CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- **Air Intake**
- **Exhaust**
- **Starting Air**
- **Crankcase Fumes Disposal**

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Engine Systems - Air Intake

Engine Room

Diesel engine rooms contain many pieces of equipment using combustion and ventilation air. Air requirements other than the engine must be considered.

A method for evaluating both combustion and ventilating air requirements is provided at the end of this section. Classification society and/or regulatory rules should also be reviewed.

The following systems may require engine room combustion and/or ventilation air.

Combustion Air	Ventilation Air/ Heat radiation
Main engines Ship service generator engines Boilers	Main Engines Ship service generator engines Exhaust piping Boilers Steam and condensate piping Generators Electrical equipment including motors Hot tanks

Engine room air flow arrangements generally fall into two categories:

- Engine room supplied with filtered air for engine combustion and radiated heat removal. The engine uses combustion air from the engine room using an air intake silencer at the turbo inlet. This system is normally used in vessels operating in clean ambient surroundings.

- Engine room supplied with ventilation air for heat removal and engine combustion air supplied through dedicated air cleaners. The cleaners may be engine room mounted. This arrangement is normally used in inland waterways where the vessel can encounter dirty ambient conditions. The air cleaners for the engine can be part of the Caterpillar engine supply.

Combustion Air

High temperature air supplied to the engine inlet (combustion air) can cause severe engine problems including high exhaust temperatures, piston problems, turbocharger compressor life reduction and turbocharger turbine damage. The maximum air temperature supply to the engine inlet is 45°C (113°F) for standard ratings. This should be the maximum temperature air that the engine receives under the highest ambient temperatures expected. Cooler air in the range of 10° - 30°C (50° - 86°F) is generally desirable.

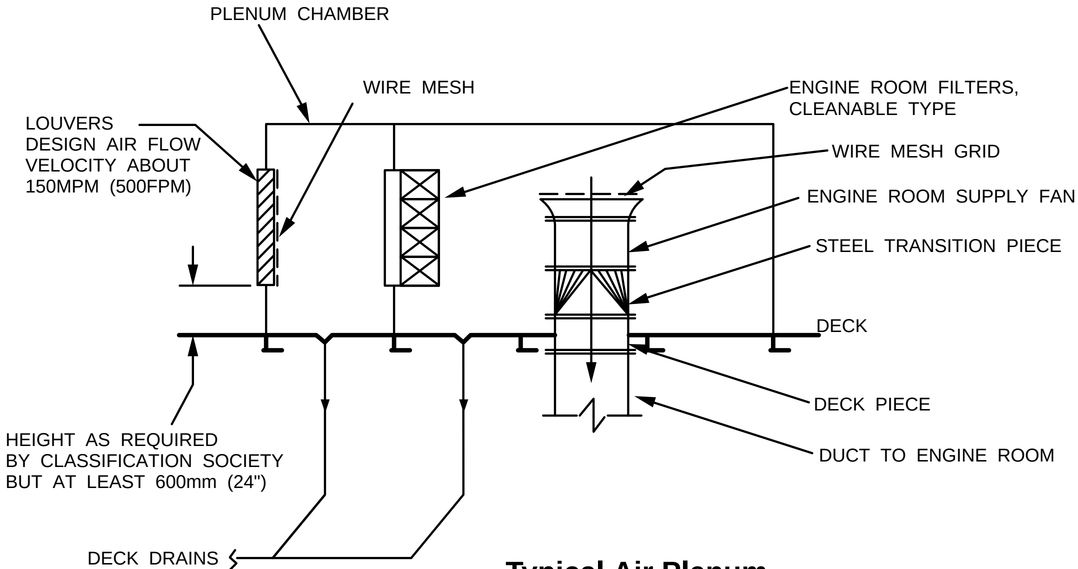
Temperatures above 45°C (113°F) will usually require a derated condition, even if this occurs for only a short time.

Filtered Air To Engine Room

The engine room air must supply engines and boilers with combustion air, remove radiant heat, and provide comfortable engine room working conditions. The following factors must be considered:

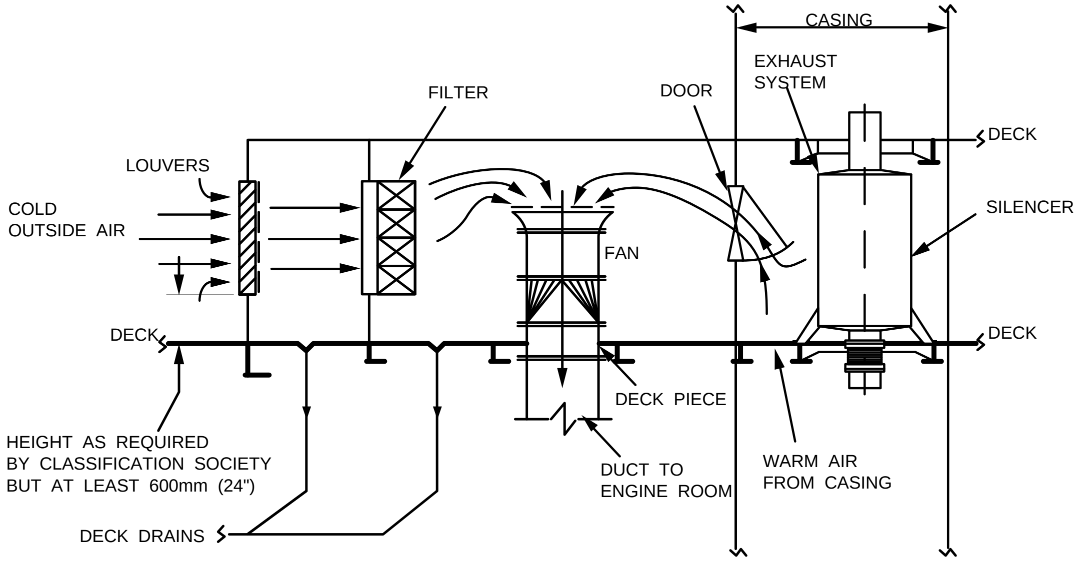
- Combustion air must be free from water spray, dust and oil mist.

- Water spray, dust, exhaust gas fumes, oily vapors, etc. must not enter the ventilation fan air inlet plenums. Figure 1 is a suggested plenum arrangement for filtered combustion and ventilation air.



Typical Air Plenum Arrangement

Figure 1



Typical Warm Air Arrangement

Figure 2

- Heated engine room air may be required (for starting purposes only) in applications at very cold ambients (-25°C (-13°F)). This assumes combustion air is being drawn from outside the ship and the engine is preconditioned with preheaters for fuel, water and oil temperatures of 0°C (32°F). In cold weather operations provide a door from the engine room casing into the plenum to warm the cold outside air. The door would be closed in warm weather. A suggested arrangement is shown in Figure 2. Admitting engine room air must be done without the possibility of allowing dirt or debris in the engine air inlet system. Also, do not recirculate oil laden air or warm engine room air through engine room doors.

- Air cleaner icing can occur in saturated air environments when the ambient air dew point is near freezing temperature. Velocity and pressure changes at the air cleaner inlet reduce the moisture holding capacity of the air, resulting in moisture condensation and ice crystal formation. The ice buildup reduces air flow area and increases the pressure differential across the air cleaner. Eventually a plateau is reached where the pressure differential remains constant even though ice buildup may continue. Power loss and increased fuel consumption will result during these periods.

- Consider two speed engine room supply fans for cold climate operation.

- Engine room air ducting design should consider:
  - a) Engine cool air duct discharges should be near and directed at the turbochargers air inlets. This arrangement assumes water free air.
  - b) A smaller air flow should evenly distribute ventilation air alongside the engine, coupling, reduction gear, and generator (if fitted) to dissipate radiant heat.
  - c) Distribute sufficient air flow throughout the engine room and in areas where work or maintenance take place.

- Engine room supply fans should maintain a slight overpressure in the engine room. This pressure should normally not exceed 0.062 kPa (0.25 in H_2O).

- Exhaust fans may be required if the ventilation air from the engine room cannot be led through a stack with natural ventilation.

- Rooms with fuel oil centrifuges should have separate spark proof exhaust fans discharging to atmosphere. Do not locate the discharge near fresh air inlets.

- Install fire dampers in the ventilation ducting at fans and all exhaust openings.

Outside Air To Engine Air Filters

Air Cleaners Outside The Engine Room

Combustion air should be taken directly from the atmosphere through remote mounted air cleaners in dirty environments, hot climates, and tropical service operations (see Figure 3 on page 23). They are dedicated to engine combustion air and can be Caterpillar supplied. One air cleaner is provided for each turbocharger. Combustion air is ducted from the air cleaner to the turbocharger air inlet. The turbocharger air inlet is provided with a transition piece and flexible connection as shown in Figure 3. The ducting between the air cleaner and the turbocharger should be corrosion resistant material of sufficient thickness and stiffness. The air velocity in the duct should not exceed 25 m/sec (82 ft/sec), and the ducting able to withstand a minimum restriction of 12.5 kPa (50 in. H_2O), which is also the structural capability of the Caterpillar air cleaner.

Air Cleaners In The Engine Room

Locate the air cleaners as close to the turbocharger as possible. Each turbocharger is provided with a separate Caterpillar supplied air cleaner (see Figure 4 on page 24).

Cleanliness

Air intake ducting must be cleaned of all debris. Rivet type fasteners should not be used and welding should be minimized. Remove slag from the ducting interior. Due to the distinct possibility of inlet screen failures and subsequent turbocharger damage, Caterpillar does not provide devices to trap debris ahead of the turbocharger. *Ducting should be made of material durable enough to withstand prolonged operation without debris loosening and entering the turbocharger.*

Install an identifiable blanking plate ahead of the turbocharger to prevent debris from entering during initial engine installation. The plate should have a warning tag indicating it must be removed prior to starting the engine. The Caterpillar supplied shipping cover can be used.

Install takedown flanges in the ducting to allow internal inspection prior to initial startup.

Inlet Restriction

The maximum allowable inlet restriction is 3.7 kPa (15 in. H_2O) with dirty air cleaner elements, and 1.2 kPa (5 in. H_2O) with initially clean elements.

Mass/Volume Flow Conversions

The volumetric air flow found in TMI and in the Engine Data section of this guide are at conditions of 95.9 kPa (28.4 in. hg) inlet pressure and 25°C (77°F) inlet temperature. The flow also simulates the restriction of a clean air cleaner and is applicable for conditions of 100 kPa (29.6 in. Hg) inlet pressure and 25°C (77°F) inlet temperature (which represent SAE J1995 and ISO 3046 conditions).

The corresponding mass air flow ($\dot{M}$) can be calculated using the following relationships:

$$V_{Air}\ (\text{m/min}) = .01486 \times \dot{M}_{Air}\ (\text{kg/hr})$$

$$V_{Air}\ (\text{cfm}) = .2382 \times \dot{M}_{Air}\ (\text{lb/hr})$$

***Note**: Heavy fuel oil burning engines require higher inlet air flow than distillate burning engines. See the Engine Data section of this guide.*

Caterpillar Air Cleaners

Caterpillar air cleaners consist of high efficiency washable paper elements packaged in a low restriction weatherproof housing. They may be bulkhead or deck mounted with the air inlet facing downward. Modification is required for element support if horizontal entry is required. Depending on environmental operating conditions, two housings are available. One housing contains two elements (double) and the other contains three elements (triple). Housings are also available with precleaners (see Figure 5).

Figure 5

	Standard Duty Without Precleaner	Heavy Duty With Precleaner
3606	1-Double Element Housing	1-Triple Element Housing
3608	1-Double Element Housing	1-Triple Element Housing
3612	2-Double Element Housing	2-Triple Element Housing
3616	2-Double Element Housing	2-Triple Element Housing

The cleaners are 99.5 percent efficient for proper turbocharger and aftercooler performance. Use of less efficient elements will result in turbocharger compressor wheel and aftercooler fouling. Dirt on the turbo compressor wheel can cause rotating imbalances leading to turbocharger failure. Fouling of the aftercooler core results in reduced performance and high exhaust temperature problems.

All air cleaner housings are now epoxy coated and can be used for operation in a salt spray environment.

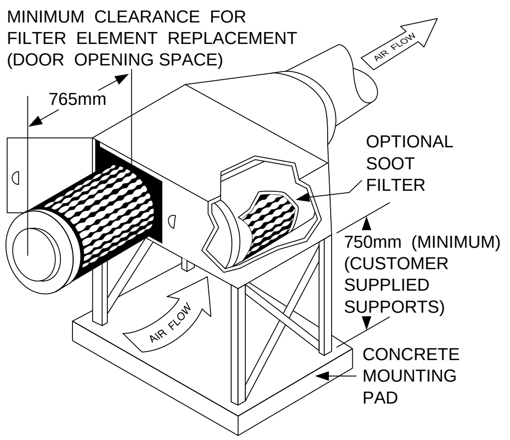


Figure 6

An optional soot filter rated at 70% efficiency is available (Figure 6) to extend element life in applications where exhaust gases can be recirculated.

Consideration should be given to air cleaner element service as a dirty element can weigh 35 kg (78 lb).
See Figure 7.

Precleaners

Precleaners adapt to standard air cleaners (Figure 8) producing heavy duty air cleaners which extend filter service periods. *They impose added air restriction and are not recommended for heavy fuel engines.* Precleaners provide 94 percent efficiency in severe dust applications. Heavy duty air cleaners provide the same protection as standard filters, but they allow further extension of filter change periods. Service periods improve six to seven times over that of standard air cleaners.

Air Cleaner Dimensions

See Figure 9 on page 10.

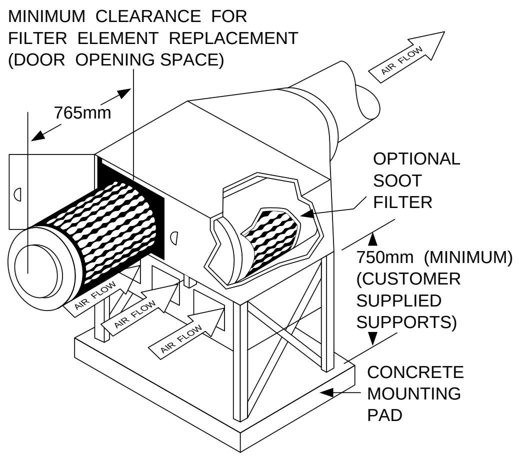


Figure 8

Air Cleaner Restriction

Air cleaner restriction versus engine air flow is shown in Figure 10. Restriction includes the air cleaner housing and elements. The air flows shown are based on the amount of air going through one double or one triple element housing. Total engine air flow for propulsion engines can be found in the *Engine Data* and *Engine Performance* sections of this guide. Heavy fuel engine air flow is in the *Engine Data* section. Also check the TMI System. The air flow entered on the chart is the flow through one air cleaner housing.

Caution*: TMI air flow data is the flow required for an entire engine. As an example, since the vee engines require two air cleaner housings, the air flow taken from TMI for a 3612 or 3616 Engine requires division by 2 before entering the chart.*

The Caterpillar supplied air cleaner housings contain a *pop up* type indicator set for a maximum restriction of 3.7 kPa (15 in. H$_2$0).

Air Cleaner Specifications - kg (lbs.)

Duty Rating	Element Qty.	Clean Element Weight (ea.)	Dirt Retention Cap. (ea.)	Total Weight (including housing)	
				Clean	Dirty
Standard	2	16 (35.3)	23 (50.7)	232 (511.5)	278 (612.9)
Heavy	2	16 (35.3)	23 (50.7)	352 (776.0)	435 (959.0)
Heavy	3	16 (35.3)	23 (50.7)	490 (1080.3)	566 (1247.8)

Figure 7

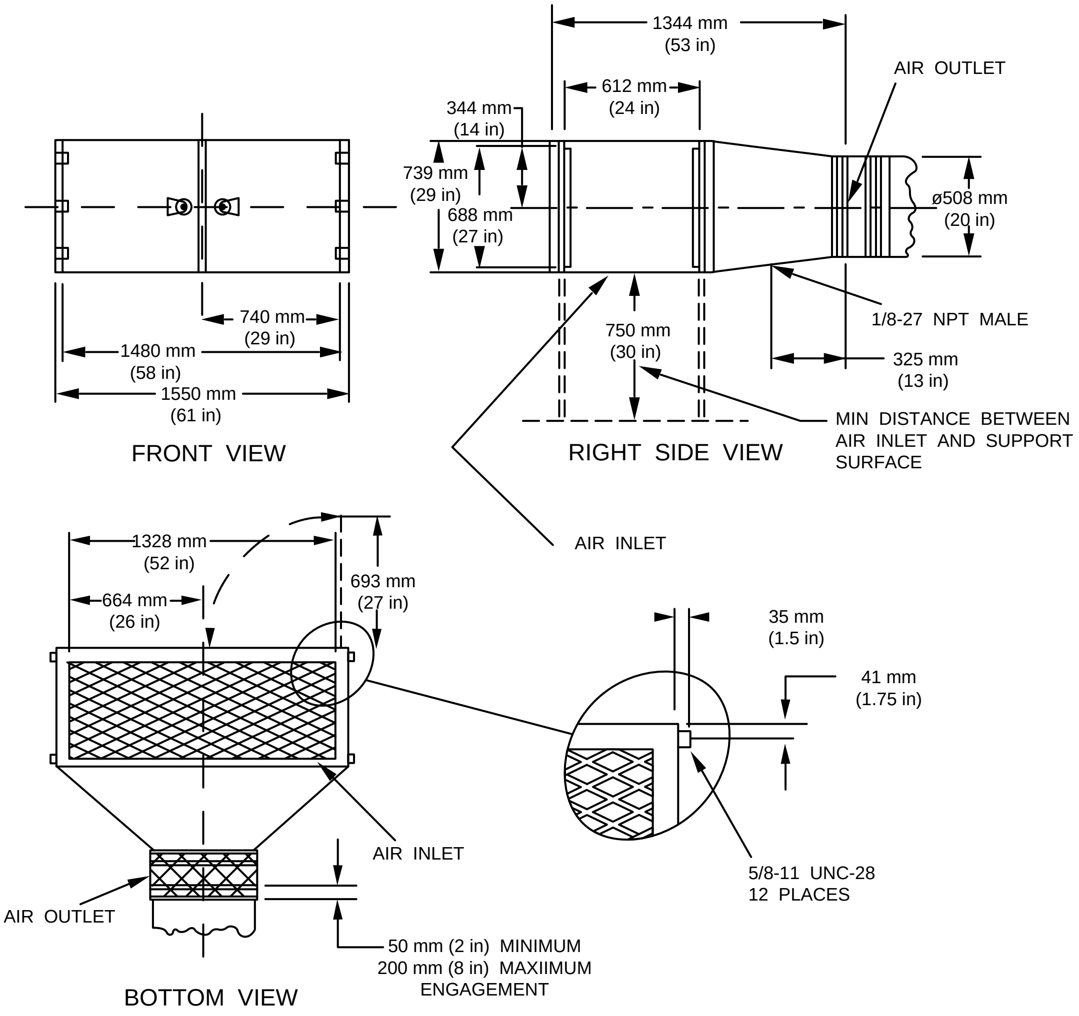


Figure 9

Engine Air Intake Silencer

A Caterpillar air intake silencer can be used in an engine room using filtered air. The silencer can be mounted directly to the turbocharger compressor inlet as shown in Figure 11.

A Caterpillar air intake filter/silencer is also available for use with 3606 and 3612 engines. It cannot be used with 3608 and 3616 engines due to excessive inlet restriction. The filter/silencer provides good air filtration, but it should be used in a clean engine room environment (filtered air). It should be remote mounted from the turbocharger inlet as shown in Figure 11.

Air Inlet Adapters

Caterpillar offers various air inlet adapters for connecting the shipyard furnished ducting to the turbocharger air inlet. They are shown in Figures 12 through 14. They are shipped loose and include gaskets and mounting hardware.

***Caution**: Turbocharger performance may be adversely affected if Caterpillar supplied air intake components are not used. They are designed to provide the proper air flow pattern ahead of the turbocharger.*

Air Cleaner Performance Curves

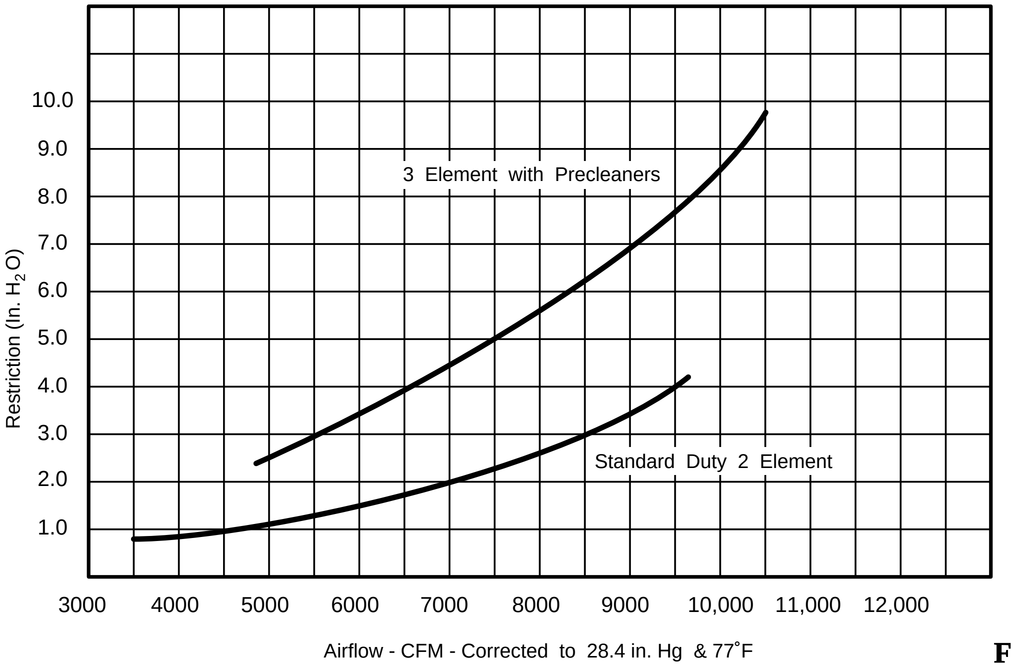
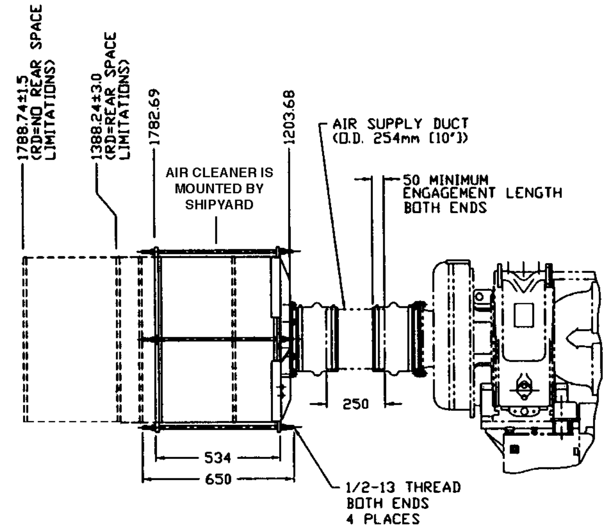


Figure 10



Typical Air Inlet Filter/Silencer
(for 3606 and 3612 engines only)

Figure 11

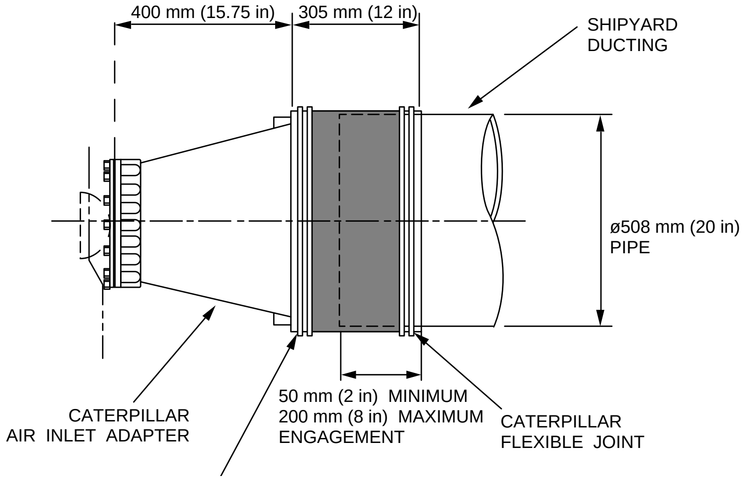


Figure 12

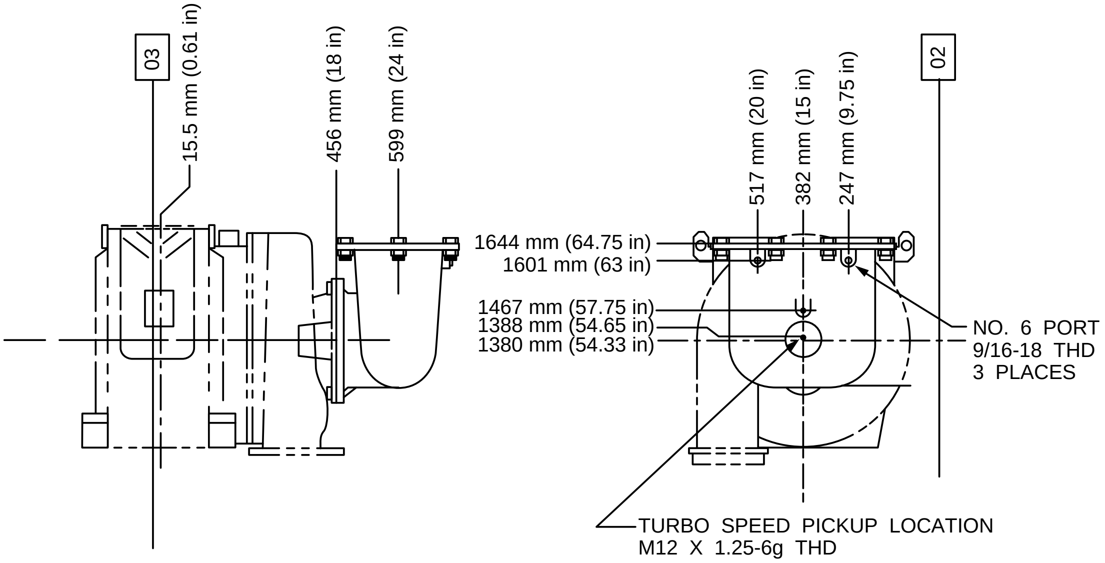
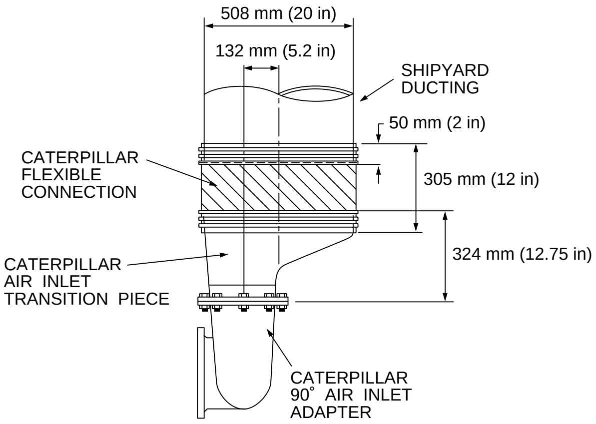


Figure 13

The inlet elbow shown in Figure 13 can be rotated in 30° increments.

Flexible Connections

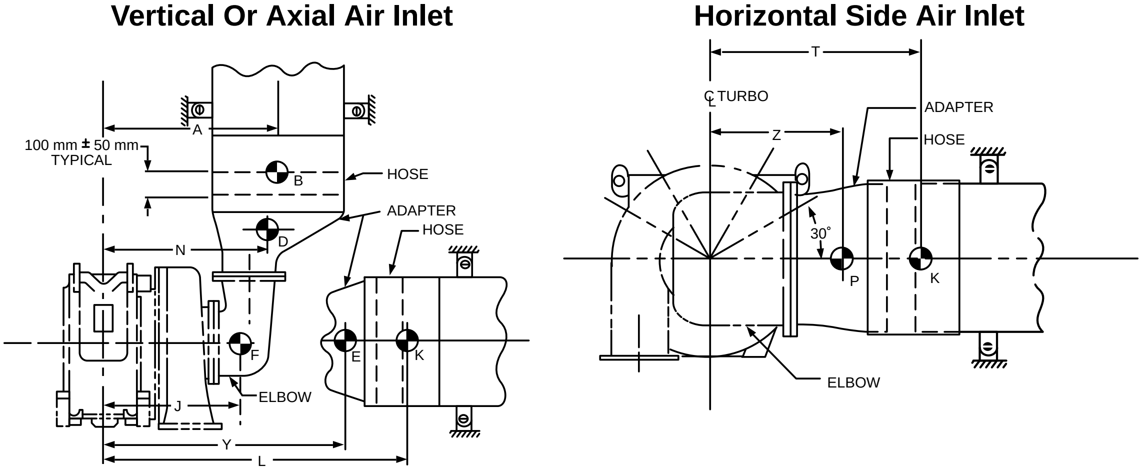
Flexible connections are required to isolate engine vibration and noise from the ducting system. The flex should be as close to the engine as practical. The flex engagement with the air intake duct should be a minimum of 50 mm (2 in.) and a maximum of 200 mm (8 in) (see Figures 12 and 14). Care must be used to prevent exhaust piping heat from deteriorating rubber flex connections.



Typical Air Inlet Transition Piece Adapter (Rectangular To Round)

Figure 14

Maximum Loads For Turbocharger Intake



Vertical Or Axial Air Inlet

Horizontal Side Air Inlet

D, F & E = Adapter Weight
B & K = 1/2 Hose Weight
Moment (Vertical Inlet):
M_V = JF + ND + AB
Moment (Axial Inlet):
M_A = YE + LK

Allowable
Max Moment = 30 kg-m

With Caterpillar Supplied Hardware

J = 548 mm N = 625 mm A = 700 mm
Y = 705 mm L = 945 mm
D = 13 kg E = 14 kg F = 16 kg
$B = \frac{3\ \text{kg}}{2}$ $K = \frac{3\ \text{kg}}{2}$
M_V = .548 (16) + .625 (13) + .700 (1.5)
M_V = 18 kg-m which is less than 30 kg-m/OK
M_A = .705 (14) + .945 (1.5) = 11 kg-m which is less than 30 kg-m/OK

P = Adapter Weight
K = 1/2 Hose Weight
$M_S = ZP + TK \le 7$ kg-m

With Caterpillar Hardware
P = 13 kg $K = \frac{3\ \text{kg}}{2}$
Z = 420 mm T = 500 mm
M_S = .420 (13) + .500 (3/2) = 6.21 < 7/OK

Figure 15

Air Inlet Shutoff

An inlet air shutoff *must* be mounted directly in the air stream between the turbocharger compressor outlet and the aftercooler housing. The shutoff is actuated either manually or electronically. It is for emergency use only, not for normal engine shutdowns.

Turbocharger Speed Sensor

If a turbocharger speed sensor is required, the magnetic speed pickup is mounted in the 90° inlet compressor inlet elbow (see Figure 13). A special compressor nose cone and signal conditioner is required with the straight inlet adapter shown in Figure 12.

Turbocharger Loading

Figure 15 shows the maximum turbocharger loads and how to calculate the turbocharger load.

Turbocharger Air Inlet Design

For an axial air inlet, the Caterpillar air inlet adapter shown in Figure 12 should be used. This ensures smooth flow conditions at the turbocharger inlet. If a bend is used to connect to the Caterpillar straight inlet adapter, make the bend radius as large as possible. As a minimum the bend radius should be equal to the pipe diameter, 508 mm [20 in.], or preferably one and a half times the pipe diameter. If an air inlet elbow is required, use the Caterpillar supplied adapter shown in Figure 14. These two adapters are designed in conjunction with the turbocharger to provide favorable air flow at the compressor inlet.

Ventilating Air Calculation Guide

Definition of Engine Room

The space containing propulsion machinery, auxiliary diesel engines, boilers, generators and other major electrical machinery, etc.

Design Conditions

The outside ambient air temperature is assumed to be 35°C (95°F).

Engine room air flow calculations

The total air flow is the sum of the combustion air flow for engines and boilers added to the ventilation air flow for removal of radiated engine room heat.

The total air flow should always be greater than 150% of the combustion air flow.

Machinery areas separated from the engine room, such as auxiliary machinery and boiler rooms, should be calculated separately.

Combustion Air Flow Requirements

Air flows at various engine ratings are in the Engine Data section of this guide. Consult TMI for the latest data.

For repowers where a non-3600 ship service generator engine may remain in place, the combustion air flow for the generator can be estimated by:

$$q_{dg} = \frac{P_{dg} \times Q_d}{p}$$

Where:

q_{dg} = Combustion air flow for non-3600 engines, m^3/sec

P_{dg} = Maximum brake shaft power, kW

Q_d = Specific combustion air requirement per manufacturer's data

Note: *Where values for Q_d are not available, the following may be used for calculations:*

Q_d = 0.0023 kg air/kW x sec

p = 1.15 kg/m^3 (density of air)

Combustion air flow for boilers can be calculated as follows:

$$q_b = \frac{Q_s \times Q_f \times Q_a}{p}$$

Where:

q_b = Combustion air flow for boilers, m^3/sec

Q_s = Total steam consumption at sea, kg/sec

Q_f = Fuel consumption in kg (fuel) per kg (steam).

Note: *If specific data is not available, Q_f = 0.079 kg/kg may be used for calculations.*

Q_a = Combustion air requirements in kg (air) per kg (fuel)

Note: *If specific data is not available, Q_a = 16.8 kg/kg may be used for calculations.*

p = 1.15 kg/m^3 (density of air)

The total combustion air flow can be calculated as follows:

$$q_c = q_{dp} + q_{dg} + q_b$$

Where:

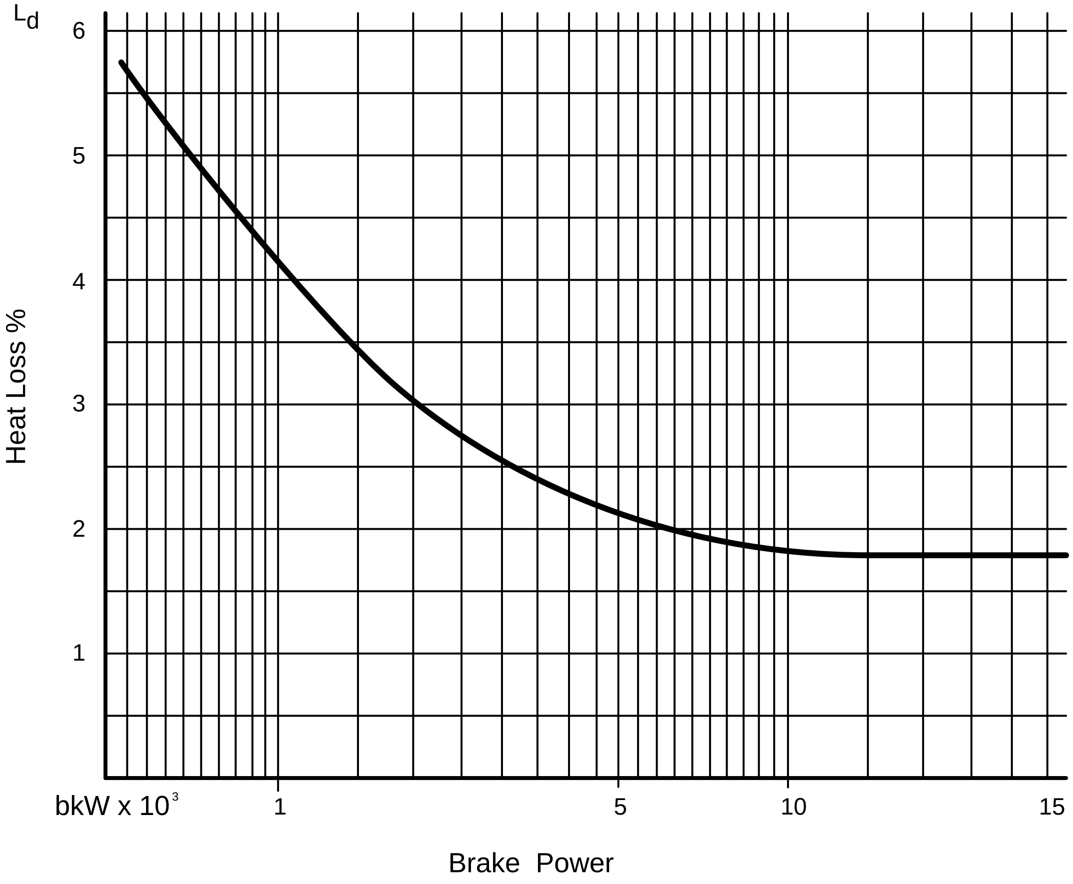
q_c = Sum of combustion air flow, m^3/sec

q_{dp} = Combustion air flow for propulsion engines, m^3/sec

Note: *If the main engines use combustion air directly from atmosphere, q_{dp} will be zero.*

q_{dg} = Combustion air flow for generator engines, m^3/sec

q_b = Combustion air flow for boilers, m^3/sec



Percent Of Heat Loss

Figure 16

Air flow requirements for removal of radiated heat

Heat radiated from propulsion engine

Heat radiated from the propulsion engines is found in the Engine Data section of this guide. Check the TMI system for the latest data.

Heat radiated from generator set engines

In repowers where a non-3600 generator set engine is already in place the radiated heat can be estimated by:

$$\O_{dg} = P_{dg} \times \frac{L_d}{100}$$

Where:

$\O_{dg}$ = Ship service generator engine radiated heat, kW
P_{dg} = Maximum brake shaft power, kW
L_d = Percent of heat loss as taken from Figure 16

Heat rejected from boilers

The heat radiated from boilers can be calculated as follows:

$$Ø_b = Q_s \times Q_f \times h \times \frac{L_b}{100} \times B_{pl} \times B_e$$

Where:

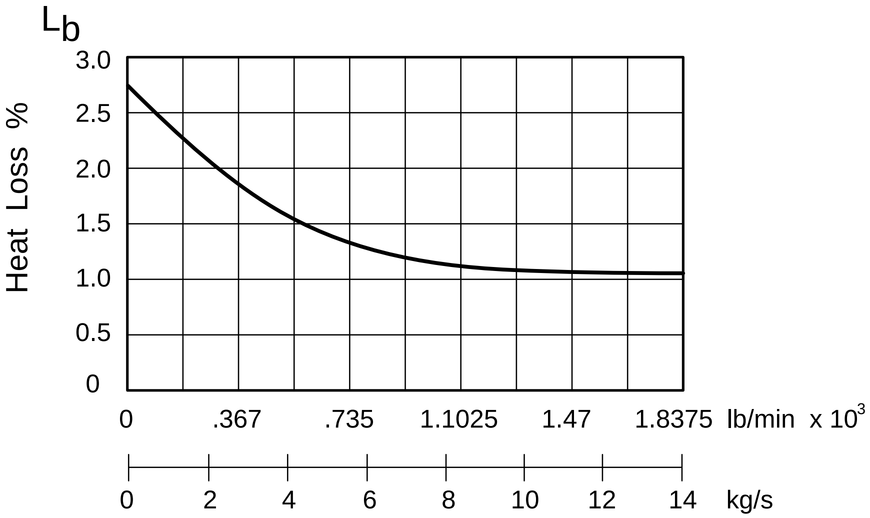
$Ø_b$ = Heat radiated from boilers, kW
Q_s = Total steam consumption at sea, kg/sec
Q_f = Fuel consumption in kg (fuel) per kg (steam)

Note: *If specific data is not available, $Q_f = 0.079$ kg/kg may be used for calculations.*

h = Lower heating value of fuel, kJ/kg

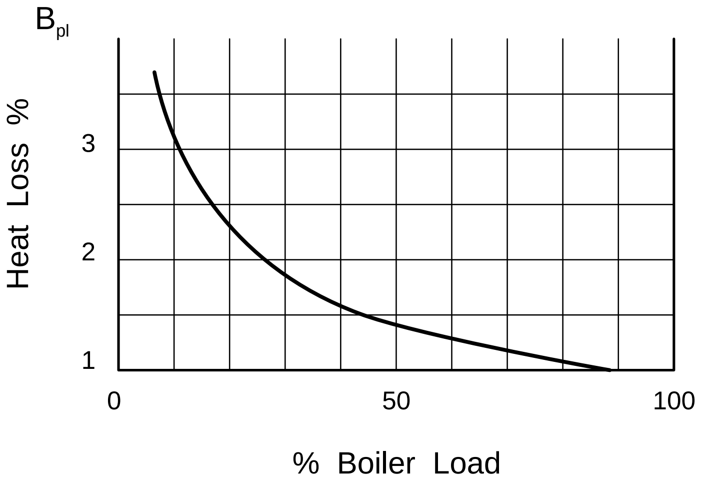
Note: *Where specific data is not available, $h = 41800$ kJ/kg may be used for calculations.*

L_b = Percent heat loss @ maximum steam consumption per Figure 17
B_{pl} = Boiler partial load constant per Figure 18 below
B_e = 0.1 for boilers located directly below exposed casing



Heat Loss In Percent From A Boiler, At Maximum Steam Consumption At Sea

Figure 17



Boiler Constant At Partial Load In Percent

Figure 18

Heat rejected from steam and condensate pipes

The heat rejected from steam and condensate pipes can be calculated as follows:

$$\text{Ø}_p = Q_s \times Q_f \times h \times \frac{L_p}{100}$$

Where:

Ø_p = Heat rejected from steam and condensate piping, kW

Q_s = Total steam consumption, kg/sec

Q_f = Fuel consumption in kg (fuel) per kg (steam)

Note: *If specific data is not available,* $Q_f = 0.079$ *kg/kg may be used for calculations.*

h = kJ/kg - Lower heating value of fuel

Note: *If specific data is not available, h = 41800 kJ/kg may be used for calculations.*

L_p = Heat loss from steam and condensate pipes as a percent of energy supplied to the boiler

Note: *If specific data is not available, 0.15 percent may be used for calculations.*

Heat rejected from generators

The heat rejected from generators can be calculated as follows:

$$\text{Ø}_g = P_g \times \left(1 - \frac{N}{100}\right)$$

Where:

Ø_g = Heat rejected by generator, kW

P_g = Output of generator, kW

N = Generator efficiency, percent

Note: *If specific data is not available, N = 96% may be used for calculations.*

Heat rejected from electrical equipment

For conventional ships where details of the electrical installation are not known the heat rejected is assumed to be 10% of the effective output of the generators and can be calculated as follows:

$$\text{Ø}_{el} = P_g \times \frac{10}{100}$$

Where:

Ø_{el} = Heat rejected by electrical machinery, kW

P_g = Output of generator, kW

Heat rejected from exhaust pipes

The heat rejected from exhaust piping, Q_{ep}, can be approximated from Figure 19. The heat rejection is given in kW/m of pipe versus diameter of pipe with four different types of insulation.

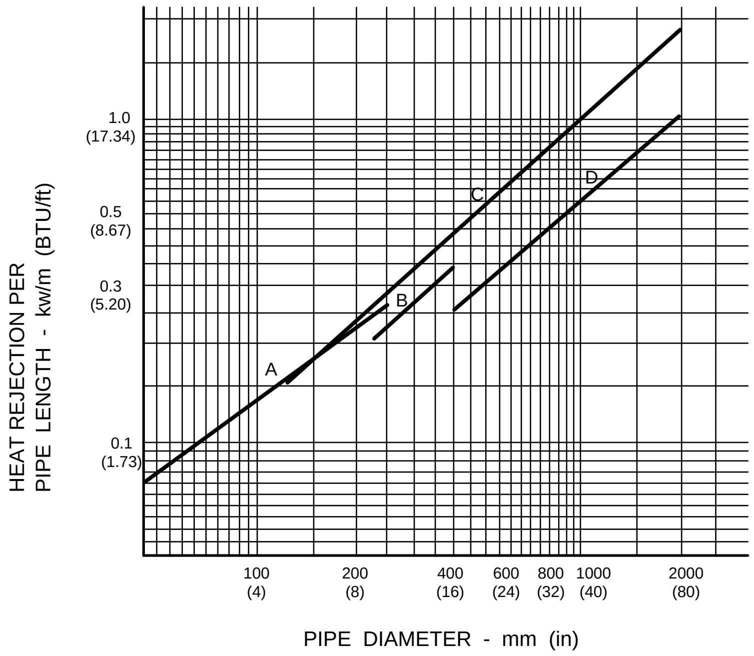
Heat rejected from hot tanks

The heat rejected by hot tanks, Q_t, is based on the sum of the hot tank surface area contiguous with the engine room. These values may be approximated from Figure 20.

Heat Rejection from Tanks

	kW/m² (Btu/min/ft²) @ 60° (140°F)	kW/m² (Btu/min/ft²) @ 70° (158°F)
Uninsulated	0.060 (0.320)	0.105 (0.550)
Approx. 50 mm (2 in.) insulation	0.012 (0.063)	0.021 (0.111)

Figure 20



The graph is based on the temperature difference Δ t = 350˚C
Curve **A** 40mm Mineral wool with λ = 0.038 W/m x C˚
Curve **B** 50mm Mineral wool with λ = 0.038 W/m x C˚
Curve **C** 70mm Asbestos free calcium silicate bowl with λ = 0.070 W/m x C˚
Curve **D** 70mm Mineral wool with λ = 0.037 W/m x C˚

Figure 19 **Heat Rejected From Exhaust Piping**

Heat rejected from other machinery

Evaluate the heat rejected from other machinery, Q_o. Include miscellaneous refrigeration compressors, steam turbines, incinerators, etc., which may be unique to the particular ship's engine room.

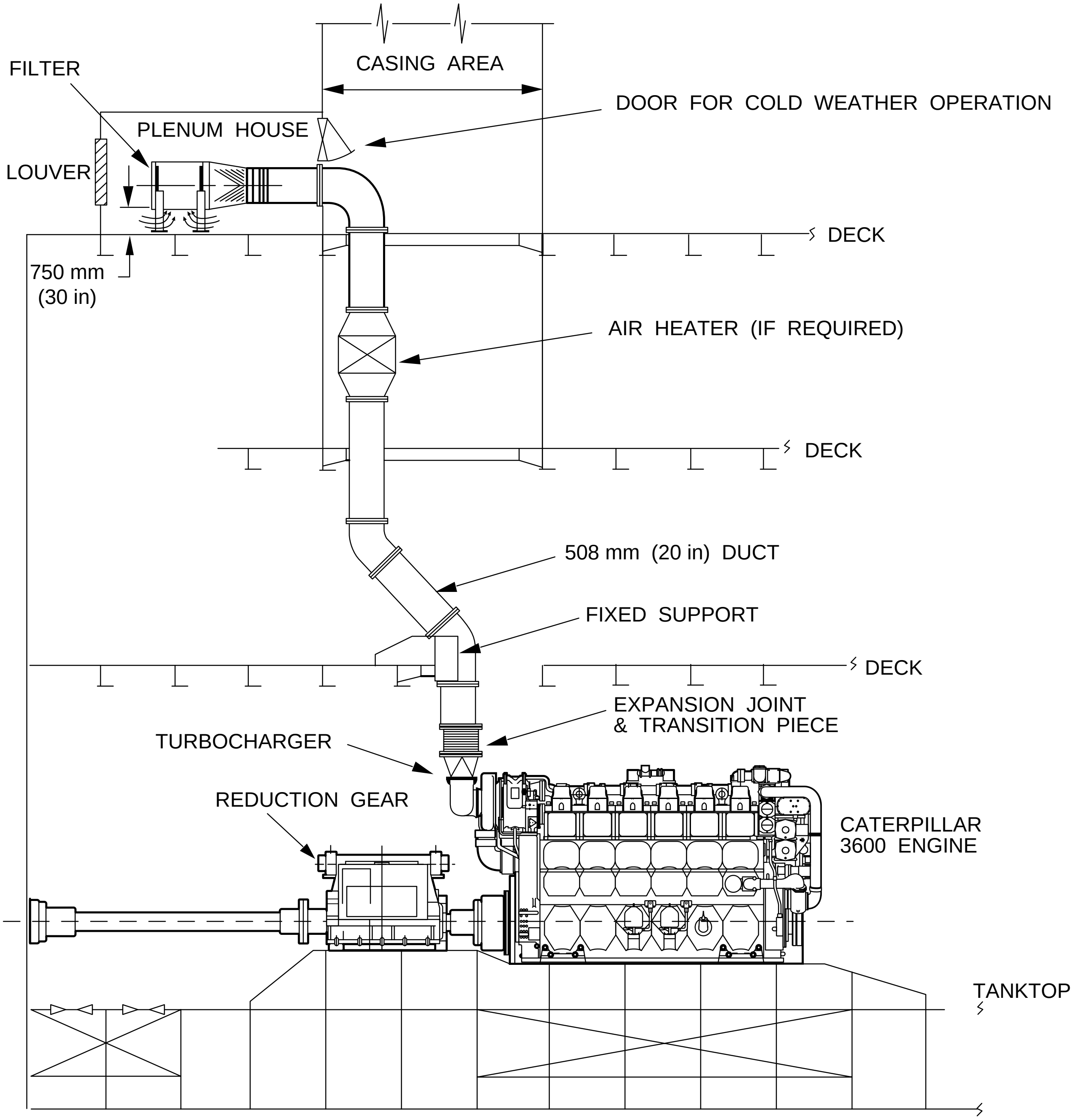
Total air flow for removal of machinery rejected heat

The sum of the air flow for removal of machinery radiated heat can be calculated as follows:

$$q_h = \frac{Ø_{dp} + Ø_{dg} + Ø_b + Ø_p + Ø_g + Ø_{el} + Ø_{ep} + Ø_t + Ø_o}{P \times c \times \Delta t}$$

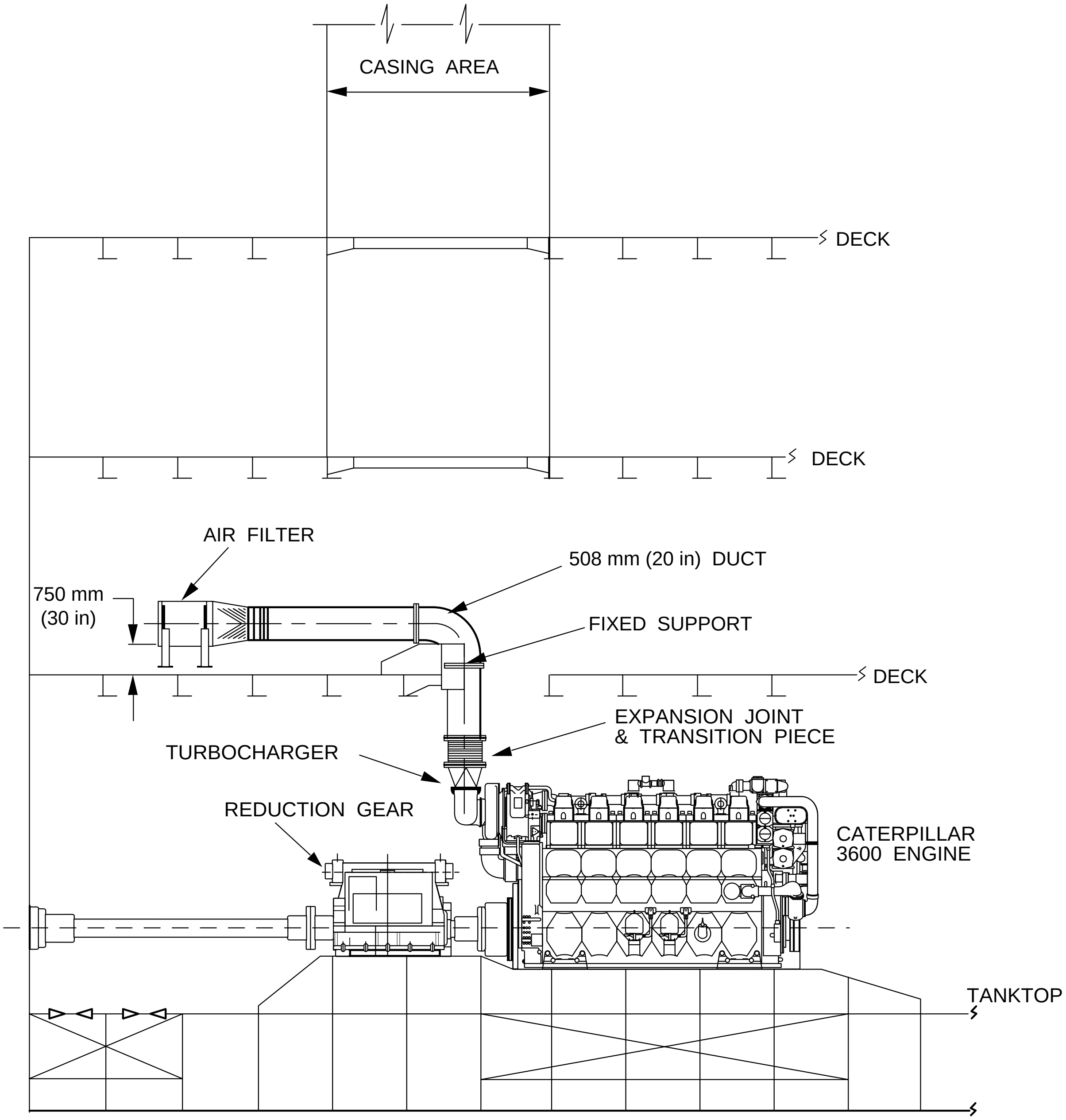
Where:

q_h = sum of air flow for removal of rejected heat, m^3/sec
$Ø_{dp}$ = heat rejected from propulsion engines, kW
$Ø_{dg}$ = heat rejected from generator engines, kW
$Ø_b$ = heat rejected from boilers, kW
$Ø_p$ = heat rejected from steam and condensate pipes, kW
$Ø_g$ = heat emitted from generators, kW
$Ø_{el}$ = heat emitted from electrical installation, kW
$Ø_{ep}$ = heat emitted from exhaust pipes, kW
$Ø_t$ = heat emitted from hot tanks, kW
$Ø_o$ = heat emitted from other components, kW
P = 1.15 kg/m^3 (density of air)
c = 1.01 kJ/kg °C (specific heat capacity of the air)
Δ t = 12.5°C (increase of mean temperature in the engine room)



Remote Mounted Air Cleaner Arrangement
Combustion Air From Outside Engine Room

Figure 3



Remote Mounted Air Cleaner Arrangement
Combustion Air From Inside Engine Room

Figure 4