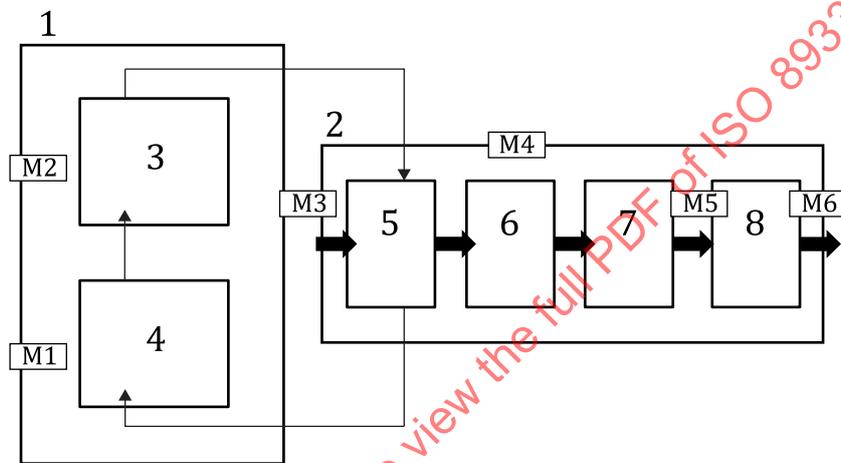
Key

M1 power measurement
M2 temp, pressure, flow of cooling water
M3 temp, humidity, flow of air to be treated
M4 energy of heat medium
M5 temp, humidity, flow treated air
M6 power measurement

➡ air piping lines

→ refrigerant piping lines

1 condensing unit
2 air-conditioning unit
3 condenser
4 compressor
5 evaporator
6 heater
7 humidifier
8 fan

Figure 8.4 — Layout of measuring points

Use a dynamometer to test the input power of the unit. Install a flow meter and a thermometer on the cooling water pipeline and install a dry-wet bulb thermometer and anemometer in front of and behind the evaporator. After the equipment achieves working condition, measure the flow rate, temperature difference of the refrigerated water, wind temperature and wind speed. Calculate the cooling refrigerating capacity of the unit.

Evaluation of the measurements can be done by using the measured data to calculate the EER of the unit in accordance with Formula (8.1) and evaluated in accordance with Table 8.2.

8.2.6   Example of measuring and calculation

Take an air-conditioning unit with compressor on board as an example:

— make the test under marine environmental boundaries;

— record the air state, flow rate and temperature of the cooling water side;

NOTE   The air mixing point is the air state in front of the evaporator in the air conditioner. The air outlet point is the air state behind the evaporator.

— calculate the unit refrigerating capacity;

— measure the consumed power;

— calculate the EER;

— measure at least three times and calculate the average energy efficiency of each one, see Table 8.2.

Table 8.2 — Calculation and measurement of energy efficiency

Parameter	1	2	3
Temperature of mixed air (°C)	30,2	30,3	30,2
Humidity of mixed air (%)	59,1	58	59,5
Temperature of outlet air (°C)	13,3	13,2	13,3
Humidity of outlet air (%)	95	94,7	94,6
Flow of air supply (m³/h)	10 000	9 950	10 120
Temperature at outlet of cooling water (°C)	36,31	36,36	36,42
Temperature at inlet of cooling water (°C)	31,76	31,81	31,86
Flow of cooling water (m³/h)	26,5	26,6	26,5
Refrigeration capacity (kW)	113,36	112,09	115,63
Measure of consumed power (kW)	27,31	29,12	25,35
Measure of coefficient of performance (COP)	4,15	3,85	4,56
Average COP	4,19		

8.3   Air-conditioning system without compressor

8.3.1   General

An air-conditioning unit without compressor (hereinafter referred to as "the unit") is a functional system that ventilates, circulates, filters, cools, heats and humidifies the cabin air. The unit cools air using a heat exchanger which can exchange heat between refrigerant inside the heat exchange tube and the air outside the heat exchange tube.

8.3.2   Definition of input and output

The input and output of an air-conditioning system without compressor consists of the following:

— Input: Total consumed electric power.

— Output: Refrigerating capacity.

8.3.3 Definitions of boundaries and media

8.3.3.1 General

An air-conditioning unit without compressor consists of a heat exchanger, fan motor and air-conditioning box, as shown in Figure 8.5.

The unit boundaries are divided into environmental boundary conditions (see 8.3.3.2) and equipment boundary conditions (see 8.3.3.3).
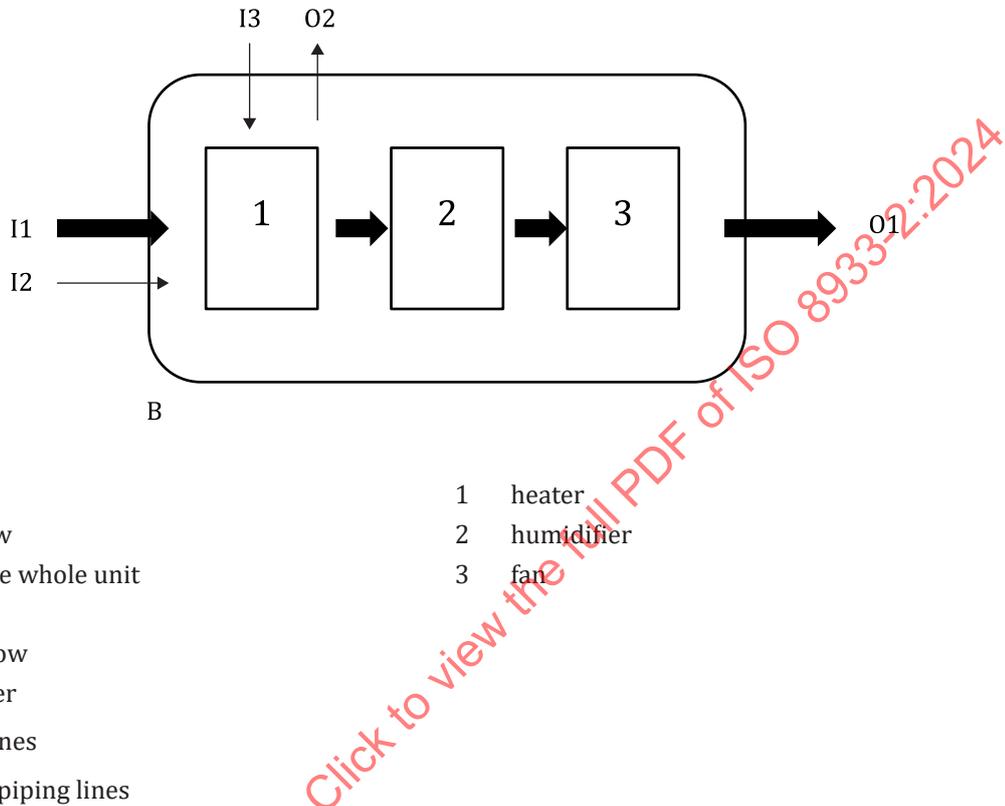
Key

B	boundary	1	heater
I1	inlet air flow	2	humidifier
I2	power to the whole unit	3	fan
I3	refrigerant		
O1	outlet air flow		
O2	heated water		
➡	air piping lines		
→	refrigerant piping lines		

Figure 8.5 — Air-conditioning unit without compressor and its boundaries

8.3.3.2 Environmental boundary conditions

Table 8.3 shows the unit temperature boundary under nominal working conditions.

Table 8.3 — Temperature boundary conditions under nominal working conditions for an air-conditioning unit without compressor

Items	Air side [a]		Refrigerant water side[b]
	Inlet dry bulb temperature °C	Inlet wet bulb temperature °C	Temperature at inlet °C
Return air	27	19,5	7
Fresh air	35	30	

[a] The air side inlet parameters are calculated according to the fresh air ratio in the contract.

[b] The refrigerant is generally fresh water produced by a chilling water unit or a sea-water-to-fresh-water heat exchanger.

8.3.3.3 Equipment boundary conditions

According to the types of fans, the units can be divided into centrifugal type, axial type and mixed-flow type. The different fans have different influences on the COP of the unit. This document mainly focuses on the units with centrifugal type and axial type fans.

8.3.4 Calculation method

The energy efficiency of the air-conditioning system without compressor is defined by the EER value, which is used to represent the full-load performance coefficient of the unit under nominal working conditions. EER can be calculated as shown in Formulae (8.5), (8.6), (8.7) and (8.8):

$$EER = \frac{\dot{Q}_n}{P_0} \tag{8.5}$$

$$\dot{Q}_n = (h_{in} - h_{out}) \cdot q_{in} \cdot \rho_{in} \tag{8.6}$$

$$h = h_1(T_d, T_w) \tag{8.7}$$

$$\rho = \rho_2(T_d, T_w) \tag{8.8}$$

where

$\dot{Q}_n$	is the measured refrigerating capacity, expressed in kW;
P_0	is the total consumed power, expressed in kW;
T_d	is the measured temperature of the dry-bulb, expressed in °C;
T_w	is the measured temperature of the wet-bulb, expressed in °C;
q	is the measured air flow, expressed in m^3/h;
h	is the enthalpy value, expressed in J/kg;
$\rho_2(T_d, T_w)$	is the density, expressed in kg/m^3;
$h_1(T_d, T_w)$	is the enthalpy function value according to the dry-bulb temperature and the wet-bulb temperature;
in	is the descriptor index for mixed air of fresh air and return air;
out	is the descriptor index for air after coil treatment.

$\dot{Q}_n$ is tested and calculated under the environmental conditions shown in Table 8.3. P_0 is the total input of the electric power from the fan motor, operation control circuit (electric control box) and internal fan in the air conditioner.

8.3.5 Measurement method

It is recommended to make the measurements in a laboratory environment.

Key
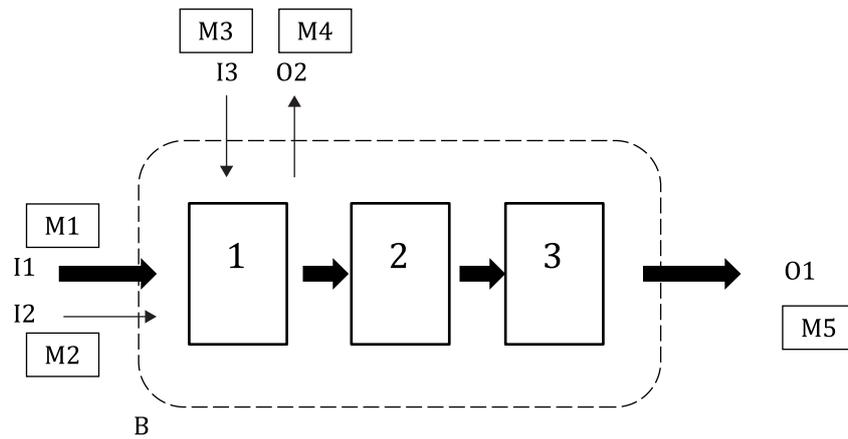
B	boundary	1	heater
I1	inlet air flow	2	humidifier
I2	power to the whole unit	3	fan
I3	refrigerant water		
O1	outlet air flow		
O2	heated water		
M1	air flow temperature/humidity inlet		
M2	power of the total unit		
M3	water temp at inlet		
M4	water temp at outlet		
M5	air flow temperature outlet		
➡	air piping lines		
→	refrigerant piping lines		

Figure 8.6 — Measuring parameters of an air-conditioning unit

Use a dynamometer to test the input power of the unit. Install a flow meter and a thermometer on the refrigerant pipeline. After the equipment achieves working condition, measure the flow rate and the temperature difference of refrigerant side. Calculate the refrigerating capacity of the unit. The five measuring points (M1 to M5) are illustrated in Figure 8.6.

Evaluation of the measurements can be done by using the measured data to calculate the EER of the unit in accordance with Formula (8.5).

8.3.6 Example of measuring and calculation

Take an air-conditioning unit without compressor on board as an example:

— make the test under marine environmental boundaries;

— record the air state, flow rate and temperature of the refrigerant side;

  NOTE   The air mixing point is the air state in front of the heat exchanger in the air conditioner. The air outlet point is the air state behind the heat exchanger.

— calculate the unit refrigerating capacity;

— measure the consumed power;

— calculate the EER;

— measure at least three times and calculate the average energy efficiency of each one (see Table 8.4).

Table 8.4 — Calculation and measurement of energy efficiency

Parameter	1	2	3
Temperature of mixed air (°C)	30,2	30,3	30,2
Humidity of mixed air (%)	59,1	58	59,5
Temperature of outlet air (°C)	13,3	13,2	13,3
Humidity of outlet air (%)	95	94,7	94,6
Flow of air supply (m³/h)	10 000	9 950	10 120
Temperature at outlet of refrigerant (°C)	9,52	9,46	9,66
Temperature at inlet of refrigerant (°C)	7,05	6,98	7,12
Flow of refrigerant (m³/h)	39,3	38,74	39
Refrigerating capacity (kW)	113,36	112,09	115,63
Measure of consumed power (kW)	15	14,89	15,21
Measure of EER	7,56	7,52	7,6
Average EER	7,56		

8.4 Absorption chiller system

8.4.1 General

An absorption chiller unit is a functional system which generates cooling. The absorption chiller primarily utilizes waste heat to power the system, thereby reducing its need for electrical power compared to marine water chillers using an electrical-driven compressor.

The absorption chiller function is based on an electrical power input and three thermal sources:

— high temperature heat source (e.g. high temperature cooling circuit for main engine jacket water);

— medium temperature cooling source (e.g. low-temperature freshwater cooling circuit or seawater cooling circuit);

— low temperature heat source (e.g. chilled water circuit).

8.4.2 Definition of input and output

The input and output of an absorption chiller system consists of the following:

— Input: Heat energy from a high temperature heat source and electrical power.

— Output: Heat energy extracted from a low temperature heat source (chilled water).

8.4.3 Definitions of boundaries and media

The functional system boundaries are the connections to the absorption chiller unit (e.g. flanges to heat exchangers and electrical terminal connections), see Figure 8.7.

The absorption chiller unit is defined as either a single effect absorption chiller or a double effect absorption chiller, based on a lithium bromide as the absorbent and water as the refrigerant, or water as the absorbent and ammonia as the refrigerant.

Key
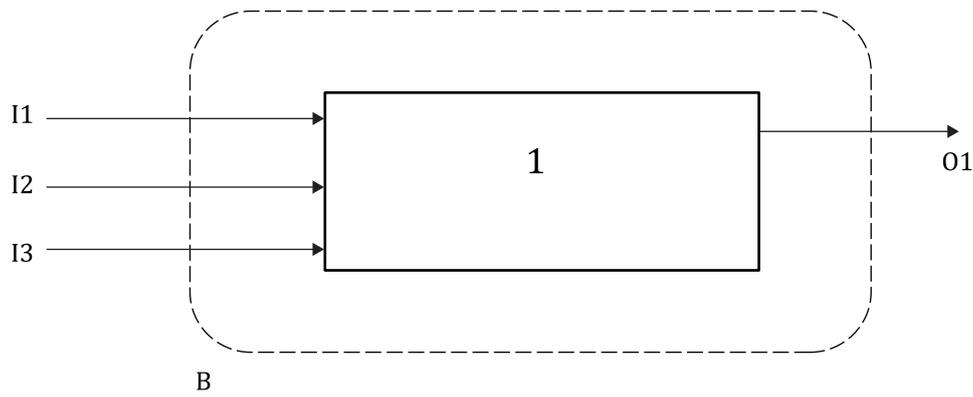
B   boundary

I1   electric power

I2   heat, high temperature

I3   heat, low temperature

O1   heat, medium temperature

1   absorption chiller unit

Figure 8.7 — Absorption chiller unit

8.4.4   Calculation method

The energy efficiency of the absorption chiller system is defined by the COP value.

As defined, the absorption chiller unit is run by an input of heat and electricity. Therefore, the COP is calculated as a thermal COP in Formula (8.9) and an electric COP in Formula (8.10):

$$COP_{\text{thermal}} = \frac{\dot{Q}_{\text{cooling}}}{\dot{Q}_{\text{heat}}} \tag{8.9}$$

$$COP_{\text{electric}} = \frac{\dot{Q}_{\text{cooling}}}{P_{\text{electric}}} \tag{8.10}$$

$$\dot{Q}_{\text{cooling}} = COP_{\text{thermal}} \cdot \dot{Q}_{\text{heat}} \tag{8.11}$$

$$\dot{Q}_{\text{heat}} = \frac{\dot{Q}_{\text{cooling}}}{COP_{\text{thermal}}} \tag{8.12}$$

$$P_{\text{electric}} = \frac{\dot{Q}_{\text{cooling}}}{COP_{\text{electric}}} \tag{8.13}$$

where

$\dot{Q}_{\text{cooling}}$ is the heat extracted from a low temperature heat source, expressed in kW;

$\dot{Q}_{\text{heat}}$ is the heat utilized from a high temperature heat source, expressed in kW;

P_{electric} is the electric power consumption, expressed in kW.

Results from Formulae (8.9), (8.10), (8.11), (8.12) and (8.13) shall be accompanied by the temperatures and flows from the three thermal sources.

8.4.5 Measuring method

In a real ship environment, the input energy and output energy are measured at the functional system boundaries.

The electrical energy consumption shall be measured with an electro-dynamometer or ammeter and a voltmeter. Heat consumption/extraction shall be measured by flowmeter and temperature difference by thermometers.

Measurements are taken at high temperature heat sources of 95 °C, 85 °C and 75 °C, and for the medium temperature cooling circuit of 32 °C, 25 °C and 20 °C. Alternatively, the measurement is taken according to the ambient conditions defined for tropical and tempered regions if seawater is used, and at low temperature heat sources of 16 °C and 12 °C. All temperatures are defined as inlet temperatures at the system boundary.

The calculated energy efficiency shall be valid in all dynamic conditions that can be expected in a marine environment.

The measuring point of $\dot{Q}_{\text{low temp}}$ shall be as close to the heat exchanger flanges as possible.

The measuring point of $\dot{Q}_{\text{high temp}}$ shall be as close to the heat exchanger flanges as possible.

The measuring point of P_{Electric} shall be as close to the electrical terminal connections as possible.

8.4.6 Example of measuring and calculation

Calculating the COP involves the following:

— Measuring condition:

— High temperature heat source: 85 °C

— Medium temperature cooling circuit: 25 °C

— Low temperature heat source: 16 °C

— Measured input and output energy:

— $\dot{Q}_{\text{heat}}$ = 440 kW

— $\dot{Q}_{\text{cooling}}$ = 316 kW

— $P_{\text{elec.}}$ = 13 kW

— $COP_{\text{thermal}} = \dfrac{316\,\text{kW}}{440\,\text{kW}} = 0{,}72$

— $COP_{\text{electric}} = \dfrac{316\,\text{kW}}{13\,\text{kW}} = 24{,}3$

Calculating the heat and electricity demand involves the following:

— Measuring condition:

— High temperature heat source: 85 °C

— Medium temperature cooling circuit: 25 °C

— Low temperature heat source: 16 °C

— Cooling demand: $\dot{Q}_{\text{cooling}}$ = 1,000 kW

— Thermal COP: COP_{thermal} = 0,72

— Electric COP: COP_{electric} = 24,3

— $\dot{Q}_{heat} = \dfrac{1,000\,kW}{0,72} = 1\,389\,kW$

— $P_{electric} = \dfrac{1,000\,kW}{24,3} = 41,2\,kW$

8.5 Compression-type water chilling system

8.5.1 General

This subclause is applicable to marine compression-type water chillers (hereinafter referred to as "water chillers") with electric drive and water as the heat source, excluding lithium bromide chiller (which is also known as "absorption chiller").

8.5.2 Definition of input and output

The input and output of a compression-type water chilling system consists of the following:

— Input: Total energy consumed from electric power.

— Output: Refrigerating capacity.

8.5.3 Definitions of boundaries and media

8.5.3.1 General

The unit consists of the following components: compressor, condenser, expansion valve, evaporator and electric control box (see Figure 8.8).

The boundary conditions of water chillers are divided into environmental boundary conditions (see 8.5.3.2) and equipment boundary conditions (see 8.5.3.3).
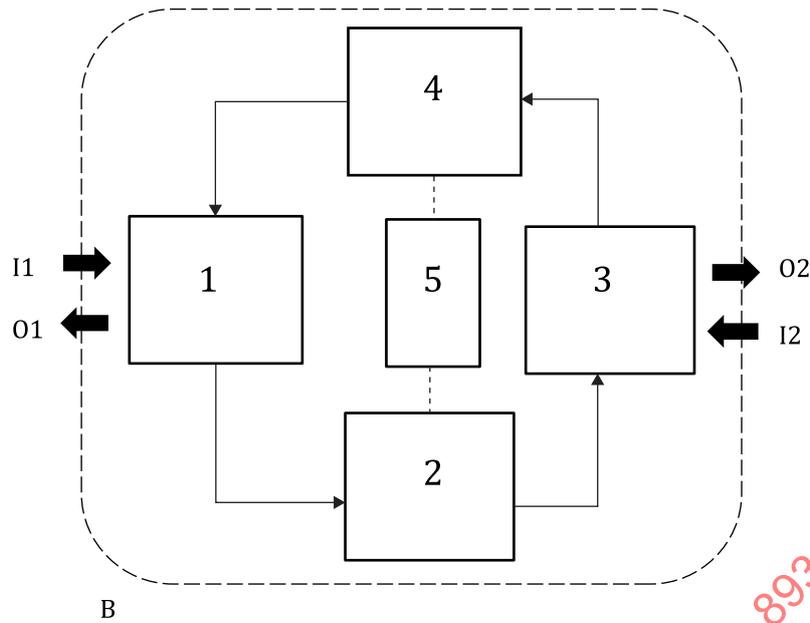
Key

B	boundary	1	condenser
I1	inlet of cooling water	2	expansion valve
I2	inlet of refrigerant water	3	evaporator
O1	outlet of cooling water	4	compressor
O2	outlet of refrigerant water	5	electronic control box

Figure 8.8 — Flow diagram for a single water chilling system

8.5.3.2   Environmental boundary conditions

Table 8.5 shows the temperature boundary of a marine water chiller under nominal working conditions.

Table 8.5 — Temperature boundary conditions under nominal working conditions for a compression-type water chilling system

Items	Refrigerant side		Cooling water side	
	Temperature at outlet °C	Refrigerant flow m^3/(h·kW)	Temperature at inlet °C	Cooling water flow[c] m^3/(h·kW)
Nominal working condition	7	0,172	32[a]	0,268
			36[b]	
[a] Cooling water is seawater.				
[b] Cooling water is fresh water in a central cooling water system.				
[c] Recommended value.				

8.5.3.3   Equipment boundary conditions

Water chillers can be divided into piston type, screw type and centrifugal type according to the types of compressors. Different types of compressors have different influences on the COP of chillers. Therefore, in industrial standards, there are different requirements for the limited values of COP of various types of chillers. The boundary conditions are shown in Figure 8.9.

Key

B   boundary
I1   electric power
I2   refrigerant water with high temperature
I3   cooling water
O1   refrigerant water with low temperature

1   water chilling unit

Figure 8.9 — Water chilling unit — Equipment boundary conditions

8.5.4   Calculation method

The energy efficiency of the compression-type water chilling unit is defined by the COP value.

The COP value is used to represent the full-load performance coefficient of the chiller under nominal working conditions. COP can be calculated as shown in Formulae (8.14) and (8.15):

$$COP = \frac{\dot{Q}_n}{P_0} \tag{8.14}$$

$$\dot{Q}_n = (T_{in} - T_{out})C \cdot q \cdot \rho \tag{8.15}$$

where

$\dot{Q}_n$ is the measured refrigerating capacity, expressed in kW;

P_0 is the total consumed power, expressed in kW;

T_{in} is the temperature at inlet of refrigerant, expressed in °C;

T_{out} is the temperature at outlet of refrigerant, expressed in °C;

C is the specific heat capacity of refrigerant, expressed in J/(kg·°C);

Q is the flow of refrigerant, expressed in m³/h;

ρ is the density of refrigerant, expressed in kg/ m³.

$\dot{Q}_n$ is tested and calculated under the environmental conditions given in Table 8.5. The layout of measuring points is shown in Figure 8.10. P_0 is the total input electric power from the compressor motor, oil pump motor and operation control circuit (electric control box).

Key

B   boundary
I1   inlet of cooling water
I2   inlet of refrigerant water
O1   outlet of cooling water
O2   outlet of refrigerant water
M1   measured inlet flow and temperature – cooling water
M2   measured outlet temperature – cooling water
M3   measured consumed power
M4   measured inlet flow and temperature of refrigerant water
M5   measured outlet temperature of refrigerant water

1   condenser
2   expansion valve
3   evaporator
4   compressor
5   electronic control box

Figure 8.10 — Compression-type water chilling system — Layout of measuring points

8.5.5   Measuring method

It is recommended to make the measurements in a laboratory environment.

Use a dynamometer to test the input power of the water chiller. Install a flow meter and a thermometer on a refrigerant pipeline and on a cooling water pipeline. After the equipment is in working condition, measure the flow rate and temperature difference of the refrigerant. Calculate the refrigerating capacity of the water chiller.

8.5.6   Example of measuring and calculation

Take a water chiller on board as an example:

— make the test under marine environmental boundaries;

— record the flow and temperature on the refrigerant water side and cooling water side;

— calculate the unit refrigerating output;

— measure the consumed power;

— calculate the COP of the compression-type water chilling unit;

— measure at least three times and calculate the average energy efficiency, see Table 8.5.

Table 8.5 — Calculation and measurement of energy efficiency

Parameter	1	2	3
Temperature at outlet of refrigerant (°C)	6,98	6,97	6,96
Temperature at inlet of refrigerant water (°C)	11,17	11,17	11,16
Flow of refrigerant water (m³/h)	35,00	35,11	35,05
Temperature at outlet of cooling water (°C)	36,31	36,36	36,42
Temperature at inlet of cooling water (°C)	31,76	31,81	31,86
Flow of cooling water (m³/h)	40,03	40,13	40,13
Refrigeration capacity (kW)	171,418	172,180	175,320
Measure of consumed power (kW)	40,95	41,02	41,50
Measure of COP	4,186	4,197	4,224
Average COP	4,202		

9 Mechanical functional systems

9.1 General

A mechanical-driven functional system is a number of components and connections between those components, whose combined key functionality is to perform mechanical work.

Examples of these systems on a ship include:

— propulsion shafting system (see 9.2);

— deck crane system (see 9.3);

— ship anchor winch system (see 9.4);

— steering gear system (see 9.5).

9.2 Propulsion shafting system

9.2.1 General

The method described in this subclause covers the propulsion shafting systems of main transport ships such as container ships, oil tankers and bulk carriers. Other types of ships can also be referred to.

9.2.2 Definition of input and output

The input and output of a propulsion shafting system consists of the following:

— Input: Power and energy input by the gearbox (the output power and energy of the engine).

— Output: Power and energy output by the stern bearing (the input power and energy of the propeller).

9.2.3 Definitions of boundaries and media

The input boundary of the system is the energy output end of the engine. The output boundary is the energy input end of the propeller.

The system composition includes a gear box (equipped with medium-speed main engine), elastic coupling, thrust bearing, intermediate bearing, shaft seal and stern bearing, as shown in Figure 9.1.
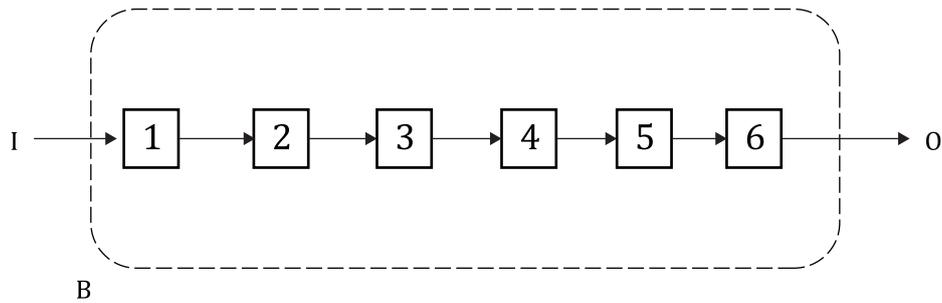
Key

B	boundary
I	engine input, P_{in}
O	propeller output, P_{out}

1 gearbox
2 elastic coupling
3 thrust bearing
4 intermediate bearing
5 shaft seal
6 stern bearing

Figure 9.1 — Composition and boundary diagram of propulsion shafting system

9.2.4 Calculation method

9.2.4.1 General

The energy effect of the propulsion shafting system is calculated in accordance with Formula (9.1):

$$\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot \eta_6 \tag{9.1}$$

where

η_1 is the efficiency of the gearbox, expressed in per cent;

η_2 is the efficiency of the elastic coupling, expressed in per cent;

η_3 is the efficiency of the thrust bearing, expressed in per cent;

η_4 is the efficiency of the intermediate bearing, expressed in per cent;

η_5 is the efficiency of the shaft seal, expressed in per cent;

η_6 is the efficiency of the stern bearing, expressed in per cent.

The output power of the system can be calculated in accordance with Formula (9.2):

$$P_{out} = P_{in} \cdot \eta \tag{9.2}$$

where

P_{out} is power at the output of the stern bearing, expressed in kW;

P_{in} is the output power of the engine, expressed in kW.

If the elements corresponding to η_1 to η_6 in Formula (9.1) do not exist in the system, the value is 1.

9.2.4.2 Energy efficiency of components

According to the energy efficiency data of products in the industry which were obtained by investigation, the average energy efficiency, η_a, of the components and the values η_{nmin} and η_{nmax} of the propulsion shafting system components were given.

9.2.4.3 Average energy efficiency of system

The average energy efficiency of the system, η_{na}, can be calculated from the average energy efficiency of the components, η_{pa}, see Formula (9.3):

$$\eta_{na} = \eta_{1a} \cdot \eta_{2a} \cdot \eta_{3a} \cdot \eta_{4a} \cdot \eta_{5a} \cdot \eta_{6a} \tag{9.3}$$

9.2.4.4 System energy efficiency value

According to the average energy efficiency, η_a, of components and the energy efficiency distribution of industrial products, the value of the propulsion shafting system energy efficiency, η_{pf}, can be analysed and proposed.

9.2.5 Measuring method

In a real ship environment, the input power and output power of the system are, respectively, measured by a dynamometer at the output shafting of the engine and at the output end of the stern bearing, as shown in Figure 9.2, where the power measurement at the output end is carried out underwater.
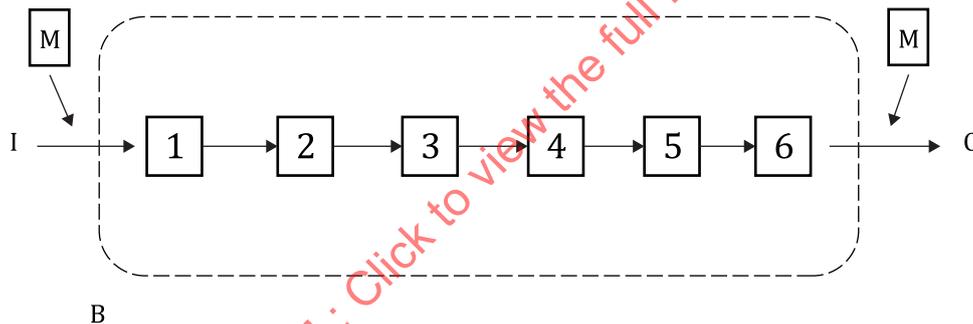
Key

B	boundary	1	gearbox
I	engine input, P_{in}	2	elastic coupling
O	propeller output, P_{out}	3	thrust bearing
M	measuring point	4	intermediate bearing
		5	shaft seal
		6	stern bearing

Figure 9.2 — Scheme diagram of the measurement

The measuring point of P_{in} is the output shafting of the engine.

NOTE   If there is no space at the output of the engine, the following formula can be used: $P_{in} = T_E \cdot V_E$, where T_E is the torque of the engine, expressed in kNm, and V_E is the speed of the engine, expressed in r/min.

The test conditions are operating points near 50 %, 75 %, 90 % and 100 % of the maximum continuous rated power (MCR).

The measuring point of P_{out} is at the output end of the stern bearing.

Some watertight and remote test measures are necessary. Future solutions (e.g. underwater dynamometers, embedded wires in the hollow shaft) can be chosen.

The test conditions will be according to the test conditions of P_{in}.

The actual energy efficiency of the propulsion shafting system can be calculated from the measured data, se Formula (9.4):

$$\eta = \frac{P_{out}}{P_{in}} \tag{9.4}$$

Carry out the actual energy efficiency, compare it with the system energy efficiency calculated in accordance with Formula (9.1) and then improve the energy efficiency calculation model.

9.3 Deck crane system

9.3.1 General

The method described in this subclause is applicable to marine deck cranes.

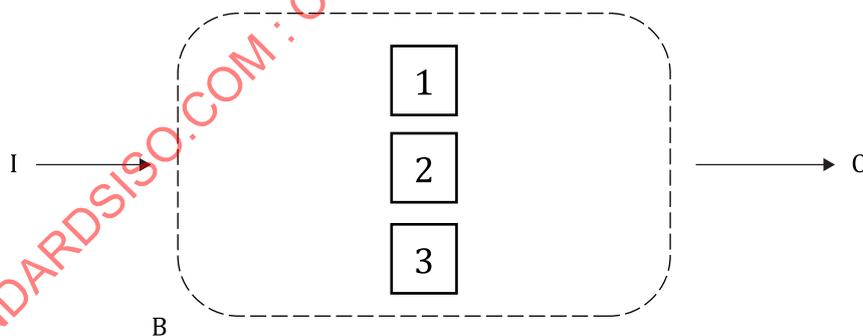The deck crane system consists of a lifting mechanism, luffing mechanism and slewing mechanism.

9.3.2 Definition of input and output

The input and output of a deck crane system consists of the following:

— Input: Energy consumed by the crane to complete a work cycle as required.

— Output: Effective energy that should be consumed theoretically when the crane completes a work cycle as required.

9.3.3 Definitions of boundaries and media

The input boundary of the system is the energy output end that the hull supplies power to the crane. The output boundary is the effective potential energy and kinetic energy generated by the goods and lifting appliances (excluding the potential energy and kinetic energy generated by the lowering action) during the crane's primary cargo handling. A schematic illustration of the boundaries is shown in Figure 9.3.

Key

B	boundary	1	lifting mechanism
I	energy delivered to the crane, E_{in}	2	luffing mechanism
O	effective energy delivered to the goods, E_{out}	3	slewing mechanism

Figure 9.3 — Boundaries of the deck crane system

9.3.4 Calculation method

In one operation cycle, the effective energy consumed by the crane in theory is calculated in accordance with Formula (9.5):

$$E_O = E_{RH} + E_{LD} + E_{SL} + E_{RD} + E_{NH} + E_{LU} + E_{SR} + E_{ND} \tag{9.5}$$

where

E_0 is the effective energy that should be consumed theoretically in a working cycle of the crane, expressed in kJ;

E_{RH} is the effective energy that should be consumed in theory when lifting under rated load, expressed in kJ;

E_{LD} is the effective energy that should be consumed in theory when luffing downward under rated load, expressed in kJ;

E_{RD} is the effective energy that should be consumed in theory when lowering down under rated load, expressed in kJ;

E_{SL} is the effective energy that should be consumed in theory when slewing to the left under rated load, expressed in kJ;

E_{NH} is the effective energy that should be consumed in theory when lifting under no-load, expressed in kJ;

E_{LU} is the effective energy that should be consumed in theory when luffing upward under no-load, expressed in kJ;

E_{SR} is the effective energy that should be consumed in theory when slewing to the right under no-load, expressed in kJ;

E_{ND} is the effective energy that should be consumed in theory when lowering down under no-load, expressed in kJ.

Theoretically, the effective energy to be consumed for lifting under rated load shall be calculated in accordance with Formula (9.6):

$$E_{RH} = (G + G_H) \cdot g \cdot H_1 + \frac{1}{2}(G + G_H) \cdot v_1^2 \tag{9.6}$$

where

G is the rated load mass, expressed in kg;

G_H is the mass of lifting appliance, expressed in kg;

g is the acceleration of gravity, expressed in m/s²;

H_1 is the lifting height, expressed in m;

t_{RH} is the time for lifting under rated load, expressed in s;

v_1 is the average lifting speed at rated load, expressed in m/s.

Theoretically, the effective energy to be consumed for luffing downward under rated load is calculated in accordance with Formula (9.7):

$$E_{LD} = (G + G_H) \cdot g \cdot (H_{R2} - H_{R1}) + \frac{1}{2} \cdot (G + G_H) \cdot \left(\frac{R_2 - R_1}{t_{LD}} \right)^2 + \frac{1}{2} \cdot (G + G_H) \cdot \left(\frac{H_{R2} - H_{R1}}{t_{LD}} \right)^2 \qquad (9.7)$$

where

G is the rated load mass, expressed in kg;

G_H is the mass of lifting appliance, expressed in kg;

H_{R1} is the cargo height of crane before luffing, expressed in m;

H_{R2} is the cargo height of crane after luffing, expressed in m;

R_2 is the working radius of crane after luffing, expressed in m;

R_1 is the working radius of crane before luffing, expressed in m;

g is the acceleration of gravity, expressed in m/s^2;

t_{LD} is the time for luffing downward under rated load, expressed in s.

The effective energy that should be consumed theoretically for slewing to the left under rated load is calculated in accordance with Formula (9.8):

$$E_{SL} = \frac{1}{2} \cdot (J + J_H) \cdot \omega^2 \qquad (9.8)$$

where

J is the rated load mass moment of inertia, expressed in kg·m^2;

J_H Is the mass moment of inertia of spreader, expressed in kg·m^2;

t_{SL} is the time for slewing to the left under rated load, expressed in s;

ω is the average slewing angular speed, expressed in rad/s.

Theoretically, the effective energy to be consumed for lifting under no-load shall be calculated in accordance with Formula (9.9):

$$E_{NH} = G_H \cdot g \cdot H_1 + \frac{1}{2} \cdot G_H \cdot v_2^2 \qquad (9.9)$$

where

G_H is the mass of lifting appliance, expressed in kg;

H_1 is the lifting height of lifting appliance, expressed in m;

t_{NH} is the time for lifting under no load, expressed in s;

g is the acceleration of gravity, expressed in m/s^2;

v_2 is the no-load average lifting speed, expressed in m/s.

Theoretically, the effective energy to be consumed for luffing upward under no-load shall be calculated in accordance with Formula (9.10):

$$E_{LU} = G_H \cdot g \cdot (H_{R2} - H_{R1}) + \frac{1}{2} \cdot G_H \cdot \left(\frac{R_2 - R_1}{t_{LU}} \right)^2 + \frac{1}{2} \cdot G_H \cdot \left(\frac{H_{R2} - H_{R1}}{t_{LU}} \right)^2 \qquad (9.10)$$

where

G_H is the mass of the lifting appliance, expressed in kg;

H_{R1} is the lifting appliance height of the crane before luffing, expressed in m;

H_{R2} is the lifting appliance height of the crane after luffing, expressed in m;

R_2 is the working radius of the crane after luffing, expressed in m;

R_1 is the working radius of the crane before luffing, expressed in m;

g is the acceleration of gravity, expressed in m/s^2;

t_{LU} is the time for luffing upward under no-load, expressed in s.

Theoretically, the effective energy to be consumed for slewing to the right under no-load is calculated in accordance with Formula (9).11:

$$E_{SR} = \frac{1}{2} \cdot J_H \cdot \omega^2 \qquad (9.11)$$

where

J is the rated load mass moment of inertia, expressed in kg·m^2 ;

J_H is the mass moment of inertia of spreader, expressed in kg·m^2 ;

t_{SR} is the time for slewing to the right under no-load, expressed in s;

ω is the average slewing angular speed, expressed in rad/s.

Theoretically, the effective energy to be consumed for lowering under rated load is calculated in accordance with Formula (9.12):

$$E_{RD} = \frac{1}{2} \cdot (G + G_H) \cdot v_3^2 \qquad (9.12)$$

where

G is the rated load mass, expressed in kg;

G_H is the mass of the lifting appliance, expressed in kg;

t_{SR} is the time for lowering under rated load, expressed in s;

v_3 is the average lowering speed at rated load, expressed in m/s.

Theoretically, the effective energy to be consumed for lowering under no-load is calculated in accordance with Formula (9.13):

$$E_{ND} = \frac{1}{2} \cdot G_H \cdot v_4{}^2 \qquad (9.13)$$

where

G_H is the mass of the lifting appliance, expressed in kg;

t_{ND} is the time for lowering under no-load, expressed in s;

v_4 is the average lowering speed with no load, expressed in m/s.

The total time for working cycle is calculated theoretically in accordance with Formula (9.14):

$$t_O = t_{RH} + t_{LD} + t_{RD} + t_{SL} + t_{NH} + t_{LU} + t_{SR} + t_{ND} \qquad (9.14)$$

The average effective power that should be consumed theoretically in a working cycle is calculated in accordance with Formula (9.15):

$$P_{out} = \frac{E_o}{t_O} \qquad (9.15)$$

where

E_o is the effective energy that should be consumed theoretically in a working cycle of the crane, expressed in kJ;

t_o is the total time for working cycle, expressed in s.

The energy efficiency of crane operation is calculated in accordance with Formula (9.16):

$$\eta = \frac{P_{out}}{P_{in}} \qquad (9.16)$$

where

P_{out} is the average effective power that should be consumed theoretically in a working cycle of the crane, expressed in kW;

P_{in} is the power consumption during crane operation cycle, expressed in kW.

9.3.5 Measuring method

The measurement environment requires the following conditions:

— The wind speed shall be less than 3 m/s.

— During the test, the inclination of the slewing plane of the crane shall not be greater than 2,5°.

— During the test, the deviation between the load mass and the specified value shall not be greater than ±5 %.

— The deviation between the crane power supply voltage and the rated value shall be within −10 % to 10 %. The unbalance rate of three-phase voltage shall not be greater than 1,5 %.

The measurement scheme requires the following steps:

— The crane shall complete three times the working cycle described in Formula (9.5).

— The electric energy measuring instrument shall be used to measure the electric energy consumed by the crane in a single operation cycle.

— Measure the lifting and slewing speed of the crane and the time required for the crane to complete the action.

The measurement evaluation requires the following steps:

— According to the measured data, calculate the actual energy efficiency within the crane operation cycle in accordance with Formula (9.16).

— Take the average value of three calculations as the actual energy efficiency.

9.4   Ship anchor and mooring winch system

9.4.1   General

The method described in 9.4.2 to 9.4.5 is applicable to the anchor and mooring winch system equipment of container ships, oil tankers, bulk carriers and other main transport ships.

### 9.4.2   Definition of input and output

The input and output of a ship anchor and mooring winch system consists of the following:

— Input: Power and energy input by the power system (power and energy output by the electric motor).

— Output: Power and energy output of the anchor chain wheel or mooring drum.

9.4.3   Definitions of boundaries and media

The input boundary of the system is the energy output end of the electric motor. The output boundary is the energy output of the anchor chain wheel or mooring drum of the anchor winch system.

The system consists of an electric motor, hydraulic pump, hydraulic motor, transmission gear, bearing, clutch, anchor chain wheel and/or mooring drum and band brake assembly, as shown in Figure 9.4.
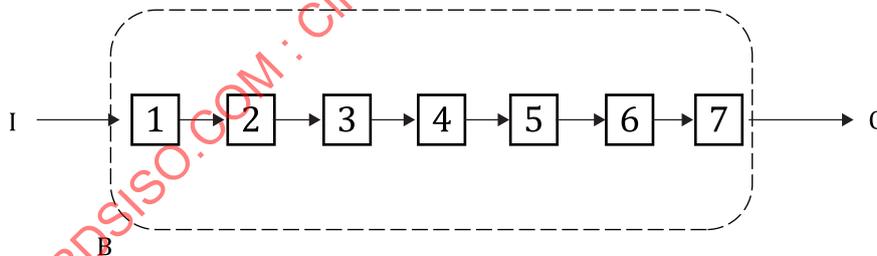
Key

B	boundary	1	hydraulic pump
I	electric motor input, P_{in}	2	hydraulic motor
O	anchor chain wheel or mooring drum output, P_{out}	3	transmission gear
		4	roller bearing
		5	plain bearing
		6	clutch
		7	band brake

Figure 9.4 — Composition of anchor and mooring winch system

9.4.4　Calculation method

The system energy efficiency of the anchor and mooring winch system is calculated in accordance with Formula (9.17):

$$\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot \eta_6 \cdot \eta_7 \tag{9.17}$$

where

η_1　is the hydraulic pump efficiency, expressed in per cent;

η_2　is the hydraulic motor efficiency, expressed in per cent;

η_3　is the transmission gear efficiency, expressed in per cent;

η_4　is the efficiency of rolling bearing, expressed in per cent;

η_5　is the plain bearing efficiency, expressed in per cent;

η_6　is the clutch efficiency, expressed in per cent;

η_7　is the winding efficiency of band brake, expressed in per cent.

The efficiency of the above components is the total efficiency. If there are multiple transmission gears, the total efficiency of the transmission gear, η_3, is calculated.

If the elements corresponding to η_1 to η_7 in Formula (9.17) do not exist in the system, the value is 1.

The output power of the anchor system shall be calculated in accordance with Formula (9.18):

$$P_{\text{out}} = \left(\frac{\rho_c \cdot g \cdot l_{\text{out}}^2}{2} + m_a \cdot g \cdot l_a \right) / t_1 = P_{\text{in}} \cdot \eta \tag{9.18}$$

where

P_{out}　is the power output of the anchor chain wheel, expressed in kW;

ρ_c　is the linear mass of the anchor chain, expressed in kg/m;

g　is the gravitational acceleration, expressed in m/s^2;

l_{out}　is the length of the dropout anchor chain, expressed in m;

m_a　is the mass of the anchor, expressed in kg;

l_a　is the vertical depth of the dropout anchor, expressed in m;

t_1　is the time for operation, expressed in s;

P_{in}　is the input power of the electric motor, expressed in kW.

The output power of the mooring system shall be calculated in accordance with Formula (9.19):

$$P_{\text{out}} = \frac{F_{\text{out}} \cdot V_{\text{out}}}{60} = P_{\text{in}} \cdot \eta \tag{9.19}$$