Influence of ambient temperature conditions

MAN Energy Solutions
Future in the making

Contents

This paper provides crucial guidance for marine two-stroke engine operation in varying climates. It covers engine start-up procedures, engine room ventilation, and operation in different conditions. It focuses on reference conditions set by the International Standard Organization (ISO) and the capabilities of MAN B&W engines to operate efficiently across a wide range of temperatures. The study highlights the importance of cooling water temperature, scavenge air cooling, and the use of an Arctic Bypass system in extreme cold environments. The paper also introduces the Economiser energy control (EEC) feature for increased service steam production in colder temperatures, demonstrating the adaptability of these engines to diverse climates. By following these recommendations, operators can ensure efficient and reliable engine performance, mitigating issues and extending the engine longevity.

Introduction

Marine two-stroke engines used as prime movers on ships are exposed to the varying climatic temperature conditions that occur in different parts of the world. The engines must therefore be able to operate under all ambient conditions, from winter to summer, and from arctic to tropical areas.

As the temperature variations on the surface of the sea are rather limited, the marine two-stroke engine will not normally be exposed to extreme temperatures. However, the changes in ambient conditions that do take place will, among other things, cause changes in specific fuel oil consumption, exhaust gas amount, and exhaust gas temperature of the marine engine.

These changes are already described in our Project Guides and will therefore not be discussed in this paper.

Furthermore, the varying climatic conditions will result in changes in scavenge air properties, compression and maximum firing pressures, which at very low ambient air temperatures may require adjustment of individual engine parameters to allow unrestricted operation of the engine.

This paper describes our recommendations for load-up procedures for engine start-up, supply of ventilation air to the engine room, and engine operation under normal, high, and extremely low ambient temperature conditions.

The paper has been divided into three chapters which can be read independently. The three chapters are entitled:

1. Temperature restrictions and load-up procedures for engine start-up
2. Ventilation of engine rooms
3. Main engine operation in different ambient conditions.

Temperature restrictions and load-up procedures for engine start-up

Before starting an engine, it is imperative to adhere to specific minimum temperature restrictions and load-up procedures to safeguard the engine against mechanical and thermal overload during start-up and to protect against cold corrosion, which primarily affects ships running on high-sulphur fuels.

It is also crucial to ensure a sufficient duration of the load-up process to allow the auxiliary system adequate time to adapt. Therefore, the engine load-up program plays a vital role in preventing mechanical and thermal overload during the load-up process. It accomplishes this by carefully controlling the rate at which the load is increased. Moreover, it facilitates a critical function by providing ample time for the auxiliary system to adapt, thereby guaranteeing a smooth and efficient operation of the engine.

The load-up procedures for engines with:
- minimum jacket cooling water temperature of 50°C (warm engine)
- minimum jacket cooling water temperature of 20°C (cold engine)

are valid for all MAN B&W two-stroke engines irrespective of the fuel type (HFO, VLSFO, LNG, and methanol).

Note: The recommendations given in the following are based on the assumption that the engine has already been well run in.

Start of warm engine – normal load-up procedures

The load-up procedures recommended for a normal engine start are shown in Table 1.

The normal load-up procedures must be followed when the cooling water of the engine has a minimum temperature of 50°C, otherwise, exceptional load procedures must be followed.

As seen from Table 1 for MAN B&W two-stroke engines coupled to fixed pitch propellers (FPPs), it is advisable to maintain a minimum engine jacket cooling water temperature of 50°C before initiating engine start-up. The loading process should be gradual, reaching up to 80% of the specified maximum continuous rating speed (SMCR rpm). Subsequently, a further loading to achieve 100% SMCR speed should align with the recommended time intervals in Table 1.

Similarly, for MAN B&W two-stroke engines coupled to controllable pitch propellers (CPPs), the same minimum engine jacket cooling water temperature of 50°C is recommended before commencing engine start-up. The loading process should be gradually progressing to 50% of SMCR power. A further loading to reach 100% SMCR power should adhere to the recommended time intervals specified in Table 1.

Adhering to the temperature and loading guidelines is crucial to ensure a safe and efficient operation of both types of propulsion systems. By following these procedures, potential issues such as mechanical overload, overheating, and cold corrosion (especially for vessels operating on high-sulphur fuels) can be prevented.

In summary, strict compliance with the specified temperature and loading procedures outlined in Table 1 is essential for the reliable and optimal performance of MAN B&W two-stroke engines coupled to FPPs and CPPs. Following the procedures will contribute to the safety and longevity of marine engines.

Recommended start of engine for normal, low-load operation

For engines normally running at low load, 10–40% load, an extra slow load-up procedure is recommended compared with the load-up procedures in Table 1.

Table 2 shows the recommended extra slow load-up procedure: minimum 30 minutes to go from 10 to 40% load, and minimum 60 minutes to go from 40 to 75% load.

Warm engine – load-up procedure

	FPP plants	
Engine load [% SMCR speed]*	Mk. 9+ and 80-bore or larger	All other engines
0–80	Increase gradually	Increase gradually
80–90	Over 60 minutes	Over 30 minutes
90–100	Over 90 minutes	Over 60 minutes

	CPP plants	
Engine load [% SMCR power]*	Mk. 9+ and 80-bore or larger	All other engines
0–50	Increase gradually	Increase gradually
50–75	Over 60 minutes	Over 30 minutes
75–100	Over 90 minutes	Over 60 minutes

Table 1: Load procedures for engines with a minimum jacket cooling water temperature of 50°C
* The provided time intervals should be added, for FPP plants, for example, an engine warm-up from 80 to 100% SMCR speed will take 60 + 90 min. = 150 min.

Low-load operation

Engine load [% SMCR power]*	
10–40	Minimum 30 minutes
40–75	Minimum 60 minutes

Table 2: Normal, low-load operation
* The time intervals should be added – see example in Table 1

Start of cold engine – exceptional load-up procedures

The exceptional load-up procedures recommended for a cold engine are shown in Table 3.

It is a requirement for the guideline in Table 3, that the engine cooling water has a minimum temperature of 20°C. If the jacket cooling water (JCW) temperature is below 20°C, the engine must not be started.

Under exceptional circumstances where it is not possible to adhere to the standard recommendations in Table 1, a minimum jacket cooling water temperature of 20°C can be considered acceptable for starting MAN B&W two-stroke engines coupled to FPPs. The engine may then be loaded gradually to reach 80% of SMCR rpm. However, before exceeding 80% SMCR rpm, it is essential to ensure that a minimum jacket water temperature of 50°C has been reached, see Table 2.

Similarly, for MAN B&W two-stroke engines coupled to CPPs, under exceptional circumstances where it is not feasible to follow the regular recommendations in Table 3, a minimum jacket water temperature of 20°C can be deemed acceptable before initiating an engine start-up. The engine can be loaded slowly to achieve 50% of SMCR rpm. Nevertheless, before surpassing 50% SMCR rpm, it is imperative to confirm that a minimum jacket water temperature of 50°C has been achieved, see Table 3.

Even in exceptional cases, adherence to these temperatures and loading provisions is crucial, in order to ensure the safe and reliable operation of both types of propulsion systems. By following these procedures, potential issues such as mechanical stress, overheating, and cold corrosion can be mitigated, particularly for vessels operating on high-sulphur fuels.

In summary, strict compliance with the specified temperature and loading protocols, as outlined in Table 2 and Table 3, when exceptional circumstances arise, is essential for maintaining the safety and longevity of MAN B&W two-stroke engines coupled to FPPs and CPPs.

The time period required for increasing the jacket water temperature from 20°C to 50°C depends on the amount of water in the jacket cooling water system, and on the engine load.

Cold engine – load-up procedure

	FPP plants	
Engine load [% SMCR speed]*	Mk. 9+ and 80-bore or larger	All other engines
0–80	Increase gradually until the jacket cooling water temperature reaches 50°C	Increase gradually until the jacket cooling water temperature reaches 50°C
80–90	Over 60 minutes	Over 30 minutes
90–100	Over 90 minutes	Over 60 minutes

	CPP plants	
Engine load [% SMCR power]*	Mk. 9+ and 80-bore or larger	All other engines
0–50	Increase gradually until the jacket cooling water temperature reaches 50°C	Increase gradually until the jacket cooling water temperature reaches 50°C
50–75	Over 60 minutes	Over 30 minutes
75–100	Over 90 minutes	Over 60 minutes

Table 3: Load procedures for engines with a minimum jacket cooling water temperature of 20°C
* The time intervals should be added – see example in Table 1

Preheating during standstill periods

During short stays in ports (less than four to five days), it is recommended to keep the engine preheated by a built-in preheater in the jacket cooling water system, or by using the auxiliary engine cooling water, or a combination. This is to prevent:

- corrosive attacks on cylinder liners during starting
- temperature variations in the engine structure
- corresponding variations in thermal expansions and the resulting risk of leakages

The engine jacket cooling water outlet temperature should be kept as high as possible, but not higher than 80°C, and if the temperature is lower than 50°C, it should be increased to min. 50°C before start-up.

Jacket cooling water system with a built-in preheater

There are two options for the position of the preheater in the jacket cooling water system. The first option in Fig. 1 has a separate preheater pump, and the second option in Fig. 2 uses the jacket water pump as the preheater pump. In both options, preheater operation is controlled by a temperature sensor after the engine outlet.

The preheating flow capacity of the preheater pump must be approx. 10% of the jacket water pump capacity. The jacket water pump capacity can be found in CEAS in table of capacities.

It is far less efficient to use the jacket water pump as preheating pump during port stays (Fig. 2) compared to a separate small dedicated preheating pump (Fig. 1). This is valid even if the jacket water pump can be specified as a two-speed pump with one speed setting for normal engine running mode and one speed setting for port stays. It should be highlighted that when the main engine is running, it is a requirement that the pump runs at 100% capacity.

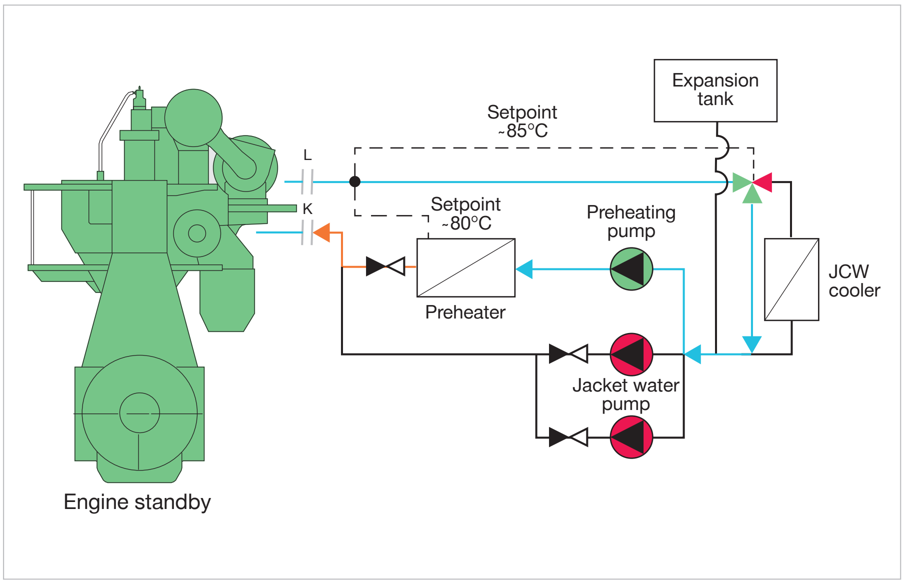


Fig. 1: Simplified sketch of installed preheater with dedicated preheater pump

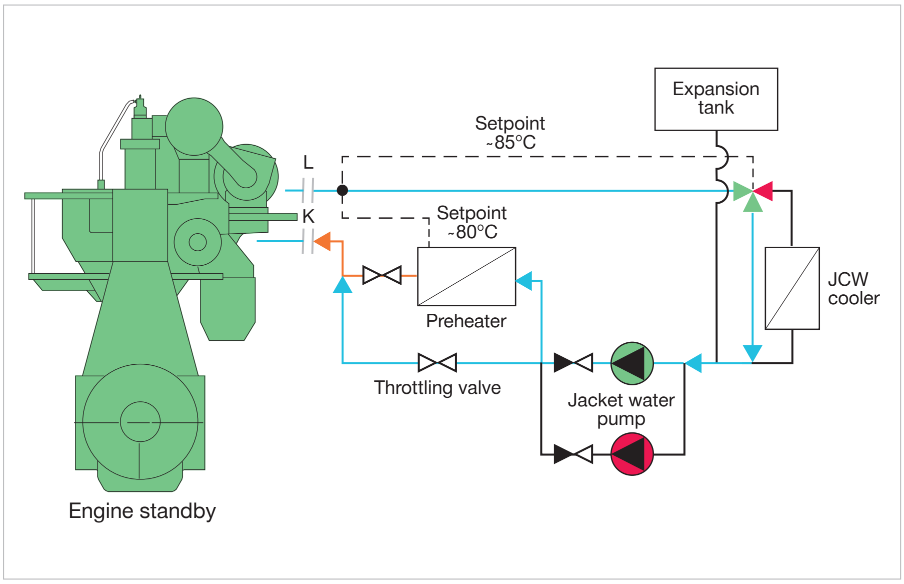


Fig. 2: Simplified sketch of installed preheater using the jacket water pump

Table 4 shows the results of comparing the pump electric power for three options, based on the engine type: 6G60ME-C10.5 with an SMCR of 17,040 kW at 103.0 r/min, as an example.

The preheater heating capacity depends on the required temperature increase of the engine jacket water and the required preheating time. Fig. 3 shows the temperature increase and time relations.

In general, a temperature increase of about 35°C (from 15 to 50°C) is required, and a corresponding preheating time of 12 hours requires a preheater capacity of about 1% of nominal maximum continuous rating (NMCR), also known as 'L1' in the engine layout diagram.

When preheating an engine in arctic areas, the required temperature increase may be higher, possibly 45°C or even higher, and therefore a larger preheater capacity is required.

The curves in Fig. 3 are based on the assumption that the engine and the engine room are of equal temperatures at the start of preheating. It is assumed that the temperature will increase uniformly across the engine structure during preheating, and for this reason, steel masses and engine surfaces in the lower part of the engine are also included in the calculation. The results of the preheating calculations may therefore be somewhat conservative.

Steam, thermal oil, or electricity can be specified as the heating medium for the preheater, depending on what is preferred. It is recommended that the pressure drop across the preheater for the jacket water part is specified to approximately 0.2 bar at the aforementioned flow of 10% jacket water pump capacity.

Since either steam, thermal oil, or electricity is used as heat input to the jacket water preheater during port stays, it is important to ensure this heat is used as efficiently as possible. It is important that energy is not lost partly through the pipe walls in the pipe system, and partly through the temperature-regulating three-way valve. For the piping system, we therefore recommend that the entire circulation system in the engine room is properly insulated.

Preheater sizes indicated in % of engine NMCR power

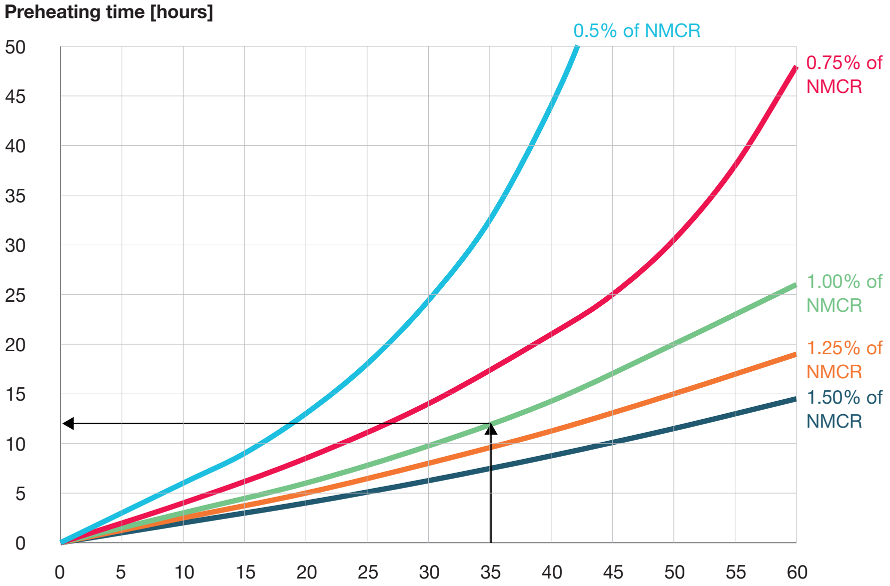
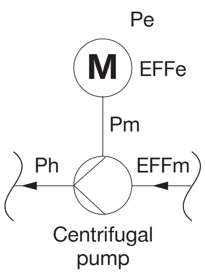


Fig. 3: Temperature increase and corresponding preheating time curves shown for different preheater sizes in percentage of engine nominal maximum continuous rating (NMCR) power

Example



Description	Unit	Preheating pump (Fig. 1)	Jacket water pump (Fig. 2) Normal engine running mode	Jacket water pump (Fig. 2) Harbour mode
Pump speed		100%	100%	50%
Pump capacity (Q)	m^3/h	13.0	130.0	65.0
Pressure head (Hp)	bar	0.6	3.2	1.0
Hydraulic power (Ph)	kW	0.22	11.56	1.81
Mechanical efficiency (EFFm)		70%	70%	70%
Mechanical power (Pm)	kWm	0.31	16.51	2.58
Electrical motor efficiency (EFFe)		98%	98%	98%
Electrical power (Pe)	kWe	0.32	16.84	2.63

Table 4: Example comparing electric power consumption for the various options

During preheating, the temperature-regulating three-way valve automatically moves to the position: ‘full jacket cooling water cooler bypass’, that is, valve port A fully open, see Fig. 4.

The reason is that the 85°C setpoint used during engine operation cannot be maintained while the engine is stopped, and during preheating. It is therefore important that no internal leakage occurs in this valve through valve port B, see Fig. 4. Such a leak will send part of the water through the jacket water cooler, where it will be cooled unnecessarily and energy will be lost. It is recommended to specify the temperature-regulating three-way valve with the lowest possible leakage, defined by a high leakage classification number, see “Control Valves – Leakage Classification” according to standard ANSI/FCI 70-2 2006 (European equivalent standard IEC 60534-4) [1].

Preheating with auxiliary engine cooling water

Preheating of the engine can be achieved with auxiliary engine cooling water, and Fig. 5 indicates how such a setup can be made.

MAN Energy Solutions recommends that the main engine and auxiliary cooling systems are separated when the main engine is in operation. This is the reason for the proposed interlock between the changeover valves in Fig. 5 which prevents simultaneous operation of the valves.

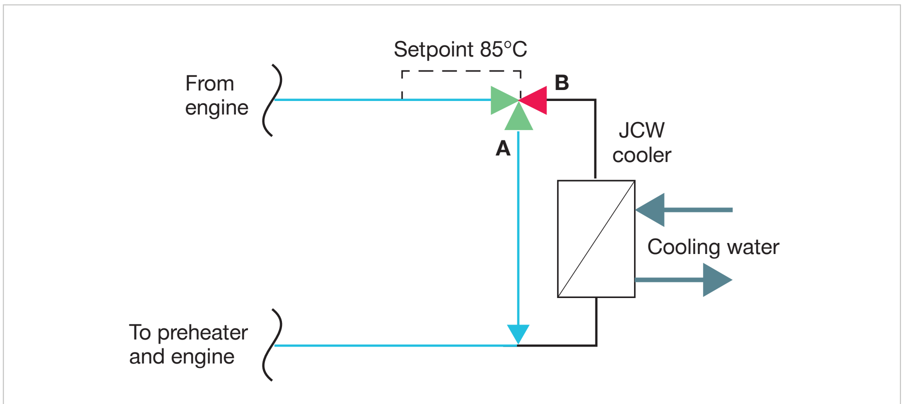


Fig. 4: Standard installation of jacket water temperature-regulating three-way valve

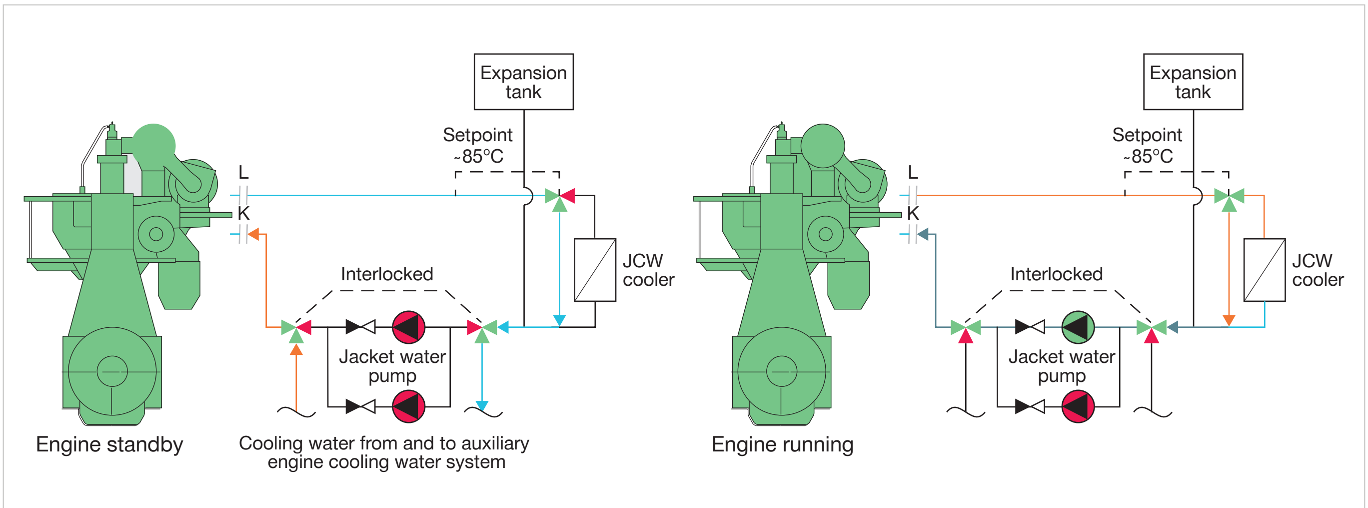


Fig. 5: Preheating using the cooling water discharge from auxiliary engines

Ventilation of engine rooms

The engine room ventilation system plays a pivotal role in optimising the ship's performance and maintaining ambient conditions, including air temperature, air supply, and pressure, within the recommended limits to ensure an acceptable and optimal operation of the main engine and other equipment.

The primary purpose of the ventilation system is to support main engine, auxiliary engines, and fuel oil-fired boilers by providing a steady supply of air for combustion. The ventilation system also removes radiation and convection heat generated by the main engine, auxiliary engines, boilers, and other crucial components.

This chapter explains MAN Energy Solutions' guidelines for ventilation systems, focusing on ambient conditions within the engine room and solutions for enhancing the efficiency of the ventilation system.

Fig. 6 illustrates one of the most commonly used ventilation systems on

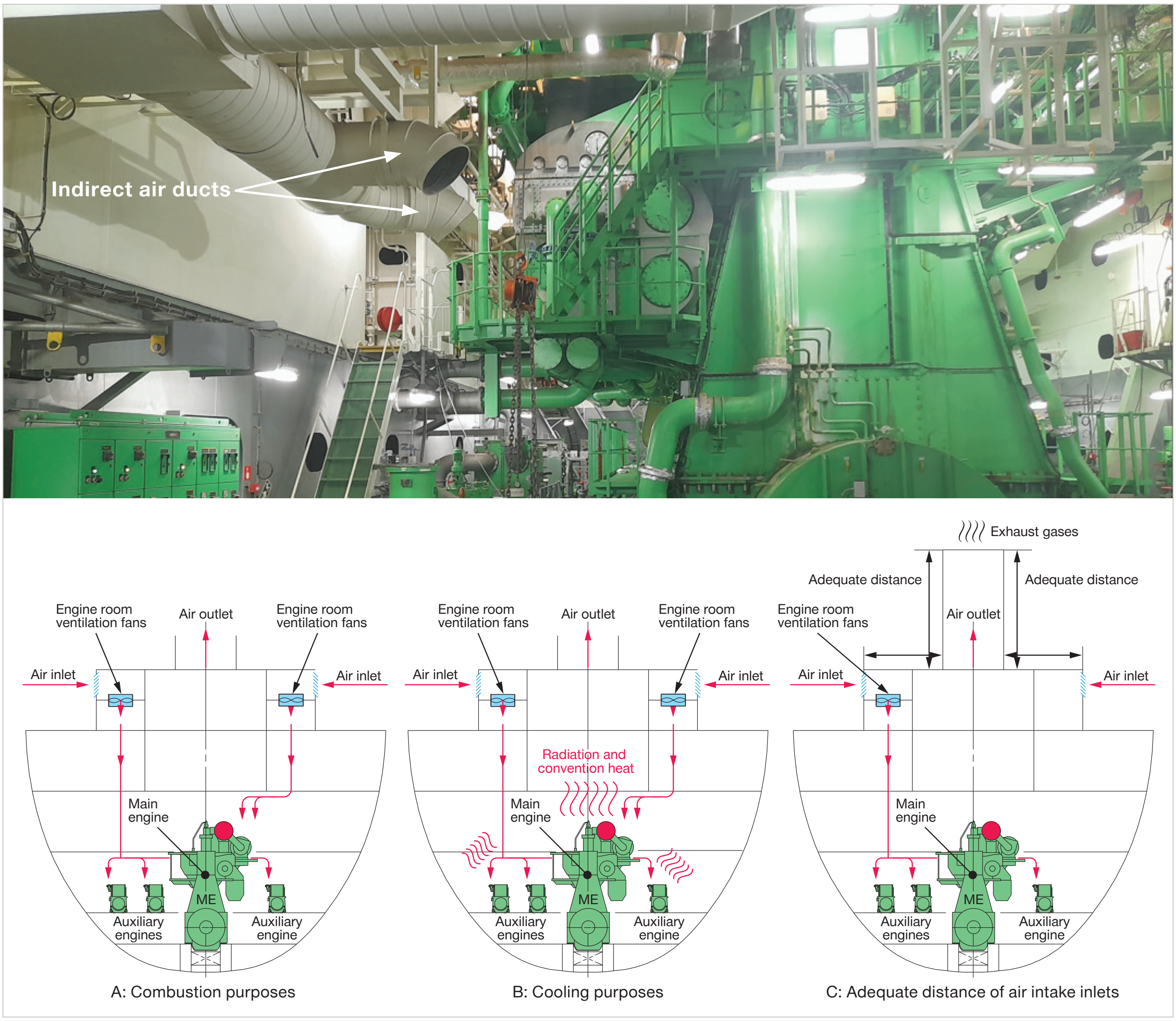


Fig. 6: Normal indirect air intake ventilation system

ships. The working principle is straightforward: Ventilation fans push air into the engine room through air ducts, and this air serves both combustion and engine room cooling purposes.

For combustion, the air duct outlets are strategically positioned near main engine turbochargers, auxiliary engines, oil-fired boilers, and other machinery requiring fresh air for combustion. Hence, the air supply temperature and quality are as good as possible since the air does not mix with the engine room air, which could be of higher temperature and contain oil fumes and contaminants.

It is essential to prevent major dust and dirt particles from fouling air coolers and cause excessive wear on combustion chamber components. To achieve this, air supplied to the engine must undergo filtration using appropriate filters. The air intake filter should effectively capture particles smaller than 5 µm. If a normal indirect air suction system is located within the engine room, the air intake filter is typically integrated into the turbocharger package with specific design criteria provided by the manufacturer.

For cooling purposes, fresh air is drawn into the engine room to remove radiation and convection heat from main engines, auxiliary engines, other driven equipment, and various engine room components. This creates an environment which is conducive to optimal machinery and equipment performance, and comfortable ambient conditions for personnel working in the engine room.

In practice, it is essential to supply an adequate volume of ventilation air and exhaust it through appropriately protected openings designed to function effectively in all weather conditions. Particular attention should be given to preventing seawater from being drawn into the ventilation air intake. Additionally, the placement of the ventilation air inlet should be carefully chosen, maintaining a safe distance from the exhaust gas funnel to prevent the inadvertent suction of exhaust gases into the engine room. Furthermore, the noise level from the ventilation ducts should be considered and corresponding to the regulations.

Next, specific recommendations are given for air temperature, air supply and pressure.

Air temperature

Since ambient air has a lower heat capacity than water, it will be subject to temperature variations on a diurnal and seasonal basis. This means that the surface seawater temperature will change much more slowly than the ambient air intake temperature. However, measurements have shown that the ambient air intake temperature (from the deck) at sea typically remains within the range of the seawater temperature plus 1–3°C, which gives a maximum of 35°C for seawater at 32°C.

Additionally, similar measurements have revealed that in a standard ventilation system with indirect air intake where combustion air is drawn directly from the ship’s engine room, the engine room temperature usually registers 10–12°C higher than the outside ambient air temperature. It is important to note that this temperature difference can be even greater during winter when ambient air temperatures are lower, see Fig. 7

Typically, the engine room temperature should never fall below 5°C. This is achieved by temporarily stopping one or more of the air

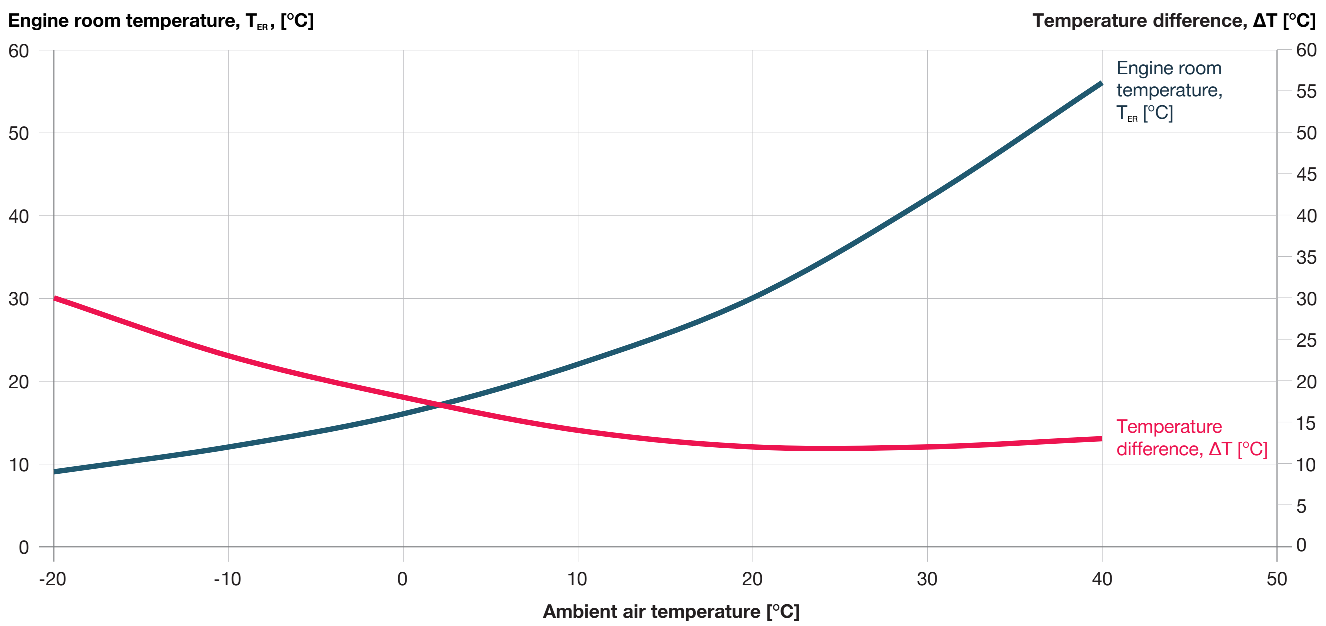


Fig. 7: Engine room temperature

ventilation fans, reducing the air supply, and consequently, the venting of the engine room. As a result, the average air temperature in a ventilated engine room remains within the range of 5–55°C, where the maximum value is often used as the maximum temperature for designing engine room components.

Since the air ventilation ducts for a normal air indirect system are placed near the turbochargers, the air inlet temperature to the turbochargers will be lower than the engine room temperature. Under normal air temperature conditions, the air inlet temperature to the turbocharger is only 1–3°C higher than the ambient outside air temperature.

Air supply

It is crucial to ensure that the ventilation system is adequately sized to supply air for both a spacious and a compact engine room housing a large low-speed two-stroke combustion engine, or a small two-stroke combustion engine, respectively.

In addition to providing sufficient air for combustion purposes of main engine, auxiliary engines (gensets), fuel-fired boiler(s), etc., the ventilation system should also be designed to remove radiation and convection heat from these, and other components.

The total air flow to the engine room must be at least the larger value of the two following calculations (required according to ISO 8861:1998(E)):

- capacity of the ventilation system ensuring an air volume of at least 150% of the total air consumption of main engine, auxiliary engines, and boiler(s), all at maximum continuous rating
- sum of the airflow for the combustion of main engine, auxiliary engines, and boiler(s) plus the sum of the airflow for evacuation of heat emissions.

As a rough guideline, the minimum ventilation air volume for the engine room should be around 200% of the main engine air consumption at 100% SMCR engine load. This figure is stated in the CEAS engine data report. The air volume may be sufficient for: combustion air flow (100%), cooling air for removing main engine radiation heat (50%), estimated volume of combustion air for gensets/boilers and cooling air for removing radiation heat (25%), and estimated radiated heat from other equipment (25%).

To ensure a proper air supply for the main engine combustion process, it is recommended that almost the entire air flow for the main engine combustion is directed towards the top of the main engine, near the air intake for the turbochargers, as shown in Fig. 6. Failure to ensure a proper air supply near the turbochargers can negatively impact the main engine performance.

Additionally, a correct air supply near the turbochargers helps prevent the deterioration of turbocharger air filters which can occur as a result of exposure to oil fumes, and other contaminants in the engine room air. It also helps avoid excessive draughts in the engine room. Furthermore, it is essential to provide an ample air supply to areas with high heat dissipation rates, such as around main engines, auxiliary engines, generators, and boilers. Note that the working principle of ventilation ducts for these specific areas is illustrated in Fig. 6b. Ventilation air must also be directed to intermediate galleries and the engine structure at engine room floor level. During the winter months, the required air volume for removing radiation and convection heat from the engine room may be reduced.

Air pressure

The air pressure in the engine room should be slightly positive, typically not exceeding the outside pressure at the air outlets in the funnel with more than approximately 5 mm WC (water column). In accommodation quarters, a slightly higher overpressure is typically maintained to prevent engine room oil fumes from seeping through doors into the living areas.

Ventilation air can be supplied using various types of fans, such as low-pressure axial and high-pressure centrifugal, or axial fans. The necessary pressure head for the supply fans depends on the resistance in the air ducts. Generally, all ventilation air is delivered by low-pressure air supply fans, which may require extensive ducting, and a pressure head as described below to ensure an adequate air distribution throughout every corner of the engine room.

To create an effective ventilation system, the fan pressure has to be as low as feasible. Before the corresponding fan pressure head has been settled, the pressure loss across the entire system must be carefully calculated.

For further information, see engine room ventilation standard ISO8861: 1998 (E) [2].

Efficiency improvements to the ventilation system

After discussing the most commonly employed ventilation system, this section provides a concise overview of additional solutions aimed at enhancing the ventilation system efficiency. For detailed information regarding efficiency improvements for ventilation systems, see the technical paper ”Efficiency improvements” [3]. Each solution offers distinct advantages of optimising performance and environmental conditions within the engine room.

Main engine direct air intake duct

Implementing an air intake duct that directly connects turbochargers with the outside environment, as shown in Fig. 8, offers several benefits.

Notably, it reduces the electrical power consumption of the ventilation system by eliminating the need for a ventilation fan to supply combustion air to the main engine. However, it is important that the ventilation fan capacity must supply combustion air to auxiliary engines and the oil-fired boiler, and provide ventilation air for removing radiation and convection heat generated by main engine, auxiliary engines, boilers, and other components.

When designing a direct air intake system, it is crucial to address specific considerations. Key design aspects include requirements for air filtration, noise attenuation for turbochargers, and structural integrity of the duct. For comprehensive design details, see document No. 0787858-0, which is available upon request [4].

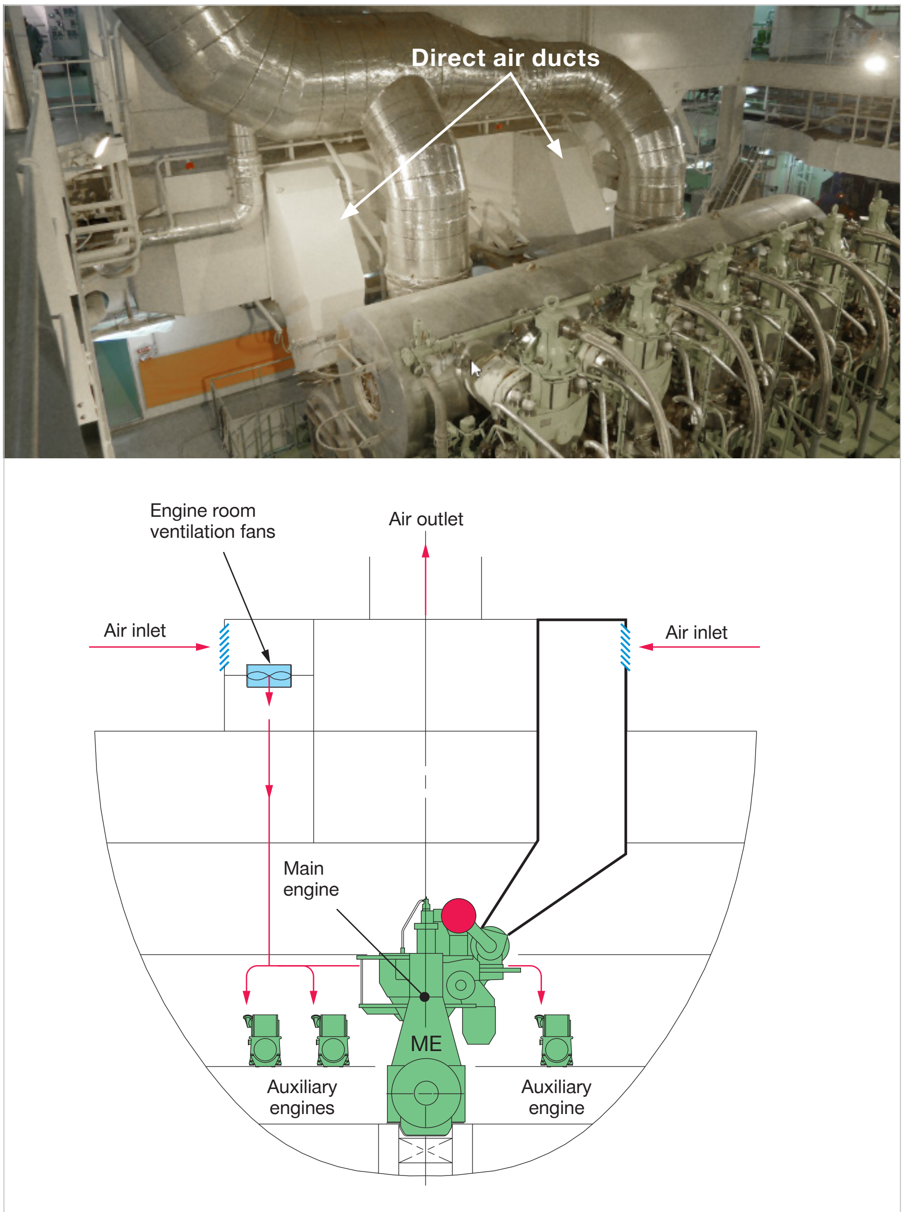


Fig. 8: Direct air intake

Besides the power saving obtained by eliminating the fan capacity for main engine combustion, the specific fuel oil consumption (SFOC) of the main engine will also be improved by the slightly lower air intake temperature. As described, the air temperature will be approx. 4°C higher than the outside deck temperature for a conventional indirect air intake system. For the direct air intake system, the air intake temperature will be more or less identical to the ambient air intake temperature (from the deck). Detailed calculations of potential savings are provided in the technical paper "Efficiency improvements" [3].

For arctic running conditions, the direct air intake system can be an advantage for maintaining sufficiently high temperatures for the crew in the engine room. Last but not least, attention should be paid to the noise level for this system, the duct must be reinforced to counter vibrations. Absorbent material should be fitted in the duct close to the air-intake compressor (turbocharger), and the air intake fitted with a noise silencer.

Automatic adjustment of ventilation system based on main engine air demand

An alternative option for improving the efficiency is to install an automatically controlled fan motor equipped with a variable frequency drive (VFD) operated by a differential pressure, see Fig. 9.

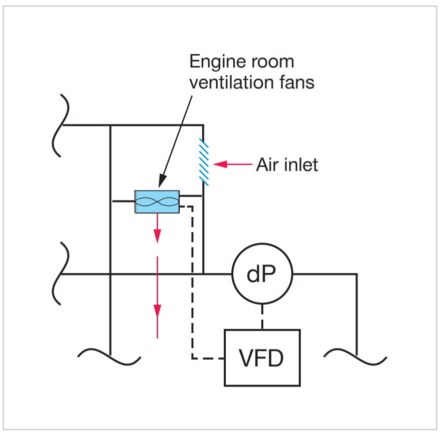


Fig. 9: Adjustable engine room ventilation fans

This option can be used when a conventional ventilation system with indirect air intake is installed, i.e. combustion air for the main engine is supplied by a ventilation duct terminated close to the turbochargers.

The differential pressure between the engine room and the outside atmospheric pressure is normally 5 mm WC (overpressure), which can be the operating parameter for the VFD. Assuming that the main engine combustion air fan follows the air required by the turbocharger, and that the fan has a minimum rpm level at 40% of maximum rpm, the fan power savings can be determined based on engine load. Detailed calculations of potential savings are provided in [3].

Main engine operation at ambient reference conditions

Standard ambient design temperature conditions

To establish a reference for specific fuel consumption and exhaust gas data for internal combustion engines, ambient reference conditions have been defined. The International Standard Organization (ISO) has outlined these conditions in ISO 3046-1:2002 and ISO 15550-1:2016(E), which is commonly referred to as ISO conditions and serve as the basis for engine matching and design [5].

However, it is essential for the engine to operate in unrestricted service, reaching up to 100% SMCR across the typical ambient temperature range that a ship may encounter. This range spans from high tropical conditions to low winter ambient conditions.

Therefore, for high air and sea temperatures, tropical conditions have been defined according to the International Association of Classification Societies (IACS), Rule M28. For low ambient temperatures, winter conditions have been employed as the specified ambient condition.

In CEAS, the specified ambient conditions can be adjusted for custom ambient conditions with air temperatures from 10–45°C, and scavenge air cooling water temperatures from 10–36°C. Table 5 provides an overview of standard and specified ambient conditions used in the design of all MAN B&W engines.

In addition to the winter condition, an extremely low ambient temperature condition, the arctic condition, has been defined where specific design features have been employed to secure the efficient and reliable operation of the main engine. These design features are explained in a separate section of this chapter.

All MAN B&W engines are designed and matched according to the aforementioned conditions, and they are able to operate continuously up to 100% SMCR in an air temperature range between low winter ambient temperatures and up to 45°C. Fig. 10 illustrates the air temperature range for main engine operation. As it can be noticed, this temperature range covers a wide range of ambient temperature variations that a ship will encounter during unrestricted operation worldwide.

Note that in tropical ambient conditions, the relative humidity of 60% at 45°C is theoretically the absolute limit at which humans can survive. The corresponding wet bulb temperature is 38°C, corresponding to 86°C for the so-called Heat Index Temperature. MAN Energy Solutions has never measured levels above 50% at 45°C, and humidity levels above standard tropical ambient conditions will most likely never occur. For the tropical condition, the corresponding central cooling water/scavenge air cooling water temperature is 4°C higher than the seawater temperature, i.e. equal to 36°C.

Reference

Ambient reference condition	ISO	Tropical	Winter
Property	ISO 3046-1:2002(E)	IACS M28 (1987)	Normally applied for MAN B&W engines
Barometric pressure [mbar]	1,000	1,000	1,000
Turbocharger air intake temperature [°C]	25	45	10
Scavenge air cooling water temperature [°C]	25	36	10
Relative air humidity [%]	30	60	60

Table 5: Reference ambient conditions

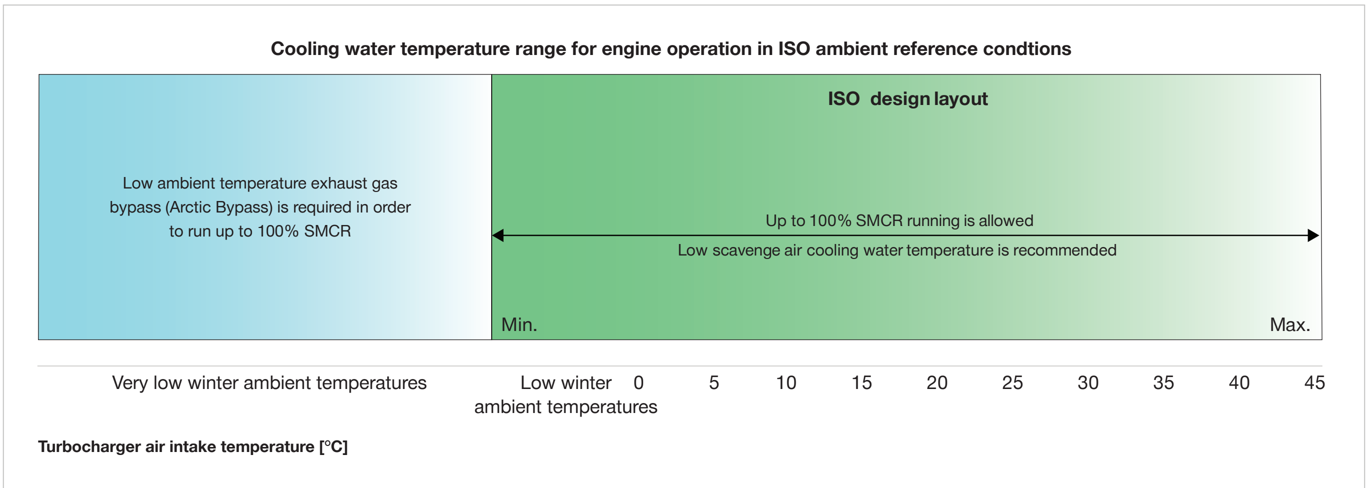


Fig. 10: Temperature range for engine operation at ISO design layout

According to MAN Energy Solutions' experience, it has been observed through the years that shipyards sometimes specify a constant (max.) central cooling water temperature at 36°C, independent of the operating ambient seawater temperature. There are various reasons for this:

- At sea trial, it must be demonstrated that auxiliary systems in engine rooms can handle tropical conditions, and afterwards the setpoint is not changed to the recommended 10°C
- Auxiliary equipment that cannot handle temperatures lower than 36°C
- Reducing the seawater pump flow rate when possible, and thereby reducing the electric power consumption, and/or reducing the water condensation in the air coolers. However, operating with 36°C cooling water to the scavenge air cooler instead of 10°C, increases SFOC by approx. 2.5 g/kWh, see Fig. 11. Any gain obtained from the reduced electric power consumption will be more than lost in additional fuel costs of the main engine.

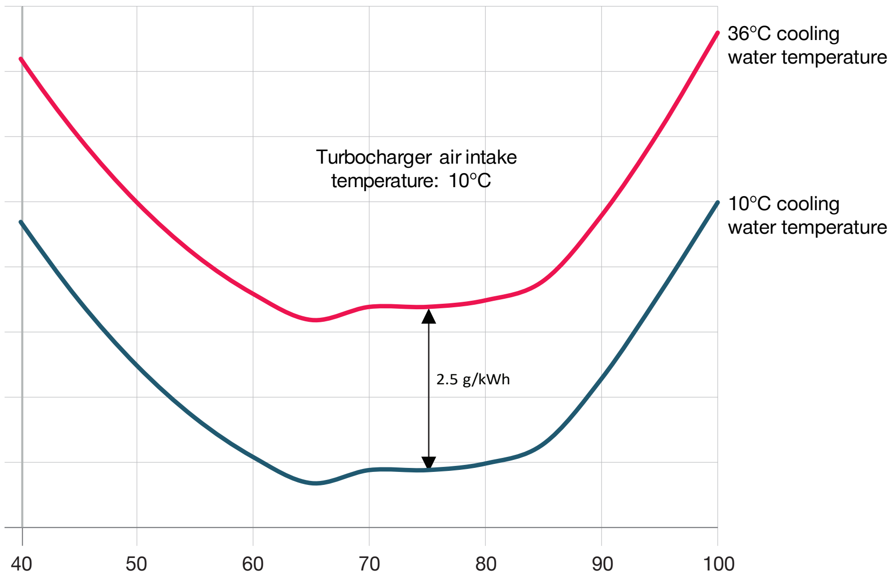


Fig. 11: Influence of central cooling water temperature (scavenge air cooling) on SFOC

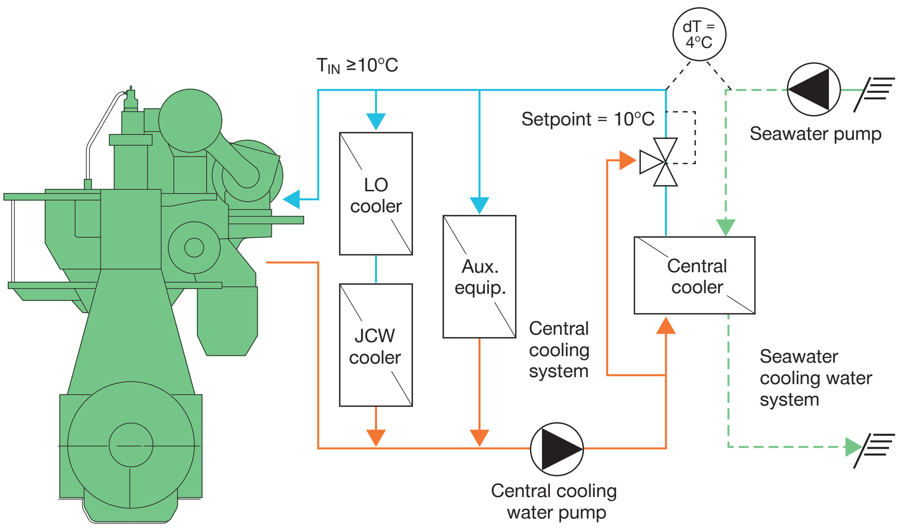


Fig. 12: Principle diagram of central cooling water system

Scavenge air cooler capacity for central cooling water system

To achieve an optimal engine performance regarding fuel consumption, cylinder condition, EGR blower power consumption, etc., it is important to ensure the lowest possible cooling water inlet temperature at the scavenge air cooler. It can be achieved with one of the control methods A or B, see also Fig. 12:

- Option A: Enter a fixed setpoint of 10°C for the thermostatic mixing valve at the central cooler
- Option B: Maintain a constant temperature difference of 4°C between sea- and freshwater sides of the central cooler when operating the seawater pump with a VFD. And ensure that the temperature never drops below 10°C.

For both options, the freshwater temperature will always follow the seawater temperature for seawater temperatures above approx. 6°C, and the central water temperature will always be approx. 4°C higher than the seawater temperature. Furthermore, applying one of the options will ensure that the fresh cooling water will always be as cold as possible, but not too cold for the main engine lubricating oil cooler.

The two options remain the standard and the recommendation of MAN Energy Solutions. However, for engines with EGR systems, it is a requirement that one of the options is implemented. The reason is that EGR engines are not designed for the increased gas flow which is the result of a high cooling water temperature combined with a cold ambient air temperature.

If a constant higher setpoint (36°C) is preferred, note that SFOC will always be higher, corresponding to approx. 1.0 g/kWh per 10°C change in cooling water temperature, compared to a central cooling water system with either option A or B, see Fig. 11. For engines running on fuels with a sulphur content higher than 0.5%, it is important that besides the increased SFOC, an increased cylinder oil consumption can be expected and/or a higher-BN cylinder oil must be used to counteract cold corrosion.

The scavenge air cooler is an integrated part of the main engine. Heat dissipation and seawater flow are based on SMCR output at tropical conditions, i.e. a seawater temperature of 32°C and an ambient air temperature of 45°C. For all Diesel-cycle MAN B&W engines, the scavenge air cooler is specified with a max. temperature difference of 12°C between the cooling water inlet and the scavenge air outlet at 100% SMCR. This gives a scavenge air temperature of 36°C + 12°C = 48°C for the scavenge air cooler design layout in Fig. 13. However, an operational margin of 3°C is considered for all MAN B&W engines. For a scavenge air temperature of 36°C + 12°C + 3°C = 51°C, the engine is able to run at 100% SMCR power. The operational margin covers any increase in seawater temperatures that may be encountered. Although seawater temperatures higher than 30°C rarely occur in the open sea, as it can be seen in Fig. 14.

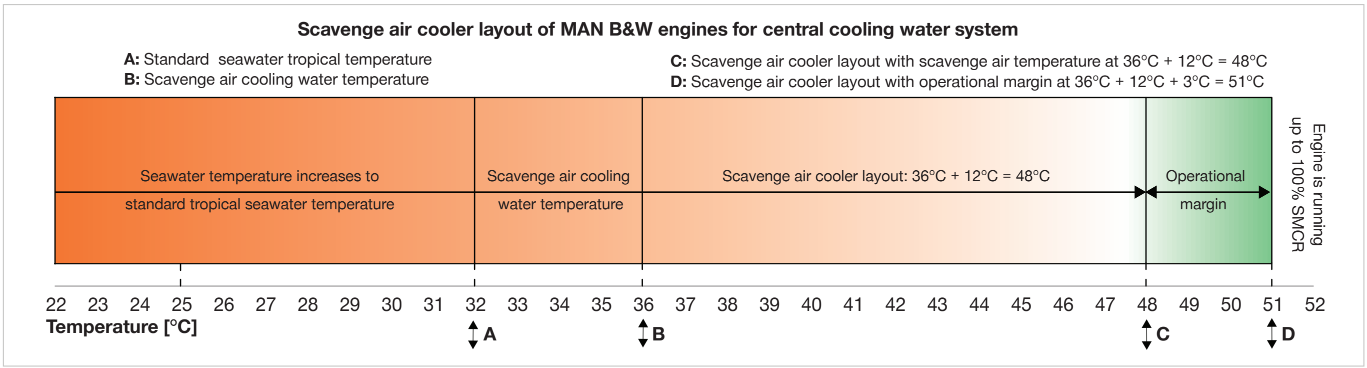


Fig. 13: Air cooler design layout for MAN B&W engines

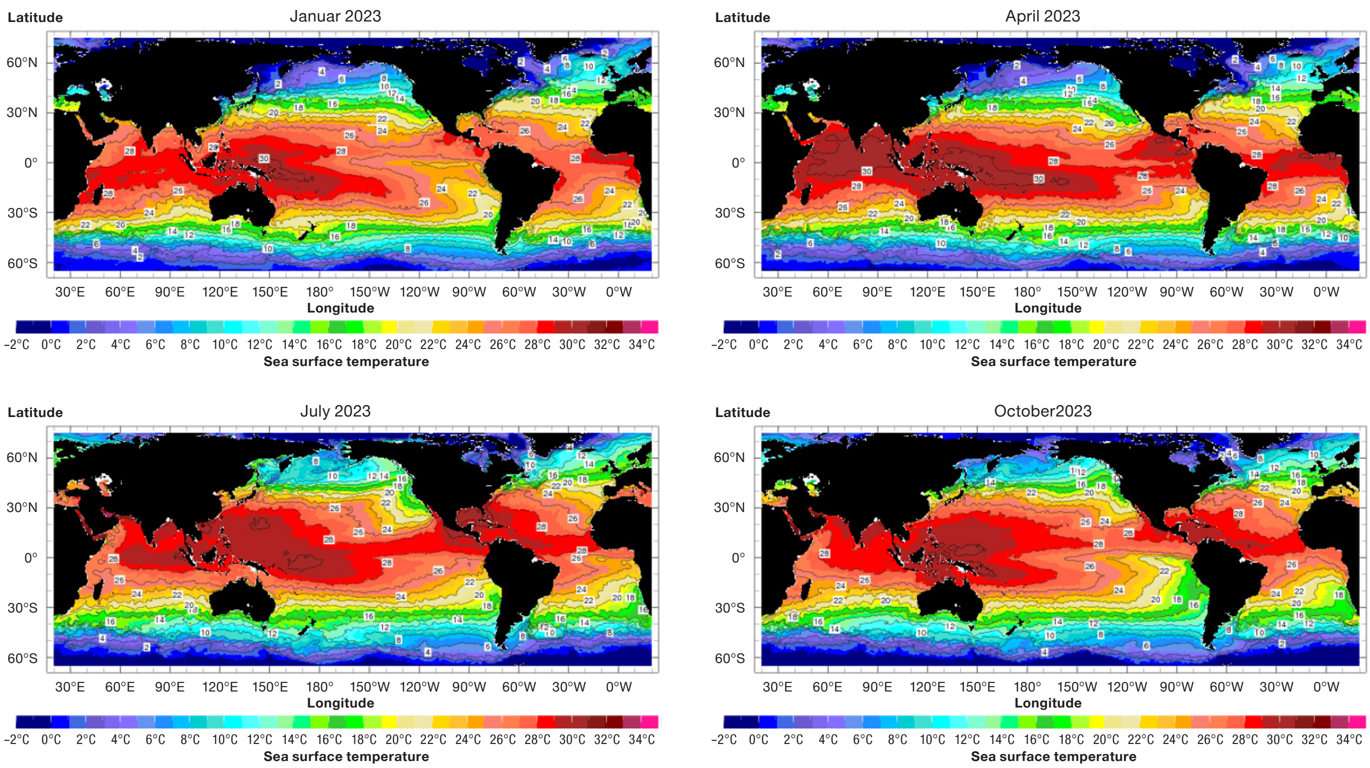


Fig. 14: Sea surface temperature [6]

However, in confined waters, such as inland, gulf, bay, and harbour areas, an increased seawater temperature may occur. All MAN B&W engines should be able to reach engine loads that ensure safe navigation and manoeuvrability for the ship during operation in these waters.

Operating at ambient conditions with high seawater and air temperatures

Higher seawater temperatures can occur in inland, gulf, bay, and harbour areas, where the vessel needs to operate for a limited time. During manoeuvring in the harbour area, for example, the engine load will normally be relatively low (15–30% SMCR), and the corresponding scavenge air temperature will only be slightly higher than the scavenge air cooling water temperature. Therefore, a seawater temperature as high as, for example, 42°C in harbour areas is not considered a problem for the main engine during manoeuvring conditions (4–6 knots). The scavenge air receiver temperature will be well within the scavenge air temperature alarm limit. All MAN B&W two-stroke engines for marine applications have an alarm setpoint of 65°C for the scavenge air receiver temperature for protection of the engine.

For all MAN B&W engines operating at increased seawater temperatures occurring in inland, gulf, bay, and harbour areas, the maximum power output of the engine should be reduced to an engine load resulting in a scavenge air temperature below the scavenge air receiver temperature alarm.

As explained, MAN B&W engines are designed according to reference ambient air temperature conditions and are therefore capable of continuous operation at up to 100% SMCR in low winter ambient temperatures and up to 45°C. This ambient air temperature range for unrestricted engine operation is quite extensive and covers the majority of trading patterns.

Fig. 14 illustrates temperatures at the surface of the sea for different geographical areas in different seasons. It can be noted that in the open sea, the seawater temperature is well within the air temperature range of -10–45°C which MAN B&W engines are capable of operating in.

Especially for ambient conditions with temperatures higher than for tropical conditions, the seawater temperature does not exceed 30°C even in the most extreme conditions. Considering that at sea, the ambient air intake temperature from the deck typically remains within 1–3°C of the seawater temperature, it is safe to conclude that an air intake temperature of 45°C is almost unthinkable.

Even though ambient conditions with temperatures higher than for tropical conditions are highly unusual at open waters, extremely low ambient and water temperatures can occur in arctic areas. For ships continuously operating in the Arctic area, specific measures and design precautions have to be considered for the main engine. These will be described in the next section.

Arctic Bypass

Very low temperature environments, for example in the Gulf of St. Lawrence, the Baltic Sea, the Arctic, and the Antarctic Oceans, where the temperature can reach below -10°C, present numerous challenges related to operation of equipment, including the main engine of a ship.

Ships designed and constructed without addressing the effects of very low temperatures may experience an increased number of equipment failures and non-functioning systems. When a ship's main engine operates in these environments with very low turbocharger air intake temperatures, the air density becomes too high. As a result, scavenge air pressure, compression pressure and maximum firing pressure will be too high. For very low temperature conditions, some additional engine design features might be necessary for the engine to reach 100% load reliably and without any failures. For this purpose, MAN Energy Solutions has developed an Arctic Bypass solution which ensures that the engine can deliver 100% power in very low temperature environments.

Design recommendations for operation at extremely low air temperature

The Arctic Bypass is a load-dependent exhaust gas bypass (EGB) system shown in Fig. 15, which is MAN Energy Solutions' recommendation for operation in extreme low air temperatures.

The working principle of the system is based on the load-dependent maximum scavenge air pressure curve which determines the pressure level where the Arctic Bypass system will be

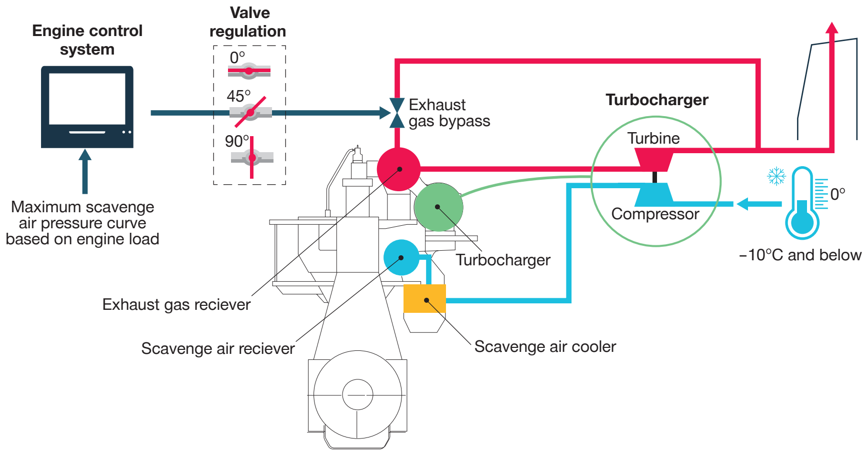


Fig. 15: Arctic Bypass principle

active. The maximum scavenge air pressure curve is integrated into the engine control system, and the EGB is controlled automatically based on the scavenge air pressure.

When the scavenge air pressure exceeds the maximum threshold, the EGB valve will open gradually. The opening of the valve continues at a constant rate until the scavenge air pressure is below the threshold again. This means that part of the exhaust gas bypasses the turbocharger turbine and less energy is delivered to the compressor, which reduces the air supply and scavenge air pressure to the engine. Once the scavenge air pressure drops below the maximum, the Arctic EGB starts to close at the same rate. The rate can be controlled with specific parameters in the engine control system.

When the engine is running in the part-load range in low ambient air temperatures, the EGB system ensures that the load-dependent scavenge air pressure is close to the corresponding pressure on the scavenge air pressure curve valid for ISO ambient conditions. When the scavenge air pressure exceeds the read-in ISO-based scavenge air pressure curve, the bypass valve opens accordingly to ensure the engine is not overloaded, irrespective of ambient conditions. At the same time, the exhaust gas temperature is kept relatively high.

If cold ambient conditions are expected, the Arctic Bypass can be used together with Tier III technologies.

For high- and low-pressure selective catalytic reduction (HPSCR and LPSCR), the Arctic Bypass increases the exhaust gas temperature which is needed for SCR operation. For EGR, the Arctic Bypass decreases the air amount and, thereby, the size and power consumption of the EGR blower. Therefore, both SCR and EGR systems will benefit from the installation of an Arctic Bypass.

Increased steam production in wintertime

When the air intake temperature drops, the exhaust gas temperature after the turbine drops as well, and the service steam production from the economiser decreases. To cover the lack of service steam, an auxiliary burner is applied but at the expense of additional fuel being burnt. To minimise the total fuel consumption of a ship, MAN Energy Solutions has developed the Economiser energy control (EEC) feature. The EEC feature minimises the overall fuel consumption by allowing more exhaust gas energy to be extracted from the main engine. The paper “Economiser energy control for increased service steam production” provides detailed descriptions of the EEC feature available for MAN B&W two-stroke engines. In addition, the paper gives an example of how the EEC feature can reduce total fuel consumption.

Closing remarks

Combustion engines installed in ocean-going ships are often exposed to different climatic temperature conditions because of the ship's trading pattern. Since temperature variations at the surface of the sea are normally relatively limited, the engines will be able to operate worldwide in unrestricted service without any precautions being taken.

Even if the ship has to operate in very cold areas, MAN B&W two-stroke engines can, as this paper illustrates, also operate under such conditions without any problems as long as special low-temperature precautions are taken.

As an additional benefit, using an Arctic Bypass system may also improve the exhaust gas heat utilisation when running at very low ambient air temperatures.

Abbreviations

CEAS	computerised engine application system
CPP	controllable pitch propeller
EEC	Economiser energy control
EGB	exhaust gas bypass
EGR	exhaust gas recirculation
FPP	fixed pitch propeller
HPSCR	high-pressure selective catalytic reduction
IACS	International Association of Classification Societies
JCW	jacket cooling water
LPSCR	low-pressure selective catalytic reduction
NMCR	nominal maximum continuous rating
SFOC	specific fuel oil consumption
SMCR	specified maximum continuous rating
VFD	variable frequency drive
WC	water column

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[2] Ventilation room standard ISO8861:1998 (E)

[3] Efficiency improvements, MAN Energy Solutions

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[5] ISO reference conditions, ISO 3046-1:2002 and ISO 15550-1:2016(E)

[6] Columbia Climate School International Research Institute for climate and Society, 2023

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