Power Generation

Chapter 6
Mechanical Design

Our energy working for you.™

CHAPTER 6 CONTENTS

6 – MECHANICAL DESIGN

Foundation and Mounting

Generator Set Mounting and Vibration Isolation

The installation design must provide a proper foundation to support the generator set, and to prevent damaging or annoying levels of vibration energy from migrating into the building structure. In addition, the installation should assure that the supporting infrastructure for the generator set does not allow vibration from the generator set to migrate into the stationary portion of the equipment.

All components that physically connect to the generator set must be flexible in order to absorb the vibration movement without damage. Components that require isolation include the engine exhaust system, fuel lines, AC power supply wiring, load wiring, control wiring (which should be stranded, rather than solid core), the generator set (from the mounting pad), and ventilation air ducts (for generator sets with skid–mounted radiators) (See **Figure 6–1**). Lack of attention to isolation of these physical and electrical interconnection points can result in vibration damage to the building or the generator set, and failure of the generator set in service.

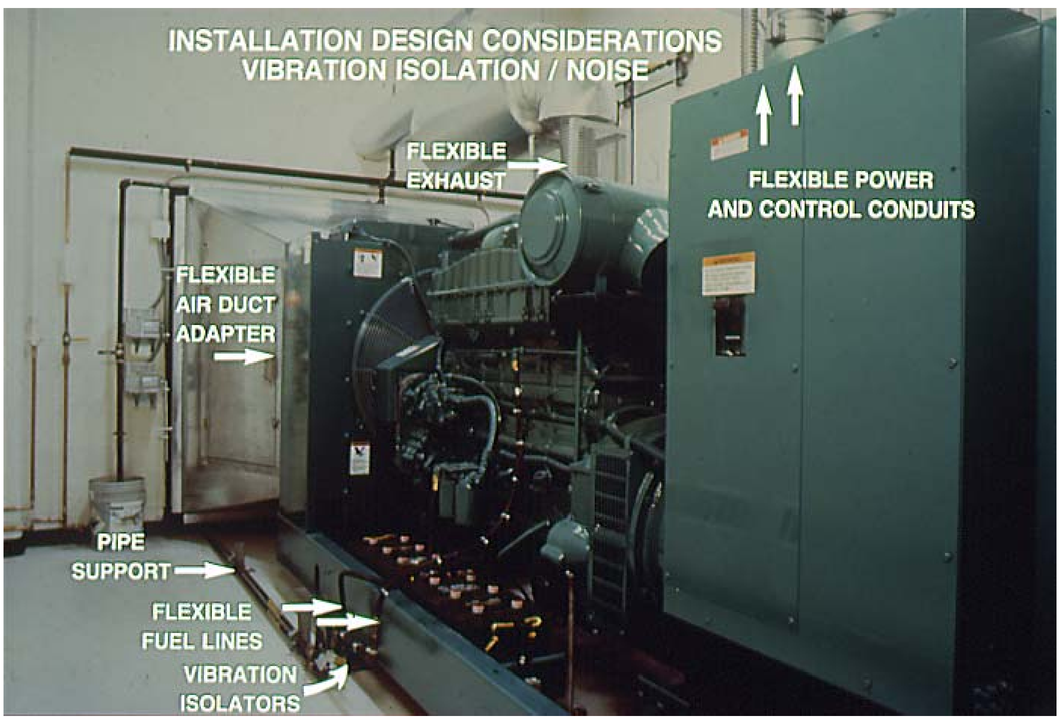


Figure 6–1. Anti–Vibration Provisions for a Typical Generator Set

The generator set engine, alternator, and other mounted equipment are typically mounted on a skid–base assembly. The skid–base assembly is a rigid structure that provides both structural integrity and a degree of vibration isolation. The foundation, floor, or roof must be able to support the weight of the assembled generator set and its accessories (such as a sub–base fuel tank), as well as resist dynamic loads and not transmit objectionable noise and vibration. Note that in applications where vibration isolation is critical the assembled weight of the package might include a massive mounting foundation (See Foundation Provisions in this section.)

Physical size, weight, and mounting configurations vary greatly between manufacturers and between various sizes of equipment. Consult the manufacturer's installation instructions for the specific model installed for detailed information on weights and mounting dimensions[1].

Foundation Provisions

Slab Floor

For many applications, a massive foundation is not necessary for the generator set. Gensets with integral vibration isolators can reduce transmitted vibrations by 60–80% and placing steel spring isolators between the genset and slab can isolate greater than 95% of vibrations (see vibration isolators later in this section). If vibration transmission to the building is not a critical concern, the major issue will be installing the generator set so that its weight is properly supported and so that the unit can be easily serviced. A concrete pad should be poured on top of a concrete floor to raise the generator set to a height that makes service convenient and to make housekeeping around the unit easier.

- The pad should be constructed of reinforced concrete with a 28–day compressive strength of at least 2500–psi (17,200 kPa).
- The pad should be at least 6 inches (150 mm) deep and extend at least 6 inches (150 mm) beyond the skid on all sides.

See generator set manufacturer's drawings for physical locations of fuel lines, control and power interconnections and other interfaces that are planned to be cast into the concrete. These interfaces vary considerably from supplier to supplier.

Vibration isolators should be secured to the mounting pad with Type J or L bolts (rag or rawl bolts) set into the concrete pad. Positioning of "cast in" bolts is problematic, since even small errors in location can cause time consuming redrilling of the skid base. Some generator set designs allow use of concrete anchor bolts. These would require the mounting points to be carefully laid out based on actual location of the mounting points on the generator set and isolators.

The mounting pad for the generator set should be level and flat to allow for proper mounting and adjustment of the vibration isolation system. Verify that the mounting pad is level lengthwise, widthwise, and diagonally.

Piers (Plinth)

Alternatively, the generator set can be mounted on concrete piers (plinth) oriented along the length of the skid of the generator set. This arrangement allows easy positioning of a drip pan underneath the generator set, and allows more room for servicing of the generator set. The piers should be physically attached to the floor.

Vibration Isolating Foundation

In applications where the amount of vibration transmission to the building is highly critical, mounting the generator set on a vibration isolating foundation may be required. In this case, additional considerations are necessary. **Figure 6–2** illustrates a typical vibration isolating foundation.

- The weight (W) of the foundation should be at least 2 times (and up to 5–10 times) the weight of the set itself to resist dynamic loading. (The weight of fuel in a sub–base fuel tank should not be considered to be contributing to the weight required of a vibration isolating foundation even though the isolators are between the tank and the generator set.)

1 Detailed information on Cummins Power Generation products can be found on the Cummins Power Suite, or may be obtained from any authorized distributor.

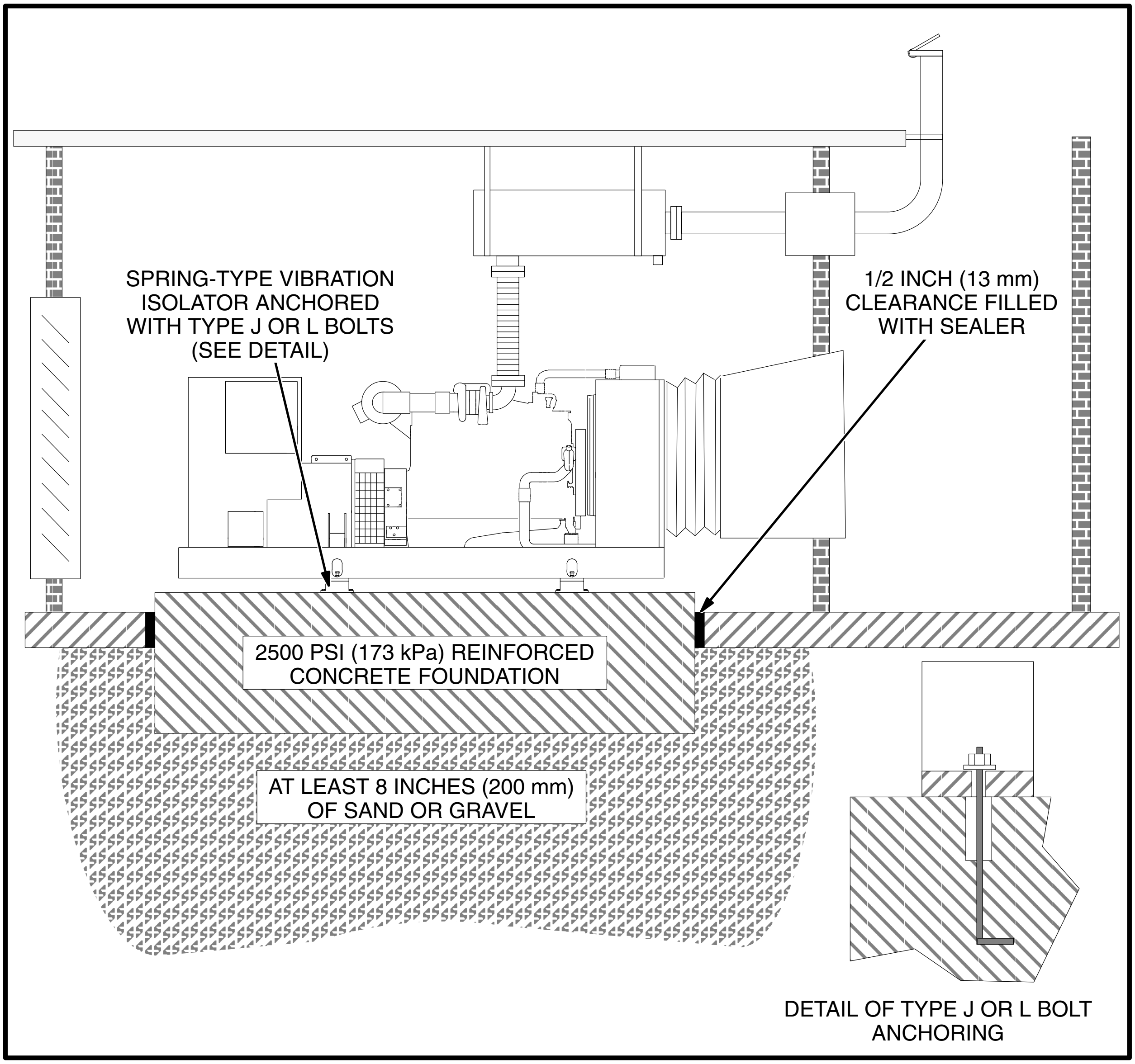


Figure 6–2 Typical Vibration Isolating Foundation

- The foundation should extend at least 6 inches (150 mm) beyond the skid on all sides. This determines the length (l) and width (w) of the foundation.
- The foundation should extend at least 6 inches (150 mm) above the floor to make service and maintenance of the generator set easier.
- The foundation must extend below the frost line to prevent heaving.
- The foundation should be reinforced concrete with a 28–day compressive strength of at least 2500 psi (17,200 kPa).
- Calculate the height (h) of the foundation necessary to obtain the required weight (W) by using the following formula:

$$h = \frac{W}{d \bullet l \bullet w}$$

Where:

h = Height of the foundation in feet (meters).
l = Length of the foundation in feet (meters).
w = Width of the foundation in feet (meters).
d = Density of Concrete – 145 lbs/f^3 (2322 kg/M^3)
W = Total wet weight of Genset in lbs (kg).

- The total weight of the generator set, coolant, fuel, and foundation usually results in a soil bearing load (SBL) of less than 2000 lbs/ft^2 (9800 kg/m^2)psi (96 kPa). Although this is within the load bearing capacity of most soils, always find out the allowable SBL by checking the local code and the soil analysis report for the building. Remember to include the weight of coolant, lubricant, and fuel (if applicable) when performing this calculation. Calculate the SBL by using the following formula:

$$\text{SBL (psi)} = \frac{W}{l \bullet w \bullet 144}$$

$$\text{SBL (kPa)} = \frac{W \bullet 20.88}{l \bullet w}$$

Sample Calculations (US units):

A 500kW genset weights approximately 10,000 pounds (4540 kg) wet (i.e., including coolant and lubricants). Skid dimension is 10 feet (3 meters) long and 3.4 feet (1 meter) wide.

l = 10 + (2 • 0.5) = 11 feet
w = 3.4 + (2 • 0.5) = 4.4 feet
Foundation weight = 2 • 10,000 = 20,000 lbs
Total weight = genset + foundation
=10,000 + 20,000 = 30,000 lbs

$$\textbf{SBL} = \frac{30{,}000}{11 \bullet 4.4} = \mathbf{620\ lbs/ft^2}$$

Vibration Isolators

The engine and alternator of a generator set must be isolated from the mounting structure where it is installed. Some generator sets, particularly smaller kW models, utilize neoprene/rubber vibration isolators that are inserted into the machine between the engine/alternator and the skid[2]. The skid of these generator sets usually can be bolted directly to the foundation, floor, or sub–structure. Other generator sets may be provided with a design that features the engine/alternator solidly attached to the skid assembly. Generator sets that do not include integral isolation should be installed using vibration isolation equipment such as pad, spring, or air isolators.

NOTE: Bolting a generator set that does not include integral isolators directly to the floor or foundation will result in excessive noise and vibration; and possible damage to the generator set, the floor, and other equipment. Vibrations can also be transmitted through the building structure and damage the structure itself.

2 Cummins Power Generation generator sets (200/175 kW and smaller) have rubber vibration isolators located between the skid and the engine–generator assembly and do not require use of external vibration isolators for most applications.

Pad Isolators

Pad–type isolators are comprised of layers of flexible materials designed to dampen vibration levels in non–critical applications, such as those on grade or for generator sets mounted in their own outdoor enclosure, or where integral isolators are used with a generator set. Pad isolators vary in their effectiveness, but are approximately 75% efficient. Depending on construction, they may also vary in effectiveness with temperature, since at cold temperatures the rubber isolating medium is much less flexible than at higher temperatures.

Spring Isolators

Figure 6–3 illustrates a steel spring vibration isolator of the type required for mounting generator sets that do not include integral vibration isolators. Depicted are the bottom rubber pad, isolator body, securing bolts, support spring, adjusting screw, and locking nut.

These steel spring isolators can damp up to 98 percent of the vibration energy produced by the generator set. Locate the isolators as shown on the generator set manufacturer's documentation. The isolators may not be located symmetrically around the perimeter of the generator set, because they are required to be located with consideration of the center of gravity of the machine. The number of isolators required varies with the ratings of the isolators and the weight of the generator set. See **Figure 6–4**.

When the machine is mounted on a sub–base fuel tank, the type of vibration isolators required to protect the sub–base fuel tank depends on the structure of the tank and the level of vibration force created by the machine. If synthetic rubber vibration isolators are installed between the engine/generator and the skid, additional vibration isolation is not usually required between the machine and the subbase tank. If the engine/alternator is solidly attached to the skid, additional vibration isolation between the skid and a sub–base tank is needed to protect the sub–base tank and adequately isolate the building from vibration. In all cases, follow the manufacturer's recommendations for the specific genset and sub–base tank combination.

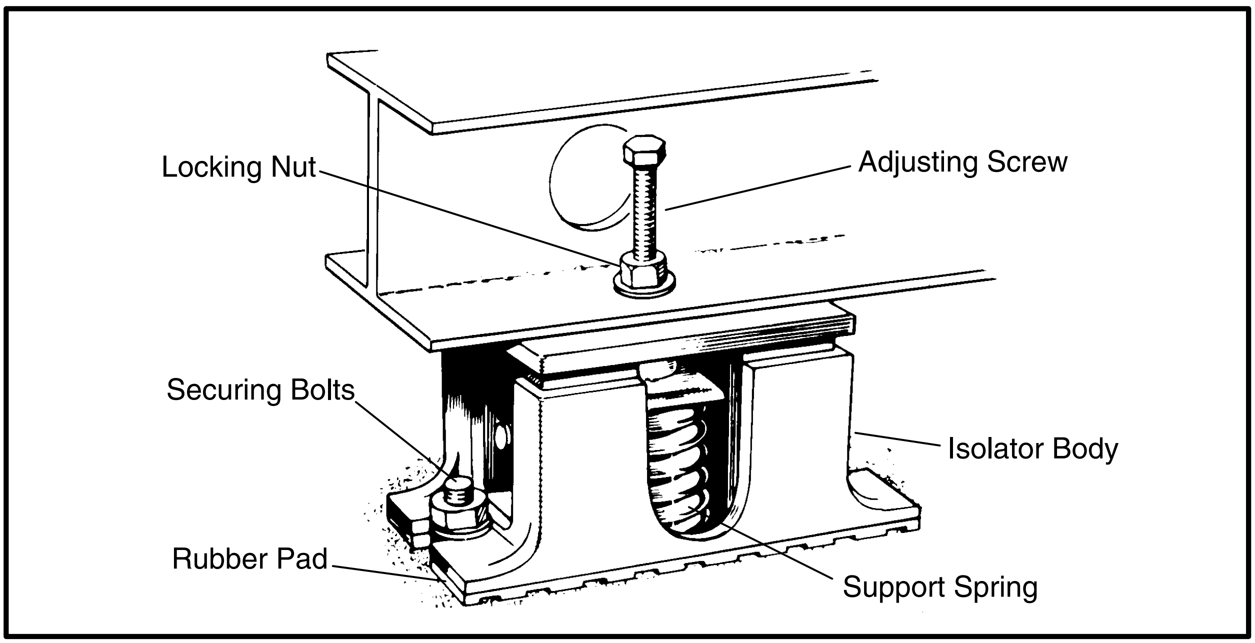


Figure 6–3. Typical Steel Spring Vibration Isolator

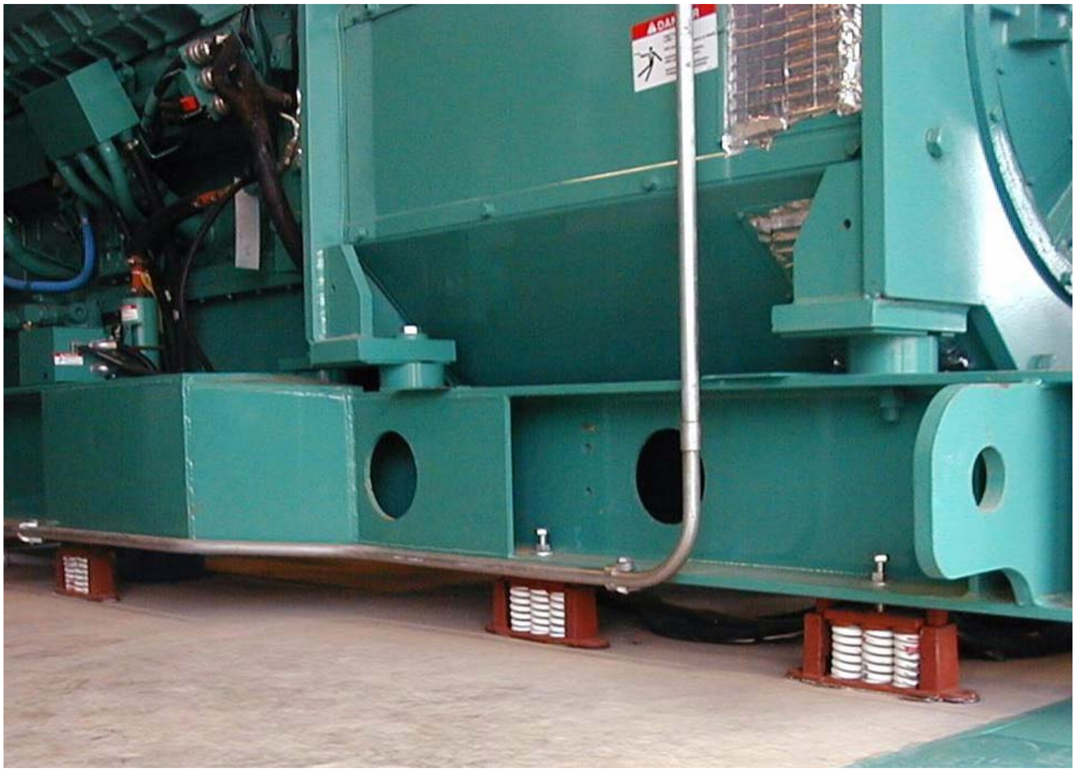


Figure 6–4. A Generator Set Mounted With Spring–Type Vibration Isolators

Spring–type vibration isolators must be properly selected and installed to provide effective isolation. The weight of the generator set should compress the isolator sufficiently to allow freedom of motion without allowing the isolator to "bottom out" during operation. This is accomplished by choosing the isolators and their number based on the isolator's weight rating and the total weight of the generator set.

The isolator should be positively anchored to the mounting pad for the generator set using Rag (L or J bolts) or Rawl (concrete anchor) bolts.

Air Isolators

An air isolator (or air spring) is a column of gas confined in a container designed to utilize the pressure of the gas as the force medium of the spring. Air isolators can provide a natural frequency lower than can be achieved with elastomeric (rubber) and with special designs lower than helical steel springs. They provide leveling capability by adjusting the gas pressure within the spring.

Air isolators require more maintenance, and temperature limitations are more restrictive than for helical springs. Stiffness of air isolators varies with gas pressure and is not constant, as is the stiffness of other isolators. As a result, the natural frequency does not vary with load to the same degree as other methods of isolation. A failure of the air supply system or leak can cause the isolators to fail completely.

Dampening in air isolators is generally low with a critical dampening ratio in the order of 0.05 or less. This dampening is provided by flexure in the diaphragm or sidewall by friction, or by damping in the gas. Incorporating capillary flow resistance (adding an orifice to the flow) may increase damping between the cylinder of the air isolator and the connecting surge tanks.

Isolators Used in Seismic Locations

Additional factors must be considered for equipment installed in seismic areas. In addition to their typical role of protecting buildings or equipment from machine induced vibration, during a seismic event vibration isolators must also ensure that the equipment remains anchored and does not break free of the structure it is attached to.

In seismic areas, vibration isolators are often used between the genset skid–base and the structure it is attached to. Seismic isolator must be captive, meaning they restrain the generator set from excessive movement and must be strong enough to withstand the seismic forces encountered. Vibration isolators suitable for use in these applications are available in both synthetic rubber and steel spring types.

Vibration isolators, if installed between the engine/alternator and skid, must also adequately secure the engine/alternator to the skid. Normally these types of isolators are of the synthetic rubber type and must be of a “captive” design so as to adequately secure the equipment. The manufacturer or supplier of the equipment should be consulted to determine suitability to the specific application.

Whenever seismic events are a consideration, a qualified structural engineer should be consulted.

Earthquake Resistance

Cummins Power Generation generator sets, when properly mounted and restrained, are suitable for application in recognized seismic risk regions. Special design considerations are necessary for mounting and restraining equipment of the mass density typical of generator sets. Generator set weight, center of gravity, and mounting point locations are indicated on Cummins Power Generation generator set outline drawings.

Components such as distribution lines for electricity, coolant, and fuel must be designed to sustain minimal damage and to facilitate repairs should an earthquake occur. Transfer switches, distribution panels, circuit breakers and associated controls for critical applications[3] must be capable of performing their intended functions during and after the anticipated seismic shocks, so specific mounting and electrical connection provisions must be considered.

Power and Control Wiring Strain Relief

Power wiring and especially control wiring should be installed with the wiring supported on the mechanical structure of the generator set or control panel, and not the physical connection lugs or terminations. Strain relief provisions, along with the use of stranded control wiring rather than single core wiring help to prevent failure of the wiring or connections due to vibration. See Electrical Connections in *Electrical Design.*

Exhaust System

Exhaust System General Guidelines

The function of the exhaust system is to convey engine exhaust safely outside the building and to disperse the exhaust fumes, soot, and noise away from people and buildings. The exhaust system must be designed to minimize backpressure on the engine. Excessive exhaust restriction will result in increased fuel consumption, abnormally high exhaust temperature and failures related to high exhaust temperature as well as excessive black smoke.

See **Figure 6–5** and **6–6**. Exhaust system designs should consider the following:

- Schedule 40 black iron pipe may be used for exhaust piping. Other materials that are acceptable include prefabricated stainless steel exhaust systems.

3 **US CODE NOTE:** NFPA110 requires these features for Level 1 and Level 2 systems.

Figure 6–5: Typical Features of an Exhaust System for a Generator Installed Inside a Building.

- Flexible, seamless corrugated stainless steel exhaust tubing at least 24 inches (610 mm) long must be connected to the engine exhaust outlet(s) to allow for thermal expansion and generator set movement and vibration whenever the set is mounted on vibration isolators. Smaller sets with integral vibration isolation that are bolted directly to the floor must be connected by seamless corrugated stainless steel exhaust tubing at least 18 inches (457 mm) long. Flexible exhaust tubing must not be used to form bends or to compensate for incorrectly aligned exhaust piping.
- Generator sets may be provided with threaded exhaust, slip–type exhaust, or flange–type exhaust connections. Threaded and flanged connections are less likely to leak but more costly to install.
- Isolated non–combustible hangers or supports, NOT the engine exhaust outlet, must support mufflers and piping. Weight on the engine exhaust outlet can cause damage to the engine exhaust manifold or reduce the life of the turbocharger (when used), and can cause vibration from the generator set to be transmitted into the building structure. The use of mounts with isolators further limits vibration from being induced into the building structure.
- To reduce corrosion due to condensation, a muffler (silencer) should be installed as close as practical to the engine so that it heats up quickly. Locating the silencer close to the engine also improves the sound attenuation of the muffler. Pipe bend radii should be as long as practical.

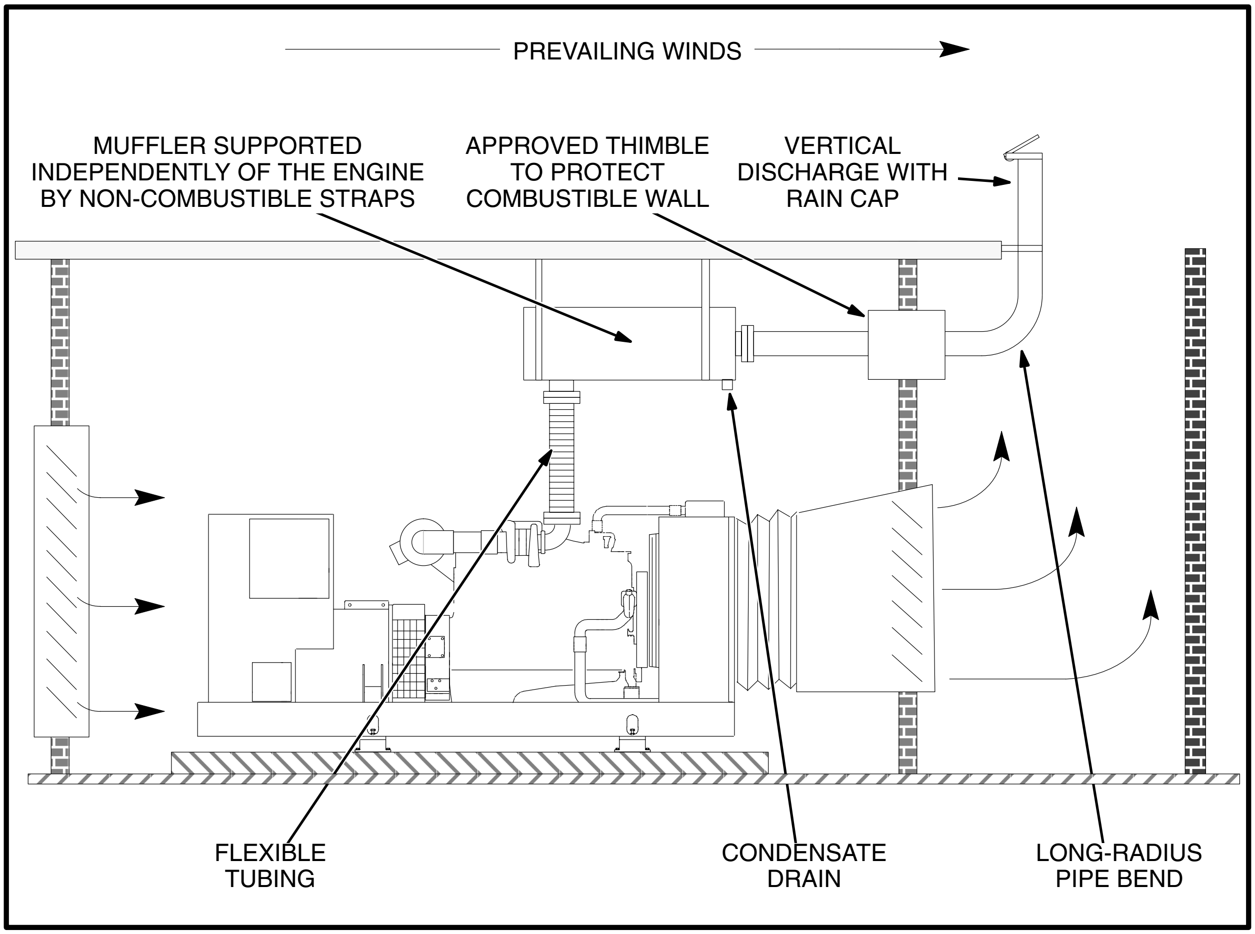


Figure 6–6. Typical Exhaust System

- Exhaust tubing and piping should be of the same nominal diameter as the engine exhaust outlet (or larger) throughout the exhaust system. Verify that the piping is of sufficient diameter to limit exhaust backpressure to a value within the rating of the specific engine used. (Different engines have different exhaust sizes and different backpressure limitations[4].) Piping of smaller diameter than the exhaust outlet must never be used. Piping that is larger than necessary is more subject to corrosion due to condensation than smaller pipe. Piping that is too large also reduces the exhaust gas velocity available for dispersing the exhaust gases up and into the outdoor wind stream.

4 Exhaust system size and other exhaust data for specific generator sets is described in the Cummins Power Suite.

- All engine exhaust system components should include barriers to prevent dangerous accidental contact. Exhaust piping and mufflers should be thermally insulated to prevent burns from accidental contact, prevent activation of fire detection devices and sprinklers, reduce corrosion due to condensation, and reduce the amount of heat radiated to the generator room. Expansion joints, engine exhaust manifolds, and turbocharger housings, unless water cooled, must never be insulated. Insulating exhaust manifolds and turbochargers can result in material temperatures that can destroy the manifold and turbocharger, particularly in applications where the engine will run a large number of hours. Routing of exhaust piping at least 8 feet (2.3 meters) above the floor will also help to prevent accidental contact with the exhaust system.
- Exhaust piping must be routed at least 9 inches (230 mm) from combustible construction. Use approved thimbles where exhaust piping must pass through combustible walls or ceilings (**Figure 6–7 and 6–8**).
- The exhaust system outlet direction should also be carefully considered. Exhaust should never be directed toward the roof of a building or toward combustible surfaces. Exhaust from a diesel engine is hot and will contain soot and other contaminants that can adhere to surrounding surfaces.
- Locate the exhaust outlet and direct it away from the ventilation air intakes.
- If noise is a factor direct the exhaust outlet away from critical locations.
- Exhaust pipe (steel) expands approximately 0.0076 inches per foot of pipe for every 100°F rise in exhaust gas above ambient temperature (1.14 mm per meter of pipe per 100° C rise). It is required that exhaust expansion joints be used to take up expansion in long, straight runs of pipe. Expansion joints should be provided at each point where the exhaust changes direction. The exhaust system should be supported so that expansion is directed away from the generator set. Exhaust temperatures are supplied by the engine or generator set manufacturer for the specific engine used[5].

5 Exhaust gas data for Cummins Power Generation products is available in the Power Suite CD package.

Figure 6–7: Generator Set Exhaust System Features. Dual Side Inlet Silencer, Flex Connectors, Exhaust Thimbles, and Mounting Hangers are Shown.

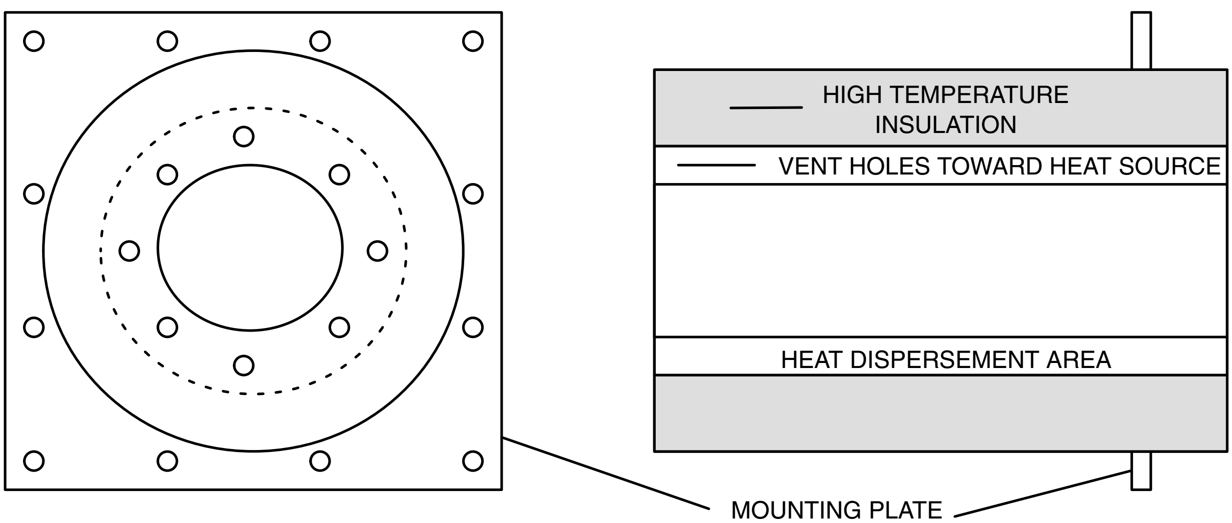


Figure 6–8: Typical Thimble Construction for Combustible Wall Installations.

- Horizontal runs of exhaust piping should slope downwards, away from the engine, to the out–of–doors or to a condensate trap.

- A condensate drain trap and plug should be provided where piping turns to rise vertically. Condensate traps may also be provided with a silencer. Maintenance procedures for the generator set should include regular draining of condensate from the exhaust system.
- Provisions to prevent rain from entering the exhaust system of an engine that is not operating should be provided. This might include a rain cap or exhaust trap (**Figure 6–9 and 6–10**) on vertical exhaust outlets. Horizontal exhaust outlets may be cut off at an angle and protected with birdscreen. Rain caps can freeze closed in cold environments, disabling the engine, so other protective devices may be best for those situations.
- A generator set should not be connected to an exhaust system serving other equipment, including other generator sets. Soot, corrosive condensate, and high exhaust gas temperatures can damage idle equipment served by a common exhaust system.
- Exhaust backpressure must not exceed the allowable backpressure specified by the engine manufacturer[6]. Excessive exhaust backpressure reduces engine power and engine life and may lead to high exhaust temperatures and smoke. Engine exhaust backpressure should be estimated before the layout of the exhaust system is finalized, and it should be measured at the exhaust outlet under full–load operation before the set is placed in service.
- See Exhaust Silencer Performance elsewhere in this section for information on exhaust silencers and various selection criteria for these devices.

WARNING: Engine exhaust contains soot and carbon monoxide, an invisible, odorless, toxic gas. The exhaust system must terminate outside the building at a location where engine exhaust will disperse away from buildings and building air intakes. It is highly recommended that the exhaust system be carried up as high as practical on the downwind side of buildings in order to discharge straight up to maximize dispersal. Exhaust should also discharge on the radiator air discharge side of the building to reduce the likelihood of exhaust gases and soot being drawn into the generator room with the ventilating air.

NOTE: Some codes specify that the exhaust outlet terminate at least 10 feet (3 meters) for the property line, 3 feet (1 meter) from an exterior wall or roof, 10 feet (3 meters) from openings into the building and at least 10 feet (3 meters) above the adjoining grade.

6 Exhaust backpressure information for specific Cummins Power Generation generator sets can be found in the Cummins Power Suite, or may be obtained from an authorized Cummins distributor.

Figure 6–9. A Simple Exhaust System Fitted With a Rain Cap to Prevent Rain From Entering the Exhaust.

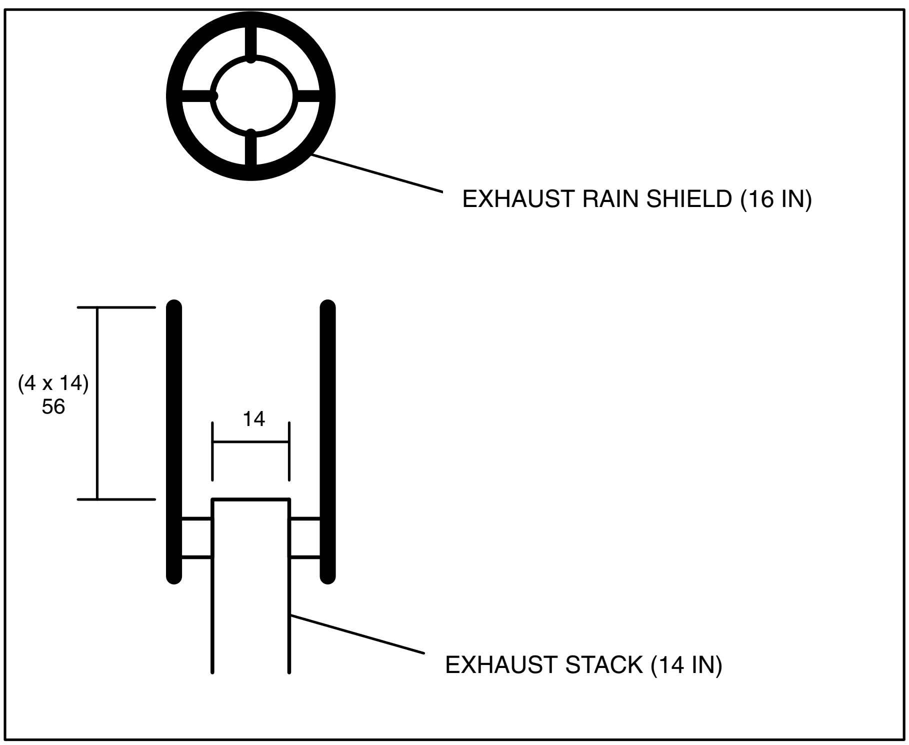


Figure 6–10. A Fabricated Rain Shield for Vertical Genset Exhaust Stack. Dimensions Shown are for a Typical 14–Inch Exhaust.

Exhaust System Calculations

Example Exhaust Backpressure Calculation (US Units)

The layout of an exhaust system in **Figure 6–11** specifies a 5–inch (125–mm) diameter by 24–inch (610 mm) long flexible tube at the engine exhaust outlet, a critical grade muffler with a 6–inch (150–mm) diameter inlet, 20 feet (610 m) of 6–inch (150–mm) diameter pipe and one 6–inch (150 mm) diameter long–radius elbow. The generator set Specification Sheet indicates that the engine exhaust gas flow is 2,715 cfm (cubic feet per minute)(76.9 m^3/min) and that the maximum allowable exhaust back pressure is 41 inches (1040 mm) WC (water column).

This procedure involves determining the exhaust back pressure caused by each element (flexible tubes, mufflers, elbows, and pipes) and then comparing the sum of the back pressures with the maximum allowable back pressure.

1. Determine the exhaust backpressure caused by the muffler. **Figure 6–12** is a graph of typical muffler exhaust backpressures. For more accurate calculations obtain data from the muffler manufacturer. To use **Figure 6–12**:

   a. Find the cross–sectional area of the muffler inlet using **Table 6–1** (0.1963 ft^2 in this example).

   b. Find the exhaust gas flow rate from the engine manufacturer[7]. For this example 2715 cfm is given.

   c. Calculate exhaust gas velocity in feet per minute (fpm) by dividing exhaust gas flow (cfm) by the area of the muffler inlet, as follows:

$$\text{Gas Velocity} = \frac{2715 \text{ cfm}}{0.1963 \text{ ft}^2} = 13{,}831 \text{ fpm}$$

   d. Using **Figure 6–12**, determine the back pressure caused by this flow in the specific muffler used. In this example, the dashed lines in **Figure 6–12** show that the critical grade muffler will cause a back pressure of approximately 21.5 inches W.C.

   3) 20 feet of 6–inch Pipe 20 ft

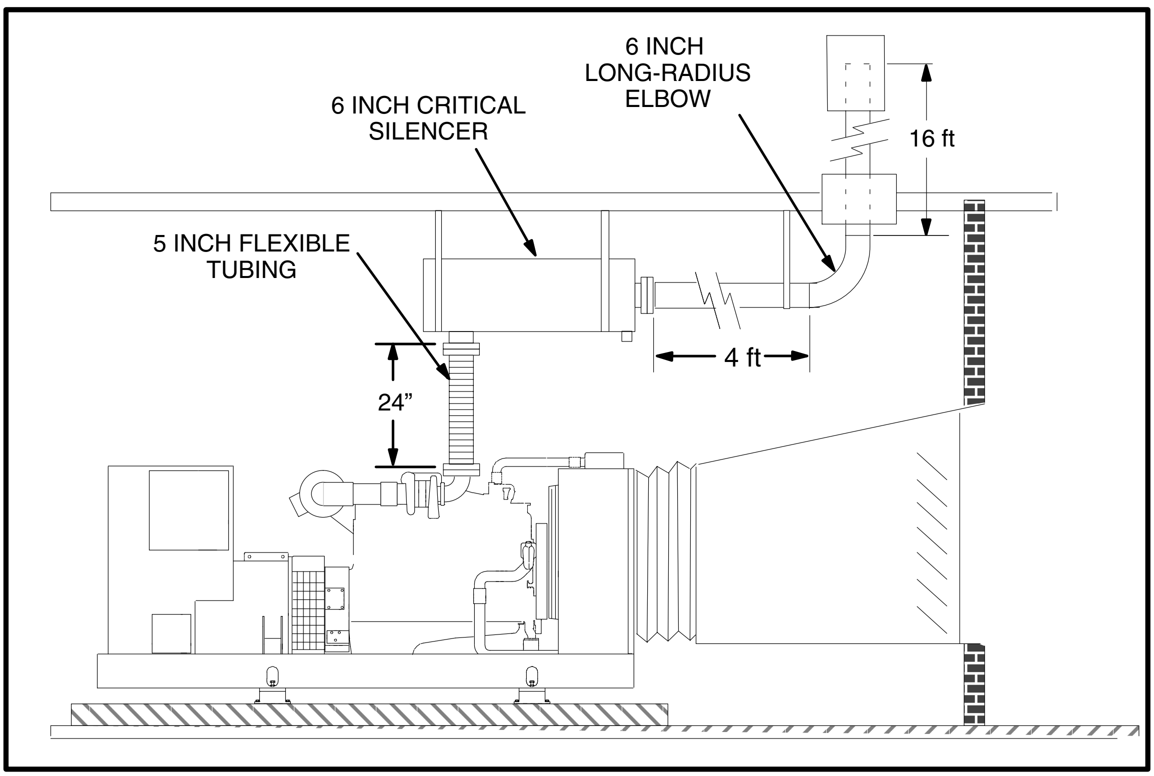


Figure 6–11. Sample Exhaust System for Calculation.

7 Exhaust gas data for Cummins Power Generation products is in the Cummins Power Suite.

2. Find the equivalent lengths of all fittings and flexible tube sections by using **Table 6–2**.
   1) 24 inch flexible tube 4 ft
   2) 6–inch long radius elbow 11 ft
3. Find the back pressure at the given exhaust flow per unit length of pipe for each nominal pipe diameter used in the system. In this example, 5 inch and 6 inch nominal pipe is used. Following the dashed lines in **Figure 6–13**, 5 inch pipe causes a back pressure of approximately **0.34** inches WC per foot and 6 inch pipe approximately **0.138** inches WC per foot.
4. Add the total back pressures for all elements of the example, as follows:
   1) 5 inch flexible tube (4•0.34) 1.4
   2) long–radius elbow (11•0.138) 1.5
   3) 20 feet of 6–inch pipe (20•0.138) 2.8
   4) muffler 21.5
   Total Restriction (inches WC) 27.2

The calculation indicates that the piping layout is adequate in terms of exhaust back pressure since the sum of the back pressures is less than the maximum allowable back pressure of 41 Inches WC.

NOTE: On engines with dual exhaust, the exhaust flow as listed on genset specification sheets from Cummins Power Generation is total flow of both banks. The listed value must be divided by 2 for correct calculation for dual exhaust systems.

DIAMETER OF MUFFLER INLET (INCHES)	AREA OF MUFFLER INLET (FT^2)	DIAMETER OF MUFFLER INLET (INCHES)	AREA OF MUFFLER INLET (FT^2)
2	0.0218	8	0.3491
2.5	0.0341	10	0.5454
3	0.0491	12	0.7854
3.5	0.0668	14	1.069
4	0.0873	16	1.396
5	0.1363	18	1.767
6	0.1963		

Table 6–1. Cross Sectional Areas of Openings of Various Diameter

TYPE OF FITTING	NOMINAL INCH (MILLIMETER) PIPE SIZE											
	2 (50)	**2–1/2 (65)**	**3 (80)**	**3.5 (90)**	**4 (100)**	**5 (125)**	**6 (150)**	**8 (200)**	**10 (250)**	**12 (300)**	**14 (350)**	**16 (400)**	**18 (450)**
90° Standard Elbow	5.2 (1.6)	6.2 (1.9)	7.7 (2.3)	9.6 (2.9)	10 (3.0)	13 (4.0)	15 (4.6)	21 (6.4)	26 (7.9)	32 (9.8)	37 (11.3)	42 (12.8)	47 (14.3)
90° Medium Radius Elbow	4.6 (1.4)	5.4 (1.6)	6.8 (2.1)	8 (2.4)	9 (2.7)	11 (3.4)	13 (4.0)	18 (5.5)	22 (6.7)	26 (7.9)	32 (9.8)	35 (10.7)	40 (12.2)
90° Long Radius Elbow	3.5 (1.1)	4.2 (1.3)	5.2 (1.6)	6 (1.8)	6.8 (2.1)	8.5 (2.6)	10 (3.0)	14 (4.3)	17 (5.2)	20 (6.1)	24 (7.3)	26 (7.9)	31 (9.4)
45° Elbow	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.2 (1.3)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)	6 (1.8)	8 (2.4)	9 (2.7)	17 (5.2)	19 (5.8)	22 (6.7)
TEE, Side Inlet or Outlet	10 (3.0)	12 (3.7)	16 (4.9)	18 (5.5)	20 (6.1)	25 (7.6)	31 (9.4)	44 (13)	56 (17)	67 (20)	78 (23.8)	89 (27.1)	110 (33.5)

18 Inch Flexible Tube	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)	3 (0.9)
24 Inch Flexible Tube	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)

Table 6–2. Equivalent Lengths of Pipe Fittings in Feet (Meters)

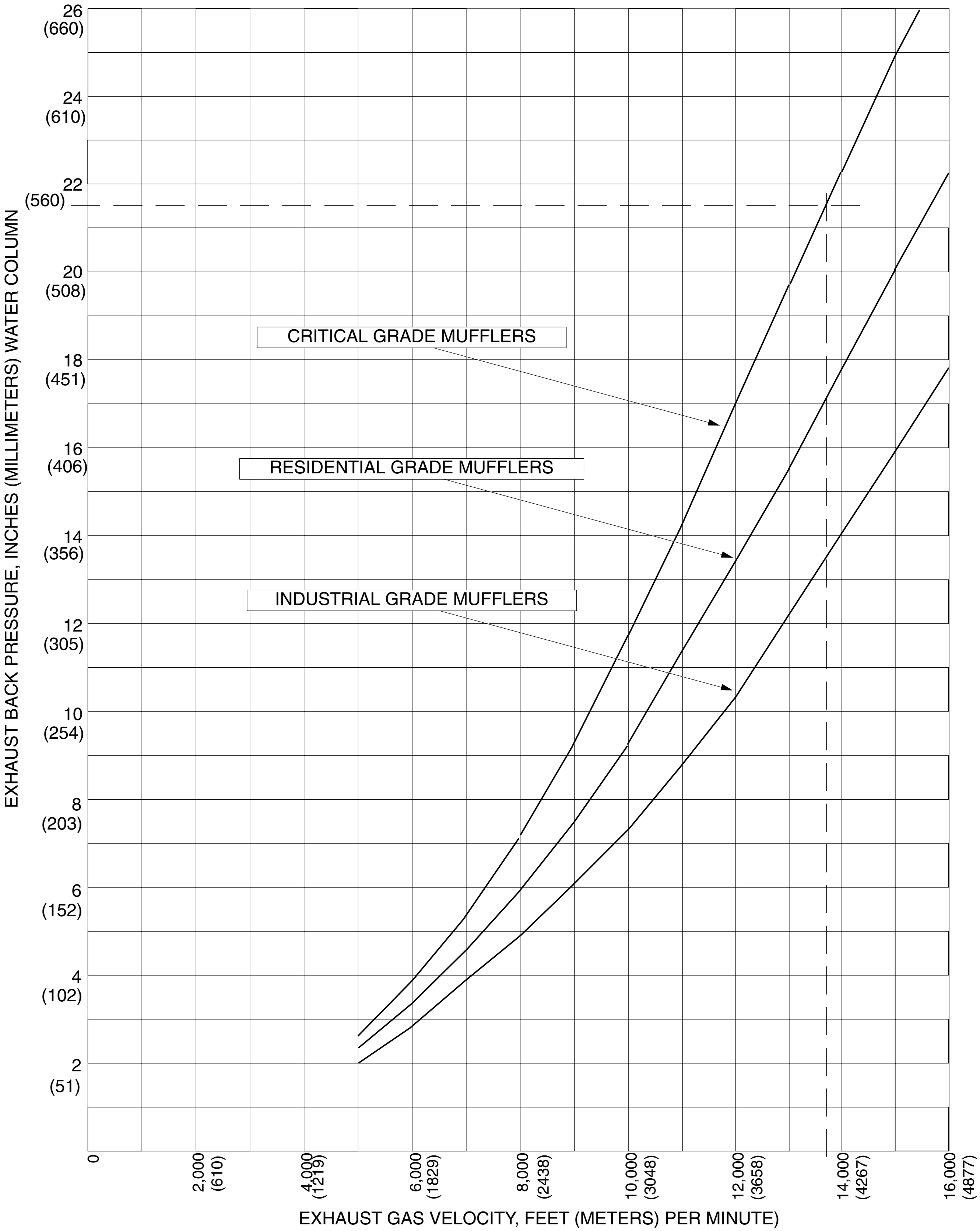


Figure 6–12. Typical Muffler Exhaust Back Pressure vs. Gas Velocity

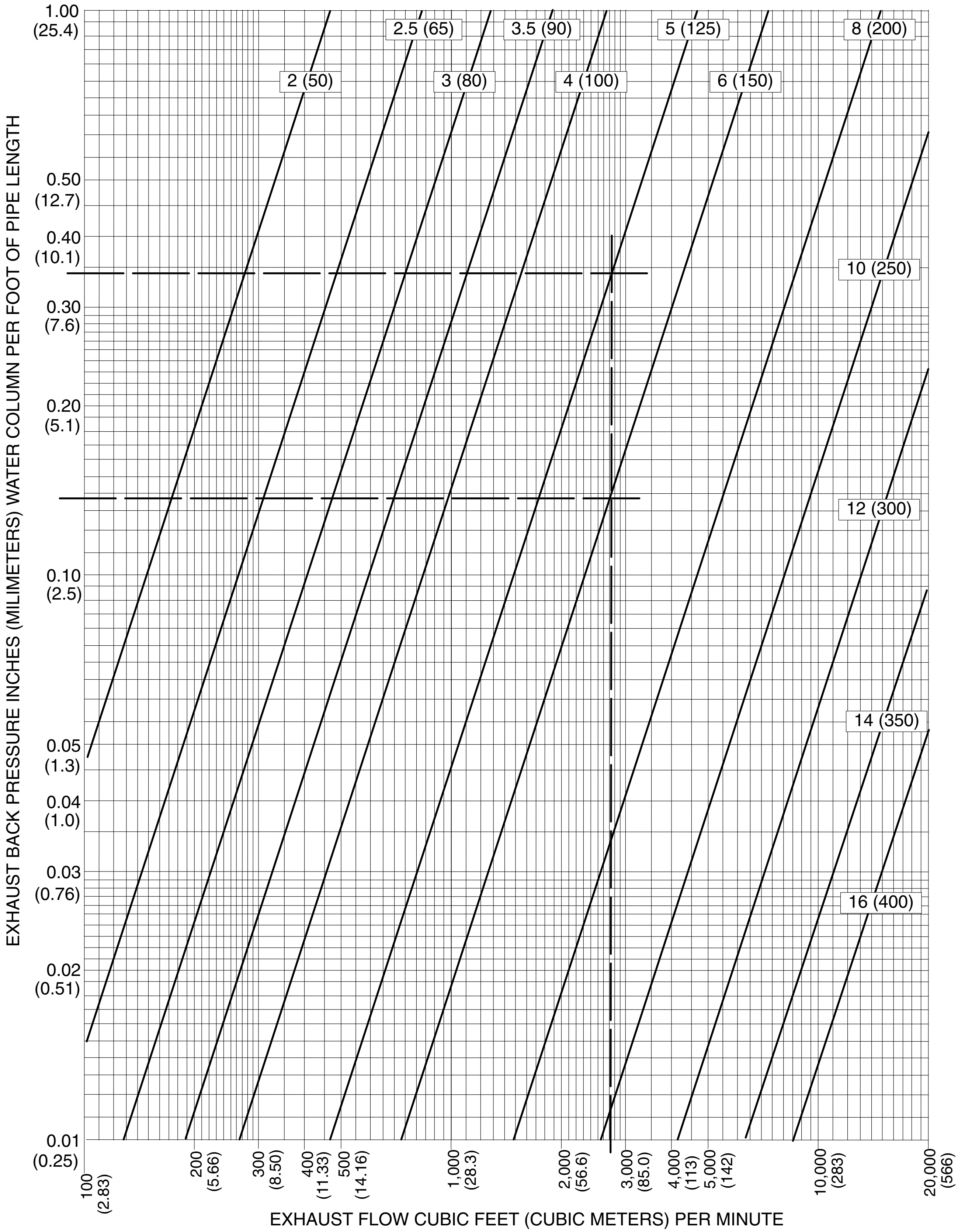


Figure 6–13. Exhaust Back Pressure in Nominal Inch (mm) Pipe Diameters

Engine Cooling

Liquid–cooled engines are cooled by pumping a coolant mixture through passages in the engine cylinder block and head(s) by means of an engine–driven pump. The most common generator set configuration has a mounted radiator and an engine–driven fan to cool the coolant and ventilate the generator room. Alternative methods for cooling the coolant include skid–mounted liquid–to–liquid heat exchangers, remote radiator, a remote liquid–to–liquid heat exchanger, and cooling tower configurations.

Requirements

All Systems

- Mixtures of either ethylene– or propylene–glycol and high–quality water shall be used for proper cooling and freeze / boil protection. (See **Coolant**, page 6–43.)
- Coolant heaters shall be installed in emergency / standby applications to ensure good engine starting (optional in tropical locations unless mandated by local ordinance). (See **Coolant Heaters**, page 6–44.)
- There shall be no loops in the coolant heater hose routing, and the hose shall run continuously uphill. (See **Coolant Heaters**, page 6–44.)
- Coolant heater connections shall be made using high quality silicon or braided hose. (See **Coolant Heaters**, page 6–44.)
- The coolant heater shall be disabled while the generator set is running. (See **Coolant Heaters**, page 6–44.)
- The cooling system shall be designed to accommodate installation site altitude and ambient temperature. (See **Altitude and Ambient Temperature**, page 6–45.)
- The radiator and other sensitive equipment shall be protected from dirt and debris. (See **Cooling System Fouling**, page 6–46.)
- Valves shall be clearly marked to identify “open” and “closed.” (See **Serviceability**, page 6–46.)
- Access shall be provided for cleaning and servicing all equipment (See **Serviceability**, page 6–46.).
- For mobile applications, special consideration shall be given to equipment durability and robustness. (See **Mobile Applications**, page 6–47.)

All Heat Exchanger Installations

- Installation shall satisfy raw water flow rate, pressure and temperature limits listed on the **Generator Set Data Sheet**.
- Raw water shall be protected from freezing.
- Local ordinances shall be consulted before designing or installing a system that draws from and / or discharges to a municipal water supply, river, or any other public water source.
- Installation shall have a sufficient generator set ventilation system.

All Non–Factory Supplied Cooling System Installations

- When placed back–to–back with the jacket water radiator with a single fan, the low temperature aftercooling (LTA) radiator shall be placed upstream in the airflow to access the coolest air. (See **Types of Cooling Systems**, page 6–25.)
- 2P2L systems shall have a thermostatic diverter valve and bypass loop to regulate intake manifold temperature. (See **Types of Cooling Systems**, page 6–25.)

- Remote–cooled installations shall have a sufficient generator set room ventilation system. (See **Non–Factory–Supplied Cooling Systems**, page 6–30.)
- System shall be designed to:
  - Limit the engine coolant outlet temperature to the 'Maximum Top Tank Temperature' value listed on the **Generator Set Data Sheet.** (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
  - Maintain positive coolant head on the engine coolant pump. (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
  - Stay within coolant pump static and friction head limits (See **System Connections and Plumbing**, page 6–35).
- LTA systems shall satisfy the aftercooler circuit requirements listed on the **Generator Set Data Sheet.** (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
- Add electrical loads for the remote radiator fan, ventilating fans, coolant pumps and other accessories to the total load requirement of the generator set. (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
- Coolant lines shall be appropriately designed rigid steel tubing or Schedule 40 pipe (with the exception of the connection requirements detailed below). (See **System Connections and Plumbing**, page 6–35.)
- Coolant piping external to the engine shall be of equal or larger diameter than the engine inlet and outlet connections. (See **System Connections and Plumbing**, page 6–35.)
- External coolant piping and connections shall be cleaned before connecting to the generator set. (See **System Connections and Plumbing**, page 6–35.)
- Consideration shall be given for thermal expansion of coolant pipes / tubes. (See **System Connections and Plumbing**, page 6–35.)
- System connections shall be designed to (See **System Connections and Plumbing**, page 6–35.):
  - Accommodate coolant pressures and temperatures.
  - Withstand vibration due to engine operation and movement during start–up and shutdown.
- Where used, connection hose shall conform to SAE J20R1 or equivalent and be rated for at least 75 psi (518 kPa) burst pressure and –40 °F (–40 °C) to 250 °F (121 °C). 100 psi (691 kPa) burst pressure capability is recommended for overhead radiator applications. (See **System Connections and Plumbing**, page 6–35.)
- Connection hose on suction side of the engine coolant pump shall resist collapse. SAE J20R1 hose meets this requirement for heavy–duty diesel engines. (See **System Connections and Plumbing**, page 6–35.)
- Coolant hose connections shall be secured with T–bolt or constant torque clamps. Worm screw–type clamps are unacceptable. If rigid steel tubing is used, it shall be beaded. (See **System Connections and Plumbing**, page 6–35.)
- System shall visibly clear itself of entrained air within 25 minutes of running time after system fill. (See **Deaerating Tank Requirements**, page 6–38.)
- Deaerating tank shall (See **Deaerating Tank Requirements**, page 6–38.):

  - Be located at the highest point in the system.
  - Have capacity of at least 17% of the total system coolant volume (11% drawdown capacity, 6% thermal expansion).
  - Be equipped with:
  - Fill / pressure cap
  - Fill neck with minimum 0.125 inch (3 mm) diameter hole through one side, located as close as possible to the top of the tank
  - Low coolant level shutdown switch (for 9 liter engines and above).
  - Have vent lines connected above the coolant level.
  - Have a dedicated connection point for each vent line. Do not tee any vent lines together.
- Engine coolant jacket and any high points in the system plumbing shall be vented to the deaerating tank. (See **Deaerating Tank Requirements**, page 6–38.)
- Generator set installation drawing shall be consulted for coolant jacket vent locations and connection sizes. (See **Deaerating Tank Requirements**, page 6–38.)
- Vent lines shall run continuously uphill to the deaerating tank. Loops / sags will cause air locks and are unacceptable. Lines shall not be pinched or constricted anywhere along their path. (See **Deaerating Tank Requirements**, page 6–38.)
- If venting valves that vent to atmosphere are used, drawdown capacity shall be increased from 11% to 14% (total tank capacity increases from 17% to 20%). (See **Deaerating Tank Requirements**, page 6–38.)
- System shall be capable of initial fill to at least 90% capacity at a minimum rate of 5 gpm (20 L/min), then topped off to 100%. (See **Deaerating Tank Requirements**, page 6–38.)
- System shall be equipped with a fill line (See **Deaerating Tank Requirements**, page 6–38.):
  - Line shall be routed directly from bottom of deaerating tank to straight section of engine coolant pump inlet piping near the engine.
  - Line shall have a continual rise from engine inlet pipe to deaerating tank.
  - No other lines may be connected to fill line
- Each generator set shall have its own dedicated complete cooling system. Do not manifold multiple generator sets to a common cooling system. (See **Interconnection of Cooling Systems**, page 6–43.)

Recommendations

All Heat Exchanger Installations

- Consideration should be given to heat exchanger tube or plate material dependent on quality of raw cooling water. (See **Set–Mounted Heat Exchanger**, page 6–28.)

All Non–Factory Supplied Cooling System Installations

- Air–to–air aftercooling (ATA) or one–pump two–loop (1P2L) systems should not be used for remote cooling applications. (See **Types of Cooling Systems**, page 6–25.)

- System should be designed for 115% cooling capability to account for system degradation. When cleaned according to manufacturer's recommended methods and frequency, a capacity of 100% should always be available. This is particularly important for generator sets installed in dusty / dirty environments. (See **General Requirements for All Non–Factory–Supplied Cooling Systems**, page 6–33.)
- Deaerating tank should be equipped with a sight glass for determining system coolant level. (See **Deaerating Tank Requirements**, page 6–38.)
- For vent line sizes not specified on the generator set installation drawing, it is recommended to use #4 hose (.25" ID – 6.35 mm ID) for vent lines less than 12 feet (3.7 m) in length. Use #6 hose (.375" ID – 9.5 mm ID) for vent lines greater than 12 feet (3.7 m) in length. (See **Deaerating Tank Requirements**, page 6–38.)
- Drain / isolation valves should be installed to allow service of the generator set without emptying the entire system of coolant. (See **Serviceability**, page 6–46.)

Overview

The heat energy rejected through the cooling system is roughly 25% of the total energy of the fuel burned in the engine (see **Figure 6–14**). The cooling system must be designed to handle this large amount of heat, or overheating and failure can occur.

Liquid–cooled generator sets are cooled by pumping a coolant mixture through passages in the engine cylinder block and head(s) by means of an engine–driven pump. The cooling system is a closed, pressurized system filled with a mixture of clean, soft (demineralized) water and ethylene or propylene glycol based antifreeze. (See **Coolant**, page 6–43.)

Read the appropriate sections of this chapter based on the type of cooling system utilized. The most common generator set configuration has a factory–supplied, set–mounted cooling system. Non–factory–supplied cooling systems are also used. Use the applicable sections of this chapter for each type of cooling system installation.

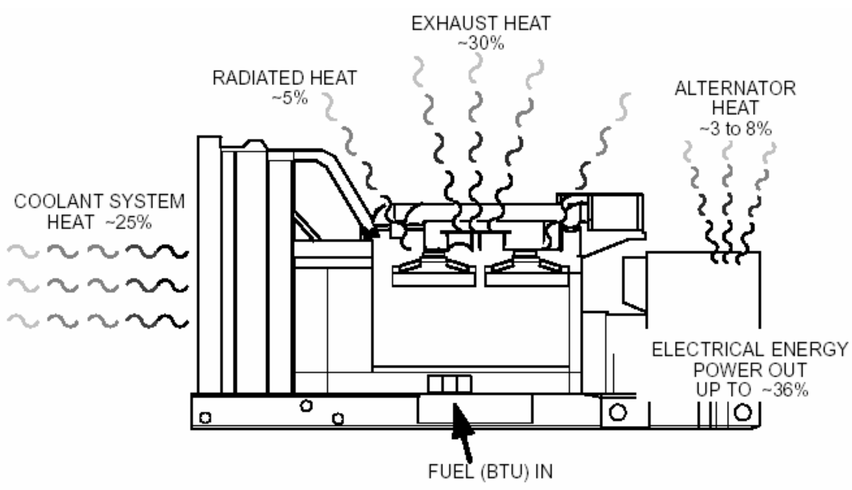


Figure 6–14. Typical Generator Set Heat Balance

Types of Cooling Systems

Generator–drive engines employ several different types of cooling systems. All engines utilize a jacket water cooling system for cooling the cylinder block and head(s). In addition, many generator sets use an aftercooling system to cool the combustion air exiting the turbocharger. This keeps intake manifold temperatures at the levels required to meet emission standards.

Generator set cooling systems include:

- non–aftercooled

- jacket water aftercooling (JWAC)
- air–to–air aftercooling (ATA)
- one–pump two–loop (1P2L)
- two–pump two–loop (2P2L).

For additional system details, contact the local Cummins distributor for access to the appropriate Application Engineering Bulletins (AEBs).

When placed back–to–back with the jacket water radiator with a single fan, the low temperature aftercooling (LTA) radiator shall be placed upstream in the airflow to access the coolest air.

Do not use ATA or 1P2L systems for remote cooling applications.

Non–Aftercooled

These engines do not require aftercooling to maintain low intake manifold temperatures. A jacket water cooling system is used for the cylinder block, cylinder head(s), and lubricating oil.

Jacket Water Aftercooling (JWAC)

With JWAC systems, the same coolant used to cool the engine block and cylinder head(s) is also used to cool the combustion air upstream of the intake manifold. The engine jacket and aftercooler coolant flows are combined, and a single engine coolant pump is utilized. This is the traditional cooling system design where the total engine coolant heat rejection is applied to a single external radiator or heat exchanger.

Air–to–Air Aftercooling (ATA)

ATA systems provide one approach to achieving low temperature aftercooling (LTA) necessary to meet current emissions standards. The charge air is routed to one or more radiator–mounted air–to–air cooler(s). See **Figure 6–15**.

These systems are not recommended for remote cooling for two reasons:

- The entire system piping and radiator are operated under turbocharged pressure (can exceed 40 psi (276 kPa) depending on the engine).
- The length of the air tube run to the radiator and back will create a time lag in turbocharging performance and could result in pressure pulses that impede proper performance.

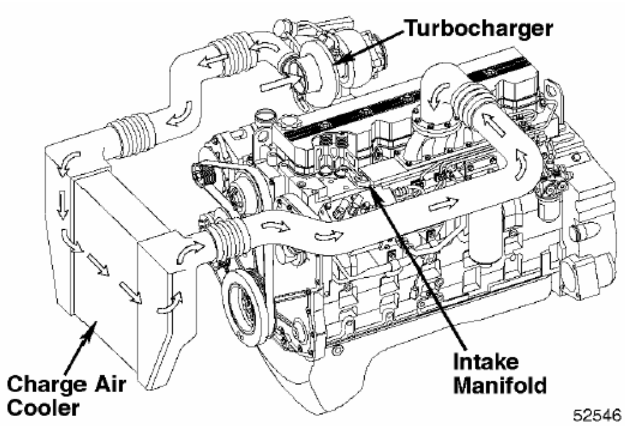


Figure 6–15. Typical Installation Of An Air–to–air Aftercooling System (jacket water system omitted for clarity)

One-Pump Two-Loop Cooling Systems (1P2L)

Another approach to achieving low temperature aftercooling (LTA) is the use of a 1P2L system. These systems utilize two cooling circuits and two radiator cores, but only one coolant pump. These systems are generally not recommended for remote cooling applications due to the difficulty of achieving balanced coolant flows and proper cooling of each circuit.

Two-Pump Two-Loop Cooling Systems (2P2L)

One more approach to achieving low temperature aftercooling (LTA) is the use of a 2P2L system. See **Figure 6-16** for a typical 2P2L system schematic. These systems utilize two completely separate cooling circuits, with two radiator cores, two coolant pumps and separate liquid coolant for each. One circuit cools the engine block and cylinder head(s), and the other cools the combustion air from the turbocharger. For remote systems, engines using this system require two separate radiator cores or heat exchangers. Each will have its own specifications for temperatures, pressure restrictions, heat rejection, etc.

2P2L systems shall have a thermostatic diverter valve and bypass loop to regulate intake manifold temperature.

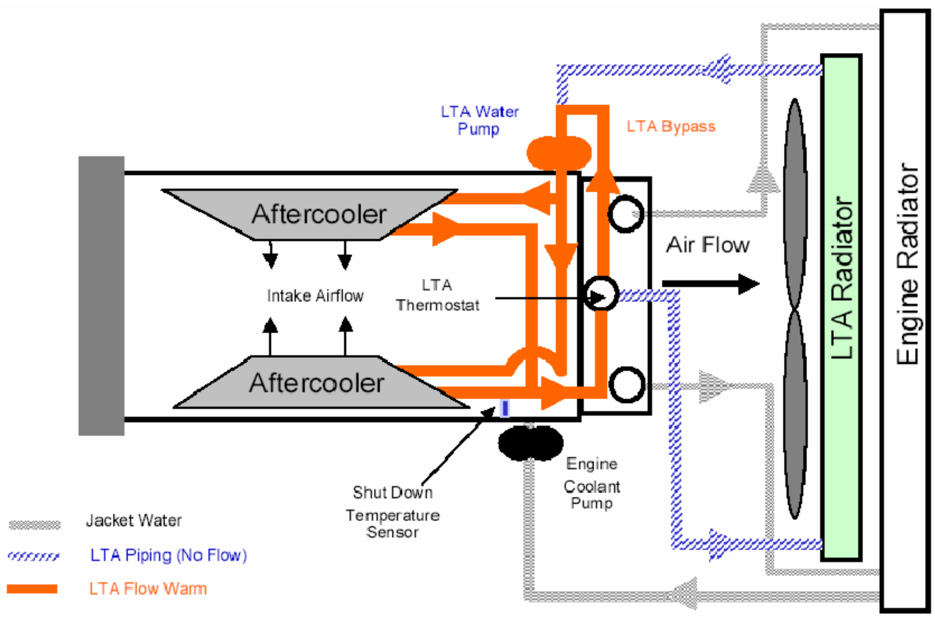


Figure 6-16. 2P2L Coolant Flow With Lta Thermostat Closed

Some generator sets are equipped with a specific type of cooling system that is referred to as "2P2L" but does not have two truly separate loops. These systems utilize one coolant pump with two impellers. Due to a small amount of coolant transfer that occurs in the pump, the system must either use one deaerating tank or two connected tanks. This is required to maintain coolant levels in each loop. See **Deaerating Tank Requirements**, page 6-38.

Factory-Supplied Cooling Systems

Factory-supplied cooling systems include both radiators and heat exchangers. A major advantage to installing a generator set with a factory-supplied cooling system is that a significant amount of design and installation work is already done. Customers installing a remote cooling system have to consider many requirements that are already satisfied by factory-installed systems.

A second advantage of factory-supplied systems is that they are prototype tested to verify overall performance.

Set–Mounted Radiator

A generator set with a set–mounted radiator has an integrated cooling and ventilation system. See **Figure 6–17**. The radiator fan is usually mechanically driven by the engine. Electric fans are used in some applications.

A requirement of the set–mounted radiator is to move a relatively large volume of air through the generator set area. Air must be provided to evacuate heat emitted from the equipment and support combustion of the fuel. This can be a large airflow requirement, and may lead to a decision to use a remote cooling system. However, even if a remote system is used, the airflow required to remove heat and provide combustion air is significant, and an adequate ventilation system will still be required. See the **Ventilation** section of this manual for additional details. With set–mounted radiator systems, the engine fan will often provide sufficient ventilation, eliminating the need for other ventilating devices and systems.

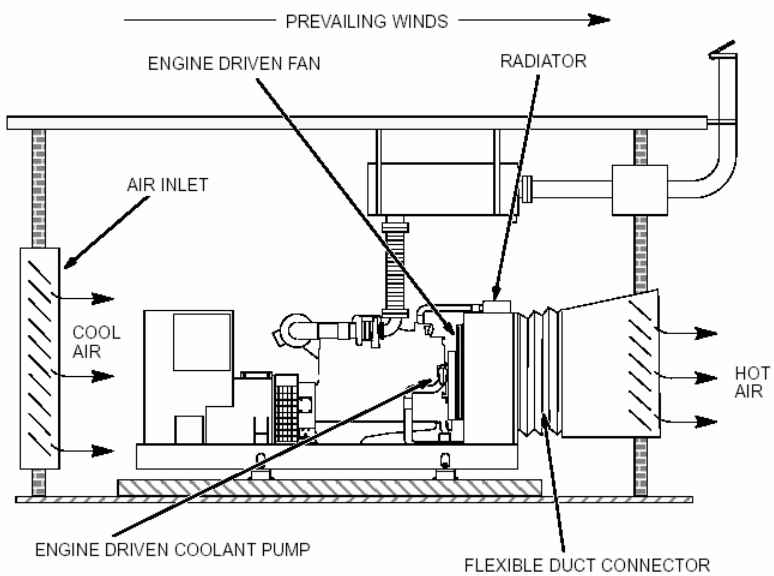


Figure 6–17. Factory–supplied, Set–mounted Radiator Cooling

Set–Mounted Heat Exchanger

With heat exchangers, heat is removed from the engine coolant in a closed system by raw water from an appropriate source. The engine, pump, and heat exchanger form a closed, pressurized cooling system. See **Figure 6–18**. The engine coolant and raw water do not mix.

- Installation shall satisfy raw water flow rate, pressure and temperature limits listed on the **Generator Set Data Sheet**.
- Raw water shall be protected from freezing.
- Local ordinances shall be consulted before designing or installing a system that draws from and / or discharges to a municipal water supply, river, or any other public water source.
- Installation shall have a sufficient ventilation system.
- Consideration should be given to heat exchanger tube or plate material dependent on quality of raw cooling water.

Additional considerations for the raw water side of the heat exchanger:

- A thermostatic water valve can be used to modulate water flow in response to coolant temperature.

- A normally closed battery–powered shut–off valve can be used to shut off the water when the set is not running (battery power should not be used to hold the valve closed).
- Potential sources for the raw water side of the heat exchanger include municipal supplies, rivers, lakes, wells, cooling towers, and others.
- Cooling tower applications will require extensive design and installation support from equipment suppliers and consulting engineers.

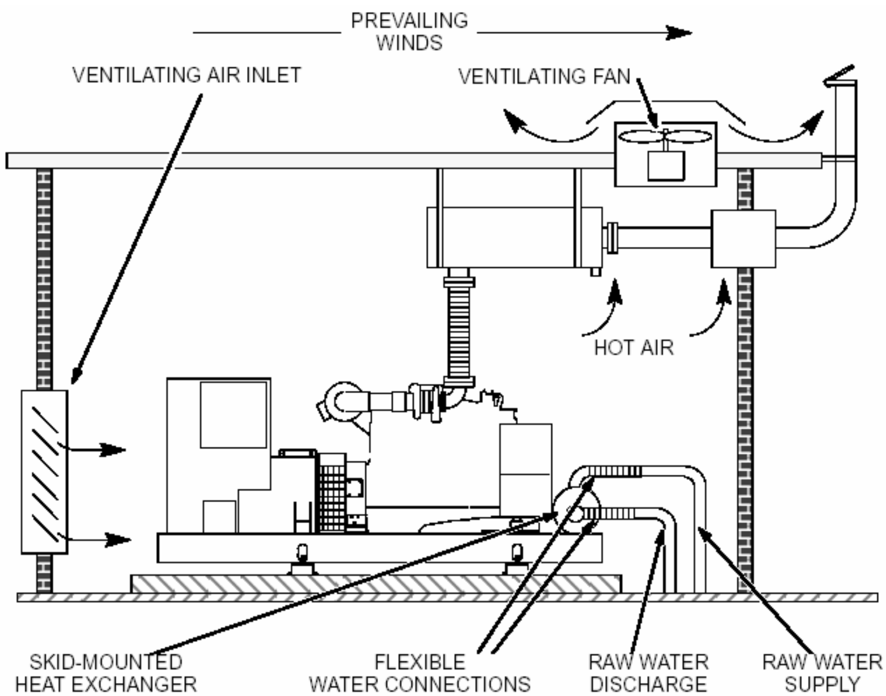


Figure 6–18. Set–mounted heat exchanger cooling.

The selection of a heat exchanger for generator set cooling eliminates the radiator fan from the set. The equipment room will therefore require a powered ventilating system to remove heat and provide the engine with combustion air. See the **Ventilation** section of this manual for additional details.

Heat exchangers are designed to work with a constant supply of clean water at a specified temperature. The quality of the raw water should be considered when specifying the heat exchanger, as impurities could lead to material degradation and reduced life. A heat exchanger made from higher–grade material may be necessary.

Calculations

There must be sufficient raw water flow to remove the **Heat Rejection to Coolant** indicated on the **Generator Set Data Sheet**.

$$RWR = \frac{HR}{(\Delta T)(c)}$$

where RWR = Raw Water Required, gallons/min (liters/min)
HR = Heat Rejection to Coolant, BTU/min (kJ/min)
?T = temperature rise of water across cooler core, °F (°C)
C = specific heat of water, 8 BTU/°F/gallon (4 kJ/°C/liter)

For example, assume the **Generator Set Data Sheet** indicates that the set rejects 15,340 BTU/minute (16,185 kJ/min), and the raw water inlet temperature is 80 °F (27 °C). Assume also that the raw water is discharged to a nearby river, and local ordinances restrict this discharge water temperature to 95 °F (35 °C). The required raw water supply flow is determined by the following:

$$RWR = \frac{15{,}340\ {}^{BTU}\!/\!_{\min}}{(15\,°F)(8\ {}^{BTU}\!/\!_{°F \cdot gallon})} = 128\ \frac{gallon}{\min}$$

OR

$$RWR = \frac{16{,}185\ {}^{kJ}\!/\!_{\min}}{(8\ °C)(4\ {}^{kJ}\!/\!_{°C \cdot liter})} = 506\ \frac{liter}{\min}.$$

Remember that heat exchangers have minimum flow requirements (listed on the **Generator Set Data Sheet**). **These requirements must be satisfied, even if the calculation above indicates that a lower flow is sufficient.**

Non–Factory Supplied Cooling Systems

With non–factory–supplied cooling systems, there are several design elements to evaluate that are taken care of with factory–supplied cooling packages. These include, but are not limited to:

- Type of system to use
- Fuel cooling
- System deaeration, venting, etc.
- Remote–cooled installations shall have a sufficient generator set room ventilation system.

Remote systems are often used when it is not practical to get sufficient ventilation air to a set–mounted radiator system. Remote cooling systems do not eliminate the need for generator set ventilation, but they may reduce it. The generator set will still emit heat to the surroundings, and this heat must be evacuated. See the **Ventilation** section of this manual for additional details.

Characteristics of remote cooling systems include:

- Ability to get ambient temperature air to the radiator core
- Flexibility in site layout
- Improved serviceability, depending on the installation.

Determining the Remote Cooling Strategy to Use

Remote radiators (either in conjunction with the standard engine coolant pump, or with an auxiliary coolant pump) and heat exchangers can be used to remote cool the generator set.

The decision of which type of system to use is often dictated by the static and friction head limitations of the engine coolant pump, as given on the **Generator Set Data Sheet**. See **Figure 6–19** and **Figure 6–20** for examples.

IEC 801... Volta...
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	22.6 (16.9)	22.6 (16.9)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	196.0 (741.9)	196.0 (741.9)
Heat Rejection To Coolant, Btu/min (MJ/min)	16350.0 (17.3)	14350.0 (15.2)
Heat Radiated To Room, Btu/min (MJ/min)	6100.0 (6.5)	5540.0 (5.9)
Maximum Coolant Friction Head, psi (kPa)	10.0 (68.9)	10.0 (68.9)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1517.0 (42.9)	1455.0 (41.2)
Alternator Cooling Air, scfm (m^3/min)	4156.0 (117.6)	4156.0 (117.6)
Radiator Cooling Air, scfm (m^3/min)	27200.0 (769.8)	27200.0 (769.8)
Max. Static Restriction, in H_2O (Pa)	0.5 (124.5)	0.5 (124.5)

Rating Definitions

...dby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No ...load capability is available for this rating. (Equivalent to Fuel ...wer in accordan... ...2789,

Figure 6–19. DFXX Generator Set Specification Sheet Showing 'Maximum Coolant Static Head'.

IEC 801... Volta...
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	22.6 (16.9)	22.6 (16.9)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	196.0 (741.9)	196.0 (741.9)
Heat Rejection To Coolant, Btu/min (MJ/min)	16350.0 (17.3)	14350.0 (15.2)
Heat Radiated To Room, Btu/min (MJ/min)	6100.0 (6.5)	5540.0 (5.9)
Maximum Coolant Friction Head, psi (kPa)	10.0 (68.9)	10.0 (68.9)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1517.0 (42.9)	1455.0 (41.2)
Alternator Cooling Air, scfm (m^3/min)	4156.0 (117.6)	4156.0 (117.6)
Radiator Cooling Air, scfm (m^3/min)	27200.0 (769.8)	27200.0 (769.8)
Max. Static Restriction, in H_2O (Pa)	0.5 (124.5)	0.5 (124.5)

Rating Definitions

...dby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No ...load capability is available for this rating. (Equivalent to Fuel ...wer in accordan... ...2789,

Figure 6–20. DFXX Generator Set Specification Sheet Showing 'Maximum Coolant Friction Head'.

Remote radiators are convenient because they do not require the continuous raw water flow that heat exchangers do. However, remote radiators are often impractical because they may need to be located a significant distance away from the generator set in order to access a continuous fresh air flow. This often leads to a violation of the static and/or friction head limitations of the engine coolant pump.

If the installation of a remote radiator would violate the engine coolant pump friction and/or static head limits, a heat exchanger can be installed. Keep in mind that the heat exchanger will need a continuous raw water supply that meets its flow, temperature and pressure requirements. The heat exchanger will need to be installed in a location that simultaneously satisfies the head limitations of the engine coolant pump and the raw water requirements of the heat exchanger itself. See **Set–Mounted Heat Exchanger,** page 6–28 and **Remote Heat Exchanger**, page 6–38.

Determining the Static Head on the Engine Coolant Pump

"Static head" refers to the static pressure on the engine coolant pump due to the height of the remote cooling system. The static head is simply the difference in height between the highest point of the cooling system and the engine crankshaft centerline. Consider the example shown in **Figure 6–21**. For the DFXX **Generator Set Data Sheet** shown in **Figure 6–19**, the vertical distance must be less than or equal to 60 ft (18.3 m).

Determining the Friction Head External to the Engine on the Engine Coolant Pump

"Friction head external to the engine" refers to the losses incurred in the coolant piping, valves, radiator core, heat exchanger, or any other cooling system equipment installed external to the engine. Calculations can be performed to estimate this value. These calculations involve determining the pressure loss caused by each individual element in the system, and then adding up all of the pressure losses to come up with the total friction head.

1. Determine the pressure loss in the radiator or heat exchanger by referring to the manufacturer's data. For example, assume a remote radiator is to be installed, and the pressure drop through the radiator is 1.5 psi (10.3 kPa) at a flow of 196 gpm (741.9 L/min).

2. Find the total length of all straight coolant pipe in the system. For this example, assume there is 80 feet (24.4 m) of 3–inch (80 mm) diameter straight pipe.

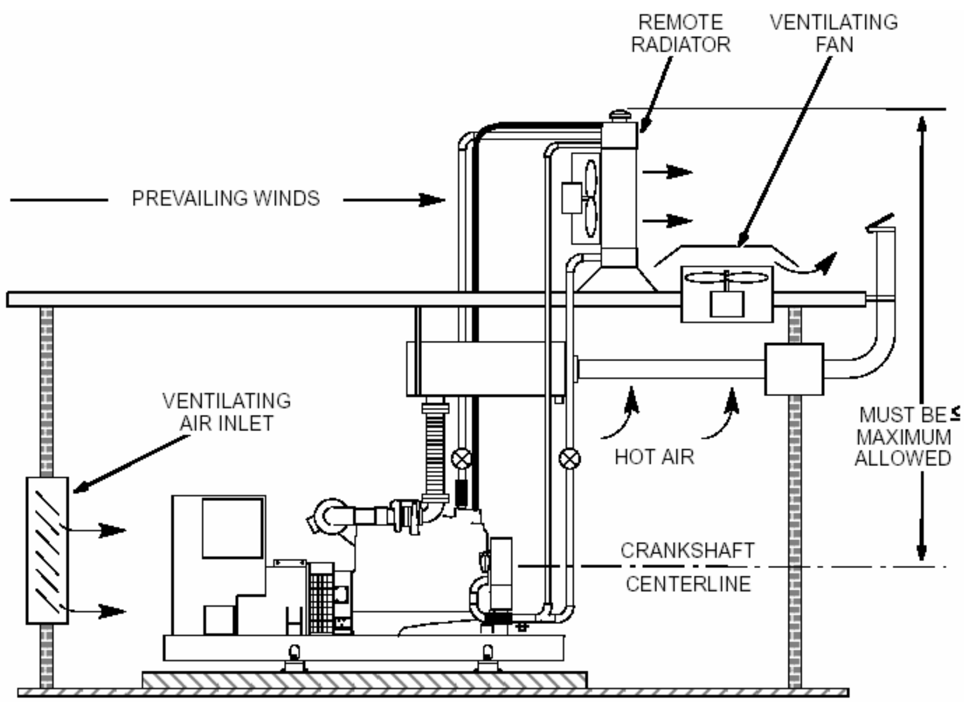


Figure 6–21. Example remote radiator system.

3. Find the estimated equivalent lengths of all fittings and valves by using **Table 6–3** and add to the total length of straight pipe. For this example, assume there are three long sweep elbows, two gate valves to isolate the radiator for engine servicing and a tee to connect the fill / make–up line.

Component	Equivalent Length, ft (m)
3 Long Sweep Elbows	3 x 5.2 ft = **15.6 ft** (3 x 1.6 m = **4.8 m**)
2 Gate Valves (Open)	2 x 1.7 ft = **3.4 ft** (2 x 0.5 m = **1.0 m**)
Tee (Straight Run)	**5.2 ft** (**1.6 m**)
80 Feet (24.4 m) Straight Pipe	**80 ft** (**24.4 m**)
Total Equivalent Length of Pipe	104.2 ft (31.8 m)

4. Find the pressure loss at the given flow per unit length of pipe for the nominal pipe diameter used in the system. In this example, 3–inch (80 mm) nominal pipe is used. From **Figure 6–23**, 3–inch (80 mm) pipe causes a pressure loss of approximately 4.0 psi per 100 feet of pipe (28 kPa per 30 m) at the required coolant flow rate of 196 gal/min (741.9 L/min). Obtain the required coolant flow rate from the **Generator Set Data Sheet**, as shown in **Figure 6–22**.

5. Calculate the pressure loss in the piping as follows:

$$PipingLoss = 104.2\ ft\left(\frac{4.0\ psi}{100\ ft}\right) = 4.2\ psi \quad \text{OR} \quad PipingLoss = 31.8\ m\left(\frac{28\ kPa}{30\ m}\right) = 29.7\ kPa$$

6. The total friction head is the sum of the piping and radiator losses. For example:

$$FrictionHead = 4.2\ psi + 1.5\ psi = 5.7\ psi \quad \text{OR} \quad FrictionHead = 29.7\ kPa + 10.3\ kPa = 40\ kPa$$

Compare the calculated value with the **Maximum Coolant Friction Head External to Engine** listed on the **Generator Set Data Sheet**. If the calculated value exceeds the maximum allowed, adjustments are required, and may include:

- Relocating the generator set and/or radiator/heat exchanger to reduce the distance between them
- Using larger diameter coolant pipes
- Redesigning the system to utilize fewer pipe bends
- Installing an auxiliary coolant pump.

For the example DFXX **Generator Set Data Sheet** shown in **Figure 6-20**, **Maximum Coolant Friction Head External to Engine** equals 10 psi (68.9 kPa). Since the calculated value is less than the maximum allowed, the system should be acceptable as designed. Upon system installation, this should be verified experimentally. Contact the local Cummins distributor for access to the appropriate system verification Application Engineering Bulletins (AEBs).

TYPE OF FITTING	NOMINAL INCH (MILLIMETER) PIPE SIZE										
	1/2 (15)	3/4 (20)	1 (25)	1-1/4 (32)	1-1/2 (40)	2 (50)	2-1/2 (65)	3 (80)	4 (100)	5 (125)	6 (150)
90° Std. Elbow or Run of Tee Reduced ½.	1.5 (0.5)	2.1 (0.6)	2.6 (0.8)	3.5 (1.1)	4.3 (1.3)	5.5 (1.7)	6.5 (2.0)	8.0 (2.4)	11 (3.4)	14 (4.3)	16 (4.9)
90° Long Sweep Elbow or Straight Run Tee	1.0 (0.3)	1.4 (0.4)	1.6 (0.5)	2.4 (0.7)	2.7 (0.8)	3.5 (1.1)	4.2 (1.3)	5.2 (1.6)	7.0 (2.1)	9.0 (2.7)	11 (3.4)
45° Elbow	0.8 (0.2)	1.0 (0.3)	1.3 (0.4)	1.6 (0.5)	1.9 (0.6)	2.5 (0.8)	3.0 (0.9)	3.8 (1.2)	5.0 (1.5)	6.3 (1.9)	7.5 (2.3)
Close Return Bend	3.5 (1.1)	4.8 (1.5)	6.0 (1.8)	8.5 (2.6)	9.9 (3.0)	13 (4.0)	15 (4.6)	18 (5.5)	24 (7.3)	31 (9.4)	37 (11.3)
TEE, Side Inlet or Outlet	3.1 (0.9)	4.0 (1.2)	5.6 (1.7)	7.2 (2.2)	9.0 (2.7)	12 (3.7)	14 (4.3)	17 (5.2)	22 (6.7)	27 (8.2)	33 (10.1)
Foot Valve and Strainer	3.7 (1.1)	4.9 (1.5)	7.5 (2.3)	8.9 (2.7)	11 (3.4)	15 (4.6)	18 (5.5)	22 (6.7)	29 (8.8)	36 (11.0)	46 (14.0)
Swing Check Valve, Fully Open	3.8 (1.2)	5.0 (1.5)	6.5 (2.0)	9.0 (2.7)	10 (3.0)	13 (4.0)	15 (4.6)	19 (5.8)	26 (7.9)	33 (10.1)	40 (12.2)
Globe Valve, Fully Open	16 (4.9)	21 (6.4)	26 (7.9)	39 (11.9)	45 (13.7)	55 (16.8)	67 (20.4)	82 (25.0)	110 (33.5)	140 (42.7)	165 (50.3)
Angle Valve, Fully Open	8.3 (2.5)	11.5 (3.5)	15 (4.6)	18 (5.5)	22 (6.7)	27 (8.2)	33 (10.1)	41 (12.5)	53 (16.2)	70 (21.3)	85 (25.9)
Gate Valve, Fully Open	0.4 (0.1)	0.5 (0.2)	0.6 (0.2)	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.4 (0.4)	1.7 (0.5)	2.3 (0.7)	2.9 (0.9)	3.5 (1.1)

Table 6-3. Equivalent Lengths of Pipe Fittings and Valves in Feet (Meters)[8].

General Requirements for All Non-Factory Supplied Cooling Systems

Regardless of the type of system installed at the generator site to cool the set, the following requirements and recommendation apply. The first design requirement is to limit the engine coolant outlet temperature to the “Maximum Top Tank Temperature” listed

[8] Cummins employees can access Cummins Technical Report 9051-2005-005 for documentation of these values.

on the **Generator Set Data Sheet**. “Heat Rejection to Coolant” and “Coolant Flow Rate” values are also listed on the **Generator Set Data Sheet**, and all of this information will be required to specify an appropriate radiator or heat exchanger.

- System shall be designed to limit the engine coolant outlet temperature to the “Maximum Top Tank Temperature” listed on the **Generator Set Data Sheet**.
- Low Temperature Aftercooling (LTA) systems shall satisfy the aftercooler circuit requirements listed on the **Generator Set Data Sheet**.
- There shall always be positive coolant head on the engine coolant pump. Negative pressure can lead to cavitation and failure.
- Add electrical loads for the remote radiator fan, ventilating fans, coolant pumps and other accessories to the total load requirement of the generator set.
- Design the system for 115% cooling capability to account for system degradation. When cleaned according to manufacturer’s recommended methods and frequency, a capacity of 100% should always be available. This is particularly important for generator sets installed in dusty / dirty environments.

IEC 801...
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	22.6 (16.9)	22.6 (16.9)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	196.0 (741.9)	196.0 (741.9)
Heat Rejection To Coolant, Btu/min (MJ/min)	16350.0 (17.3)	14350.0 (15.2)
Heat Radiated To Room, Btu/min (MJ/min)	6100.0 (6.5)	5540.0 (5.9)
Maximum Coolant Friction Head, psi (kPa)	10.0 (68.9)	10.0 (68.9)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1517.0 (42.9)	1455.0 (41.2)
Alternator Cooling Air, scfm (m^3/min)	4156.0 (117.6)	4156.0 (117.6)
Radiator Cooling Air, scfm (m^3/min)	27200.0 (769.8)	27200.0 (769.8)
Max. Static Restriction, in H_2O (Pa)	0.5 (124.5)	0.5 (124.5)

Rating Definitions

...dby **Rating based on:** Applicable for supplying emergency power for the duration of normal power interruption. No ... load capability is available for this rating. (Equivalent to Fuel ... in accordan... 3046, ...789,

Figure 6–22. DFXX Generator Set Specification Sheet showing ’Coolant Flow Rate’

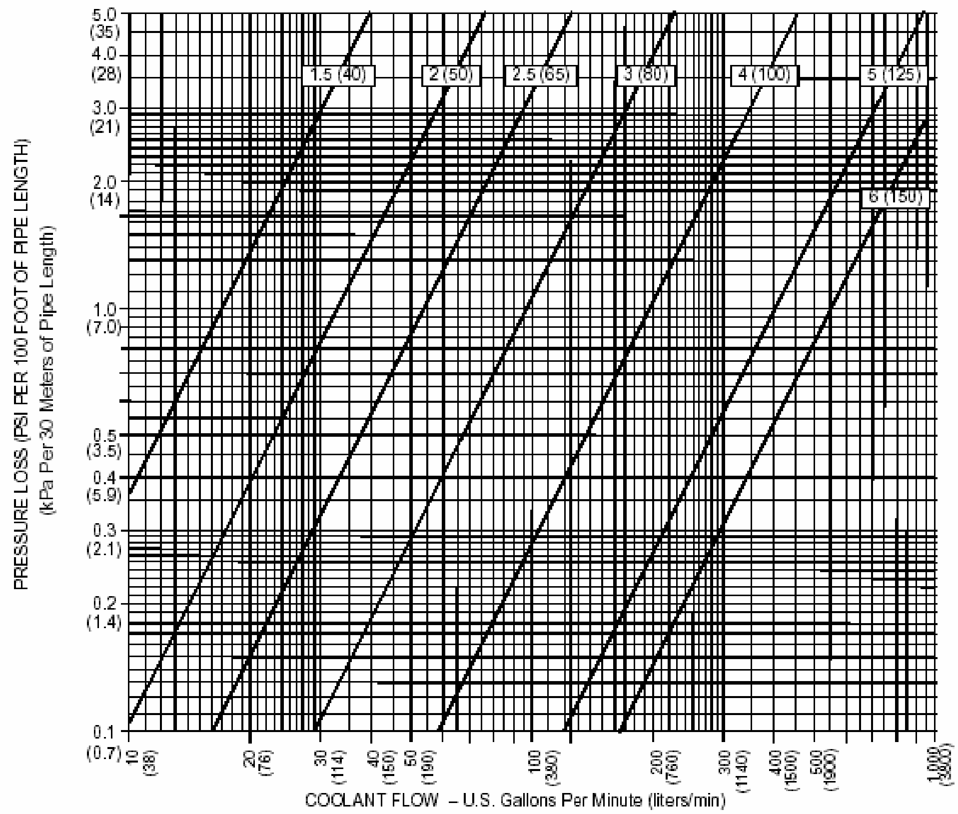


Figure 6–23. Frictional Pressure Losses For Inch (Mm) Diameter Pipes[9]

System Connections and Plumbing

Properly plumbing the remote cooling package to the engine is critical. The coolant must be able to flow freely through all piping and radiator / heat exchanger equipment external to the engine jacket. The friction or resistance generated by this flow is very important because it impairs engine coolant pump performance and the coolant flow through the engine jacket. The **Generator Set Data Sheet** shows engine coolant flow at two separate external restrictions. This is to show the system designer the relationship between coolant flow and external restriction, and takes some "guesswork" out of the design process. The following requirements apply.

- Maximum allowable values for coolant static and friction head shall not be exceeded. See **Determining the Remote Cooling Strategy to Use**, page 6–30.
- Coolant piping external to the engine shall be of equal or larger diameter than the engine inlet and outlet connections.
- External coolant piping and connections shall be cleaned before connecting to the generator set.
- Consideration shall be given for thermal expansion of coolant pipes/tubes.
- Coolant lines shall be appropriately designed rigid steel tubing or Schedule 40 pipe (with the exception of the connection requirements detailed below).
- Connections between generator set and remote system shall be designed to accommodate coolant pressures and temperatures.

[9] Cummins employees can access Cummins Technical Report 9051–2005–004 for documentation of these values.

- Connections shall also withstand vibration due to engine operation and movement during start–up and shutdown. Flexible stainless steel connections or double–clamped hoses should be used.
- Where used, connection hose shall conform to SAE J20R1 or equivalent and be rated for at least 75 psi (518 kPa) burst pressure and –40 °F (–40 °C) to 250 °F (121 °C). 100 psi (691 kPa) burst pressure capability is recommended for overhead radiator applications.
- Connection hose on the suction side of the engine coolant pump shall resist collapse. SAE J20R1 hose meets this requirement for heavy–duty diesel engines.
- Coolant hose connections shall be secured with T–bolt or constant torque clamps. Worm screw–type clamps are unacceptable. If rigid steel tubing is used, it must be beaded.

Remote Radiator

The application of a remote radiator to cool the generator set requires careful design. See **Figure 6–24** for an example system with a vertically mounted radiator, and **Figure 6–25** for a horizontal radiator.

Radiator location has a significant effect on performance. For example, rooftop (sand, parking lot, etc.) temperatures can be significantly hotter than the temperature given in local weather reports, and this must be considered. The radiator air–on–core temperature is often different than the ambient air temperature. (See **Altitude and Ambient Temperature**, page 6–45.)

The direction of prevailing winds must also be considered. Wind walls may be necessary to keep wind from opposing the cooling fan airflow. With rooftop installations, winds can be very strong and unpredictable due to neighboring structures.

Installation site conditions must be considered when selecting a radiator. Radiator cores with a high number of fins per inch are unacceptable for dirty (dusty, sandy, etc.) environments. Debris can easily be trapped in radiator cores with tight fin spacing, negatively impacting radiator performance. Wider fin spacing will allow sand, small dirt particles, etc. to pass through the core without becoming trapped.

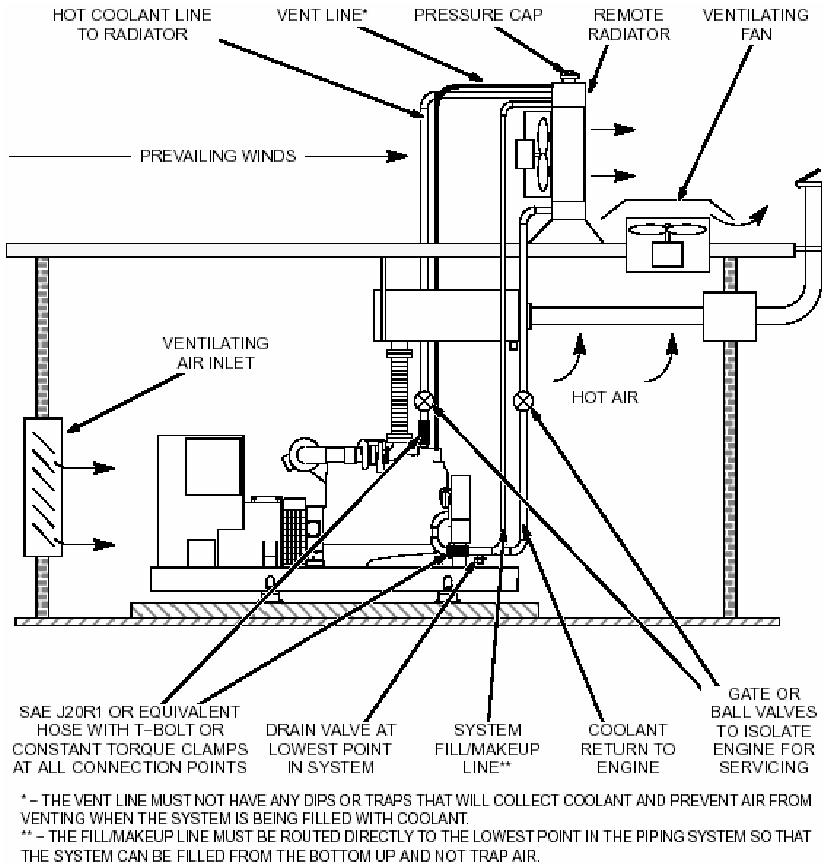


Figure 6–24. Typical Remote Radiator System

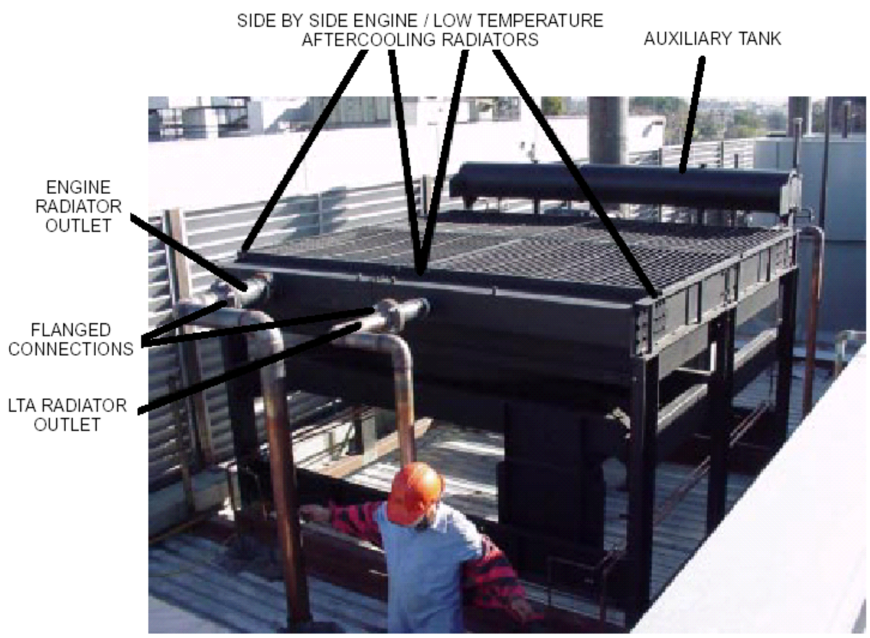


Figure 6–25. Horizontal remote radiator example.

Remote Heat Exchanger

A remote heat exchanger may be used as an alternative to installing a remote radiator. The details and requirements are the same as for a set–mounted heat exchanger. See **Set–Mounted Heat Exchanger,** page 6–28.

Dual Heat Exchanger Systems

Dual heat exchanger systems (see **Figure 6–26**) are recommended only when absolutely necessary to isolate the remote cooling system from the engine in situations where the static head limitations on the engine coolant pump are exceeded. These systems are difficult to design and implement, especially if a radiator is used to cool the heat exchanger raw water. In these situations, the radiator might be significantly larger than expected, and the factory–mounted heat exchanger will most likely be inadequate.

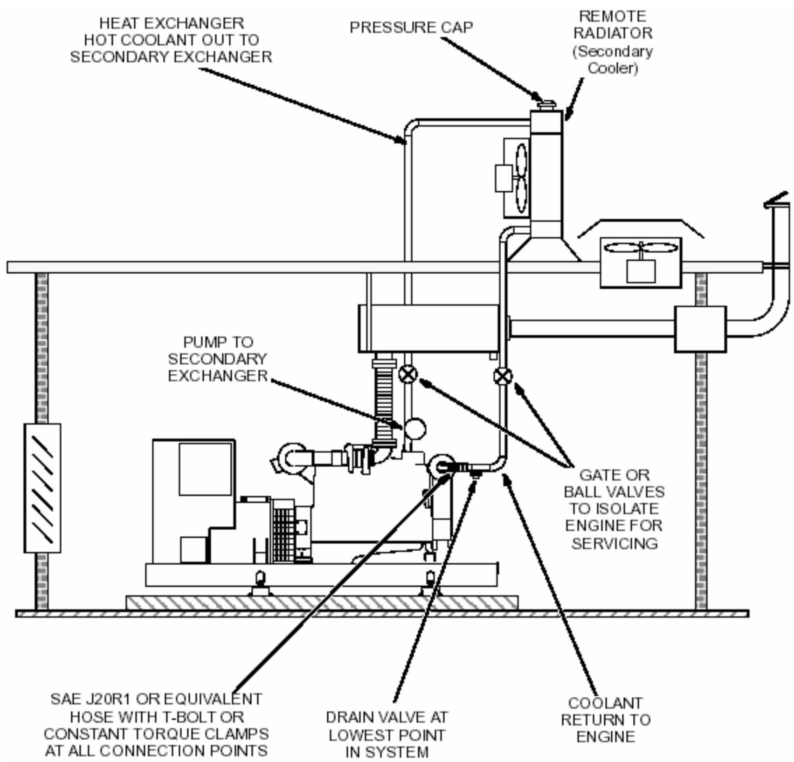


Figure 6–26. Dual Heat Exchanger System (with secondary remote radiator)

Deaerating Tank Requirements

Air entrained in the coolant can cause serious problems:

- Air accelerates erosion of water passages which in turn causes heat transfer and internal flow problems. These problems increase the likelihood of liner scoring, ring wear, and cylinder head cracking.
- Air in the system reduces the amount of heat transferred to the coolant.
- The air expands more than the coolant when heated and may cause loss of coolant from the system.
- In extreme cases air may cause loss of coolant pump prime resulting in major engine damage.

Normal generator set operation will introduce some air into the cooling system. Additional sources of air / exhaust in the cooling system include:

- Improper venting

- Turbulence in the deaerating tank
- Defective gaskets
- Faulty coolant pump seal
- Leaky injector sleeves.
- System shall visibly clear itself of entrained air within 25 minutes of running time after system fill.

Positive deaerating cooling systems utilize a sealed tank to provide an area for coolant deaeration. For details on which generator sets require a positive deaerating system, contact the local Cummins distributor for access to the appropriate Application Engineering Bulletin(s).

Deaerating tanks are used to remove entrained air from the system. These tanks function through bypassing a portion of the total coolant flow to a relatively non–turbulent area where the air separates from the coolant. Coolant from this area is then returned to the system to replace the bypassed coolant.

When a conventional downflow radiator is installed, common practice is to use an integral deaerating tank (also commonly referred to as a top tank) similar to **Figure 6–27** and **Figure 6–28**.

Installations can also use a non–integral deaerating tank (also commonly referred to as an auxiliary tank) to deaerate the coolant. A non–integral dearating tank system is shown in **Figure 6–29**.

- Deaerating tank shall be located at the highest point in the cooling system.
- Tank shall be equipped with: fill / pressure cap, means for filling at highest point, low coolant level shutdown switch (for 9 liter engines and above). The low coolant level shutdown switch will help minimize damage should the cooling system lose system pressure.
- Tank capacity shall be at least 17% of the total coolant volume in the system.
- Deaerating tank should have a sight glass to show the system coolant level.

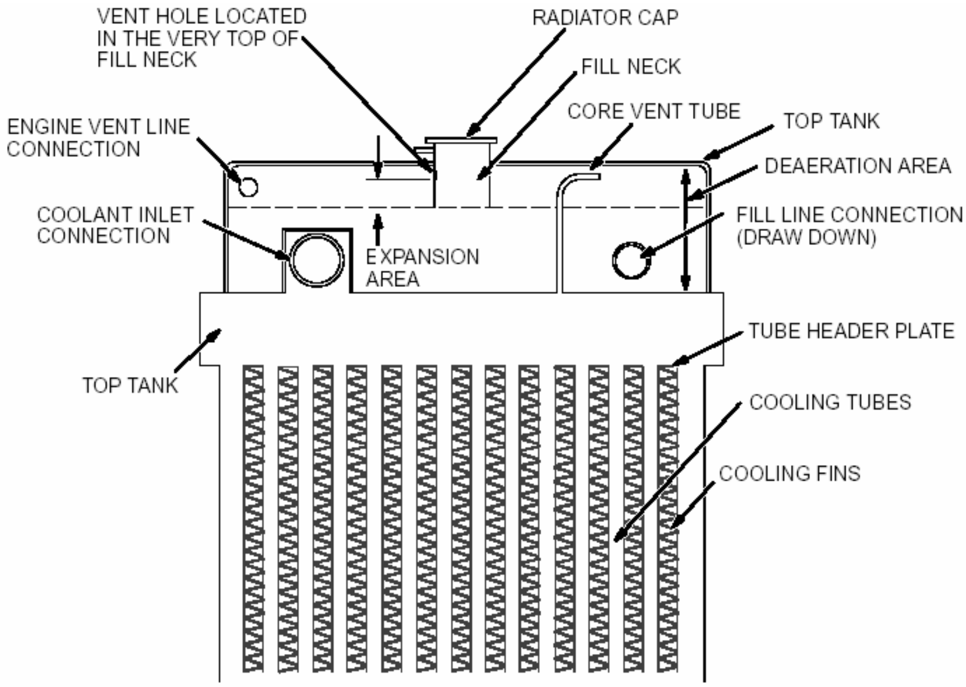


Figure 6–27. Typical Integral Deaerating Tank Configuration

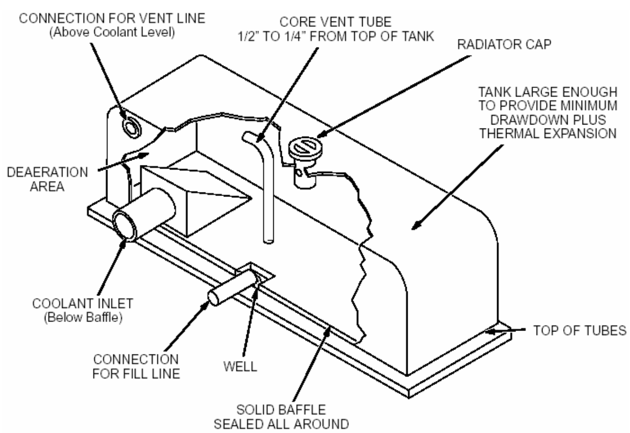
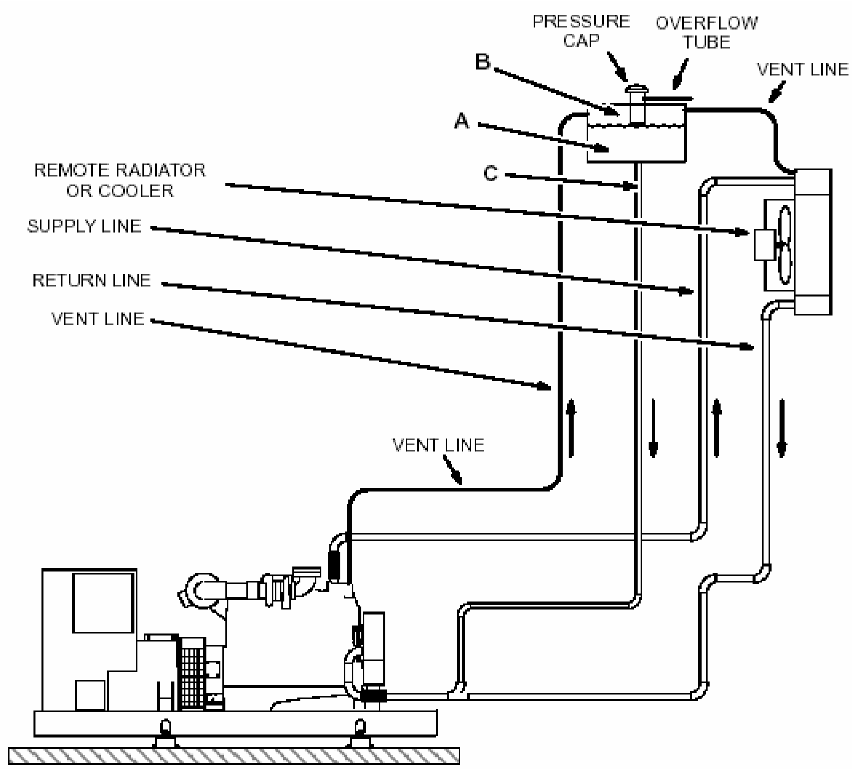


Figure 6–28. Typical Integral Deaerating Tank Configuration (radiator core omitted)



A AUXILIARY TANK SIZED TO PROVIDE RECOMMENDED DRAWDOWN CAPACITY.
B EXPANSION SPACE SIZED BY DEPTH OF NECK EXTENSION INTO TANK VENT HOLE NEAR TOP OF TANK.
C TANK RETURN LINE TO PROVIDE POSITIVE HEAD TO PUMP SUCTION. NO OTHER PLUMING NOR ACCESSORIES SHOULD BE CONNECTED TO THIS LINE.

Figure 6–29. Remote Radiator System With Non–integral Deaerating Tank

Drawdown and Expansion

The deaerating tank capacity must be at least 17% of the total coolant volume in the system. This provides coolant drawdown capacity of 11%, plus 6% for thermal expansion.

Drawdown capacity is the amount of coolant that can be lost from the system before air will be drawn into the engine coolant pump.

The system must be designed so that when completely filled cold there is at least a 6% additional capacity to allow for thermal expansion. This extra volume is defined by proper location of the fill neck. See the “Expansion Area” in **Figure 6–27**. The bottom of the fill neck defines the top of the coolant level during cold–fill. The space between the underside of the roof of the tank and the bottom of the fill neck is the volume available for coolant expansion. A hole through the fill neck provides a path for vapor to escape out of the pressure cap as the coolant expands. Without the hole, coolant expands up the fill neck and out of the radiator cap.

- Fill neck shall have a minimum 0.125 inch (3 mm) diameter hole through one side, located as close as possible to the top of the tank.

Venting

System venting serves two important functions:

- Venting of air from the engine during fill
- Continual removal of air during generator set operation.

- Engine coolant jacket and any high points in the system plumbing shall be vented to the deaerating tank.
- Generator set installation drawing shall be consulted for coolant jacket vent locations and connection sizes.
- Vent lines shall be connected to the deaerating tank above the coolant level.
- Lines shall run continuously uphill to the deaerating tank. Loops / sags will cause air locks and are unacceptable.
- Lines shall not be pinched or constricted anywhere along their path.
- For systems requiring multiple vent lines, they may not be teed together. Dedicated connection points shall be provided for each line.
- If venting valves that vent to atmosphere are used, drawdown capacity shall be increased from 11% to 14% (total tank capacity increased from 17% to 20%).
- For vent line sizes not specified on the generator set installation drawing, it is recommended to use #4 hose (.25” ID – 6.35 mm ID) for vent lines less than 12 feet (3.7 m) in length. Use #6 hose (.375” ID – 9.5 mm ID) for vent lines greater than 12 feet (3.7 m) in length).

Venting valves that vent to atmosphere are sometimes used in applications where it is difficult to run the vent line upward all the way to the deaerating tank. Drawdown capacity must be increased when using this type of venting valv~~es are used~~ because the valves lose some coolant during operation.

Filling

Proper filling is critical to help prevent air locks. The installation of a fill line will permit the system to be filled from the bottom–up, and will help reduce the risk of entraining air during system fill.

- System shall be capable of initial fill to at least 90% capacity at a minimum rate of 5 gpm (20 L/min), then topped off to 100%.
- System shall be equipped with a fill line:
  - Line shall be routed directly from bottom of deaerating tank to straight section of engine coolant pump inlet piping near the engine.
  - Line shall have a continual rise from engine inlet pipe to deaerating tank.
  - No other lines may be connected to fill line.

Engines with a coolant flow rate less than 200 gal/min (757 L/min) usually use a connection of about 0.75 in (19 mm) ID. Engines with a coolant flow rate greater than 200 gal/min (757 L/min) use lines 1 to 1.5 in (25 mm to 38 mm) ID. These are given as general guidelines only. The installation must be checked for ability to fill in the time specified above. If the line is improperly sized or routed, the system will not fill properly. Reverse flow up the line may cause overflow of the deaerating tank.

System Cleanliness

Any foreign material in the system will degrade cooling performance and could result in major generator set damage.

- External coolant piping and connections shall be cleaned before connecting to the generator set.

Fuel Cooling

Many generator sets require the use of a fuel cooling system to maintain required fuel inlet temperatures. Consult the **Generator Set Data Sheet** to determine whether or not a fuel cooler is required, and for design requirements that will aid in cooler selection. If required, it must be accommodated in the cooling system design, and will add complexity to the system. It is often impractical or against code to pipe fuel to the remote cooling location. Two possibilities for handling the fuel cooling requirements:

- Include a fuel cooling radiator and fan within the generator set space and account for the heat rejection in the room ventilation design.
- Utilize a heat exchanger fuel cooler with a remote radiator or separate water supply for the coolant side.

Interconnection of Cooling Systems

For installation sites with multiple generator sets, it is unacceptable for more than one set to share a “central” cooling system.

- Each generator set shall have its own dedicated complete cooling system. Do not manifold multiple generator sets to a common cooling system.

Coolant

- Mixtures of either ethylene– or propylene–glycol and high–quality water shall be used for proper cooling and freeze / boil protection.
- Supplemental coolant additives (SCAs) are required for engines equipped with cylinder liners.

Generator sets must not be cooled by untreated water, as this will cause corrosion, cavitation, mineral deposits, and improper cooling. Mixtures of ethylene– or propylene–glycol and high–quality water must be used. For specific water quality requirements and other coolant details, see the latest version of “Cummins Coolant Requirements and Maintenance” service bulletin #3666132.

See **Table 6–4** for freezing and boiling point comparisons of different concentrations of coolant mixtures. Note that boiling temperatures increase with increasing system pressure. Pure water is included in this table for reference. Propylene–glycol based antifreeze is less toxic than ethylene based antifreeze while providing equivalent cooling system performance. However, as indicated in **Table 6–4**, it offers slightly less freeze / boil protection.

Property	Ethylene Glycol (% by Volume)			Propylene Glycol (% by Volume)			Pure Water
Glycol Concentration	40	50	60	40	50	60	0
Freezing Point °F (°C)	–12 (–24)	–34 (–37)	–62 (–52)	–6 (–21)	–27 (–33)	–56 (–49)	32 (0)
Boiling Point °F (°C) at Atmospheric Pressure	222 (106)	226 (108)	232 (111)	219 (104)	222 (106)	225 (107)	212 (100)
Boiling Point °F (°C) with 14 psi (96.5 kPa) Pressure Cap	259 (126)	263 (128)	268 (131)	254 (123)	257 (125)	261 (127)	248 (120)

Table 6–4. Antifreeze Mixture Properties

Coolant Heaters

Thermostatically controlled engine coolant heaters are used to improve starting and load acceptance. See **Figure 6–30**. As shown in **Figure 6–30**, a heater isolation valve can be installed to prevent draining the entire system of coolant for performing heater maintenance. If such a valve is installed, it shall only be closed for isolating the heater for maintenance. The valve must be locked open at all other times.

Local codes may require the installation of coolant heaters for generator sets used in emergency or standby applications. For example, in the US, NFPA 110 requires that engine coolant for Level 1 emergency power systems be kept at a minimum of 90 °F (32 °C). NFPA 110 also requires the installation of a low engine temperature alarm.

- Coolant heaters shall be installed in emergency / standby applications to ensure good engine starting (optional in tropical locations unless mandated by local ordinance).
- There shall be no loops in the coolant heater hose routing, and the hose shall run continuously uphill.
- Coolant heater connections shall be made using high quality silicon or braided hose.
- The coolant heater shall be disabled while the generator set is running.

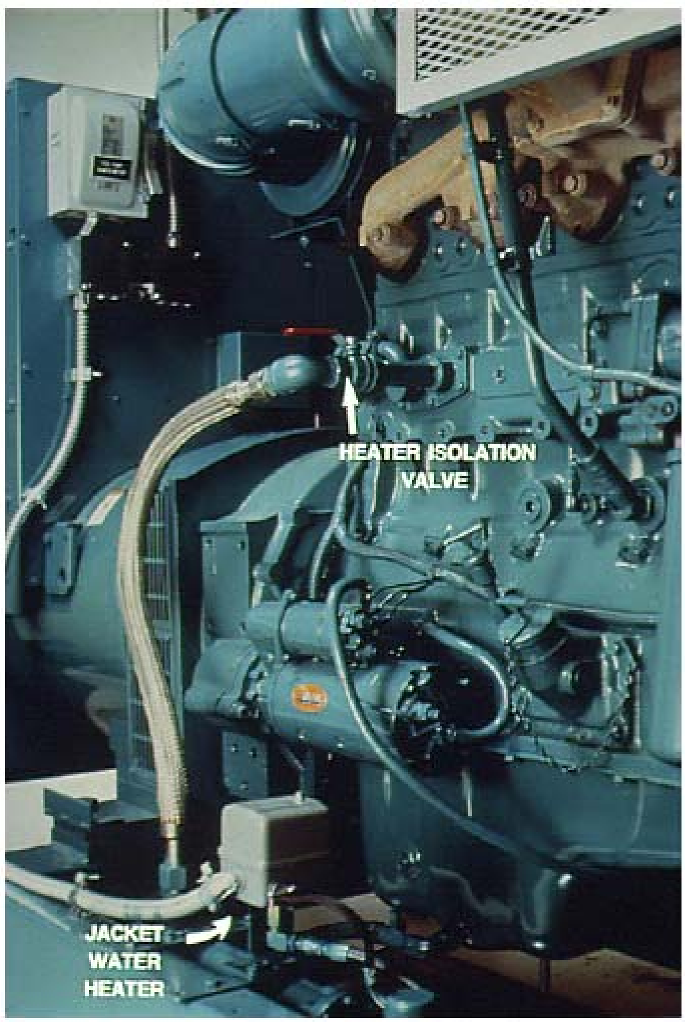


Figure 6–30. Coolant Heater Installation (note heater isolation valve, hose type, and hose routing)

Altitude and Ambient Temperature

Installation site altitude and temperature affect the density of the air surrounding the generator set, which in turn affects engine, alternator, and cooling system performance.

- The cooling system shall be designed to accommodate installation site altitude and ambient temperature.

The density of air decreases as altitude increases. This decrease in density may lead to problems achieving the required airflow and could force a system de–rate.

At high altitudes, reduced atmospheric pressure lowers coolant boiling temperatures. A higher–rated pressure cap may be required. See **Figure 6–31** for an example of altitude / system pressure effects on water. Effects on coolant mixtures are similar.

The system must be able to provide sufficient cooling at full load, even under maximum ambient temperature conditions. If a factory–supplied cooling system is installed, the suitability of this system at the site altitude and ambient temperature must be confirmed.

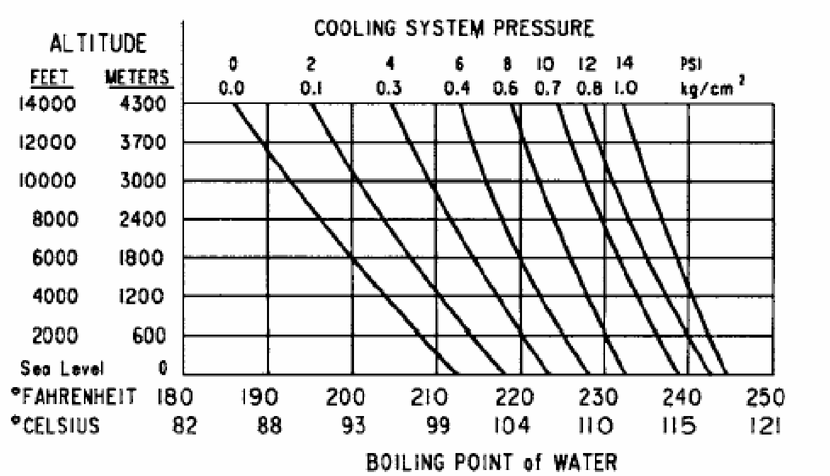


Figure 6–31. Water Boiling Temperature As A Function Of Altitude And System Pressure

It is important to understand the definition of ambient temperature and what it means for cooling system design and performance. For an open installation of a generator set (i.e. not installed in a container or housing) with a factory–supplied radiator, the ambient temperature is defined as the average temperature measured 3 feet off the corners of the generator end of the set (at 45°) and 3 feet off the floor. For housed or containerized sets, the ambient temperature is typically measured at the air inlet to the enclosure. Note that the air flowing through the radiator may be significantly warmer than this ambient temperature. Air temperature will increase as it flows into the room and across the set from rear to front (alternator end to radiator end). For this reason, many factory–supplied radiators are designed for an air–on–core temperature of 15 – 30 °F (8 – 17 °C) higher than the cooling package's rated ambient temperature. See **Figure 6–32** for a representation of the difference between ambient temperature and air–on–core temperature for a factory–supplied radiator cooling package.

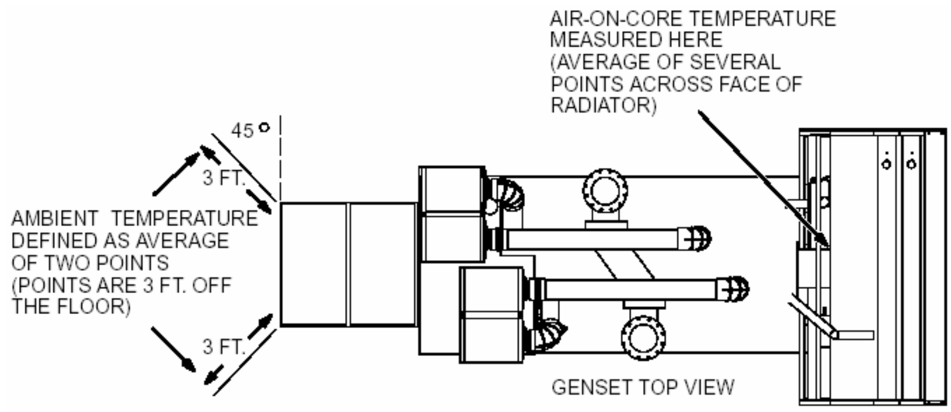


Figure 6–32. ”Ambient” vs. ”Air–on–Core” Temperature

For non–factory–supplied radiators, the critical temperature is the air–on–core temperature. The radiator should be selected to satisfy the cooling requirements at this air–on–core temperature, which can be significantly higher than the ambient temperature discussed above. It is the system designer's responsibility to ensure that this occurs. Note that the air–on–core temperature should be an average of several temperatures from different areas of the radiator face to avoid “hot” or “cold spots”. The air at the center of the face of the radiator, for example, may be significantly warmer than air near the edges of the radiator face.

In cold climates, coolant heaters can be used to improve starting and load acceptance. See **Coolant Heaters**, page 6–44.

For additional details regarding the effects of altitude and temperature on generator set operation, see the **Ambient Conditions** section of this manual.

System Limiting Ambient Temperature (LAT)

The cooling system's Limiting Ambient Temperature (LAT) is the ambient temperature up to which adequate cooling can be provided for the generator set running continuously at rated power. At ambient temperatures above LAT, the maximum top tank temperature listed on the **Generator Set Data Sheet** will eventually be exceeded if the generator set continues to be operated at full power.

For factory–supplied radiator systems, the LAT is listed as a function of airflow restriction on the **Generator Set Data Sheet**. For non–factory–supplied systems, contact the local Cummins distributor for access to the appropriate AEB(s) that discuss test procedures for determining system LAT.

Alternator Cooling

The alternator requires a steady flow of fresh ventilation air to avoid overheating. See the **Ventilation** section of this manual for details.

Cooling System Fouling

The radiator and other sensitive equipment shall be protected from dirt and debris. Dirty systems will not operate at peak efficiency, leading to poor generator set performance and fuel economy.

The radiator must be protected from dirt and debris as well as crankcase breather vapors that could foul or plug the radiator core. See the **Ventilation** section of this manual for additional details regarding filtration and engine crankcase ventilation.

Serviceability

- Valves shall be clearly marked to identify “open” and “closed”.
- Access shall be provided for cleaning and servicing all equipment.

- Drain / isolation valves should be installed to allow service of the generator set without emptying the entire system of coolant.

Drain / isolation provisions are especially important for remote systems. Draining all of the coolant in these systems can be costly. Illustrations throughout **Generator Set Cooling Systems** show locations of drains and isolation valves typically used in application. Note that all valves must be returned to operational mode once servicing is complete.

Access for cleaning / servicing should allow the removal of the radiator core. On some sets, this will require access for large equipment that may be necessary for core removal.

Mobile Applications

- For mobile applications, special consideration shall be given to equipment durability and robustness.

Mobile applications present unique challenges that do not exist in stationary generator set installations. Vibrations inherent to mobile applications can transmit forces to the generator set that can damage equipment. The radiator, coolant piping and hose connections, and other equipment must be designed and specified to withstand these forces. For additional details, see the **Special Applications – Mobile** section of this manual.

Engine Cooling

Cooling systems for reciprocating engine–driven generator sets have the following common characteristics, regardless of the heat exchanger used, to remove heat from the engine. These include:

- The engine portion of the cooling system is a closed, pressurized (10–14 psi/69.0–96.6 kPa) system that is filled with a mixture of clean, soft (demineralized) water, ethylene or propylene glycol, and other additives. Engines should not be directly cooled by untreated water, since this will cause corrosion in the engine and potentially improper cooling. The “cold” side of the cooling system can be served by a radiator, heat exchanger, or cooling tower.
- The engine cooling system must be properly sized for the ambient and components chosen. Typically the top tank temperature of the system (temperature at the inlet to the engine) will not exceed 220° F (104° C) for standby applications, and 200° F (93° C) for prime power installations.
- The cooling system must include deaeration and venting provisions to prevent build-up of entrained air in the engine due to turbulent coolant flow, and to allow proper filling of the engine cooling system. This means that in addition to the primary coolant inlet and outlet connections, there are likely to be at least one set of vent lines terminated at the “top” of the cooling system. Consult the engine manufacturer’s recommendations for the specific engine used for detailed requirements[10]. See **Figure 6–33** for a schematic representation of the cooling and vent lines on a typical engine.
- A thermostat on the engine typically is used to allow the engine to warm up and to regulate engine temperature on the “hot” side of the cooling system.
- The cooling system design should account for expansion in the volume of coolant as the engine temperature increases. Coolant expansion provisions for 6% over normal volume is required.

10 Requirements for venting and deaeration of specific Cummins engines are found in Cummins documents AEB.

- The system must be designed so that there is always a positive head on the engine coolant pump.
- Proper flows for cooling depend on minimizing the static and friction head on the engine coolant pump. The generator set will not cool properly if either the static or friction head limitations of the coolant pump are exceeded. Consult the engine manufacturer for information on these factors for the specific generator set selected. See Cooling Pipe Sizing Calculations in this section for specific instruction on sizing coolant piping and calculating static and friction head.
- Engine and remote cooling systems should be provided with drain and isolation provisions to allow convenient service and repair of the engine. See example drawings in this section for locations of drains and valves typically used in various applications.

Skid–Mounted Radiator

A generator set with a skid–mounted radiator (**Figure 6–34**) is an integral skid–mounted cooling and ventilating system. The skid–mounted radiator cooling system is often considered to be the most reliable and lowest cost cooling system for generator sets, because it requires the least amount of auxiliary equipment, piping, control wiring, and coolant, and minimizes work to be done at the jobsite on the generator set cooling system. The radiator fan is usually mechanically driven by the engine, further simplifying the design. Electric fans are used in some applications to allow more convenient control of the radiator fan based on the temperature of the engine coolant. This is particularly useful in severely cold environments.

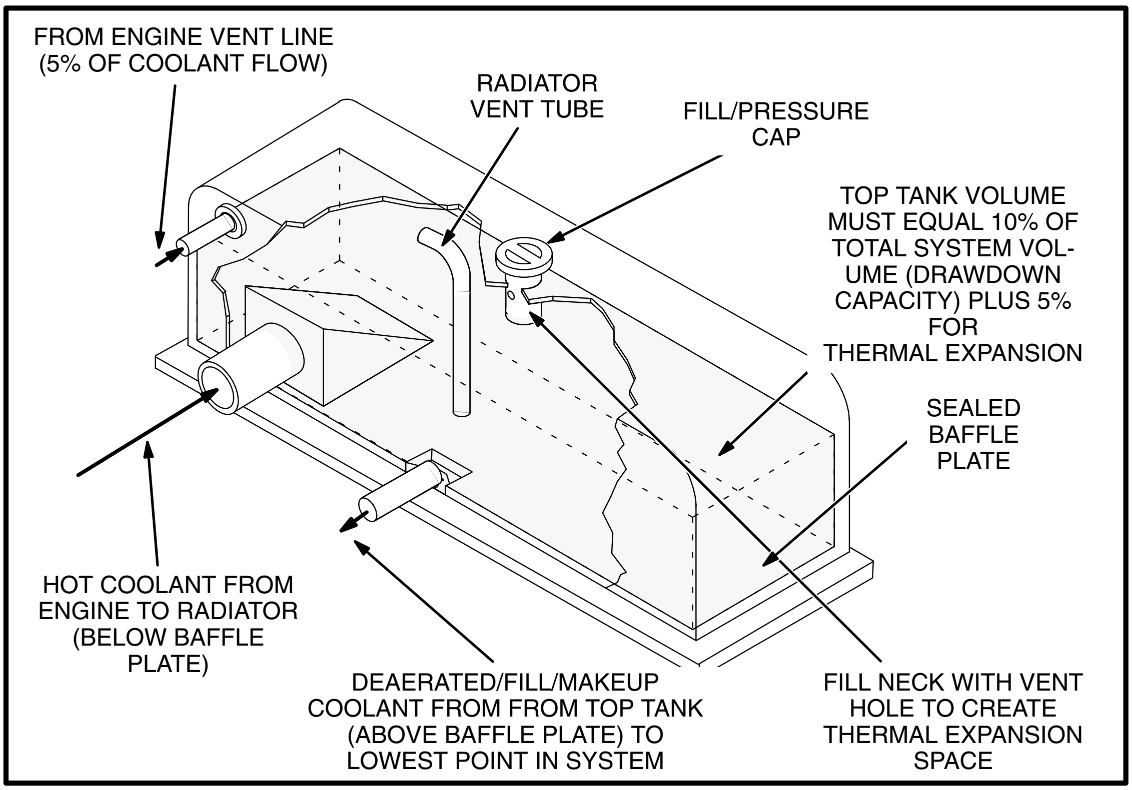


Figure 6–33. Deaeration Type of Radiator Top Tank

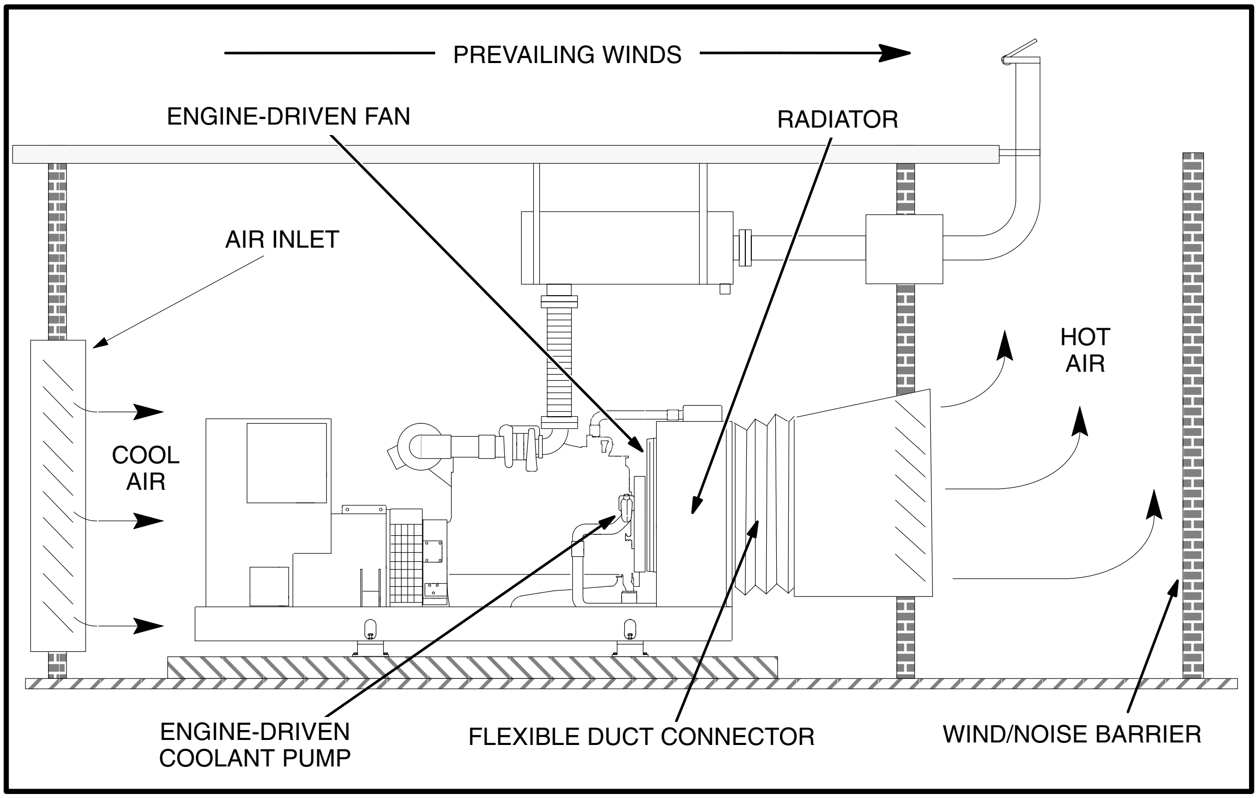


Figure 6–34. Factory-Mounted Radiator Cooling

Since the genset manufacturer typically designs skid–mounted cooling systems, the system can be prototype tested to verify the overall performance of the system in a laboratory environment. An instrumented, controlled, laboratory environment is useful in easily verifying the performance of a cooling system. Often physical limitations at a project site can limit the accuracy or practicality of design verification testing.

The major disadvantage of the skid–mounted radiator is the requirement to move a relatively large volume of air through the generator room, since the air flow through the room must be sufficient for evacuating heat radiated from the generator set and for removing heat from the engine coolant. See Ventilation in this section for details of ventilation system design and calculations related to ventilation system design. The engine fan will often provide sufficient ventilation for the equipment room, eliminating the need for other ventilating devices and systems.

Remote Radiator

Remote radiator systems are often used when sufficient ventilation air for a skid–mounting cooling system can not be provided in an application. *Remote radiators do not eliminate the need for generator set room ventilation, but they will reduce it.* If a remote radiator cooling system is required, the first step is to determine what type of remote system is required. This will be determined by calculation of the static and friction head that will be applied to the engine based on its physical location.

If calculations reveal that the generator set chosen for the application can be plumbed to a remote radiator without exceeding its static and friction head limitations, a simple remote radiator system can be used. See **Figure 6–35.**

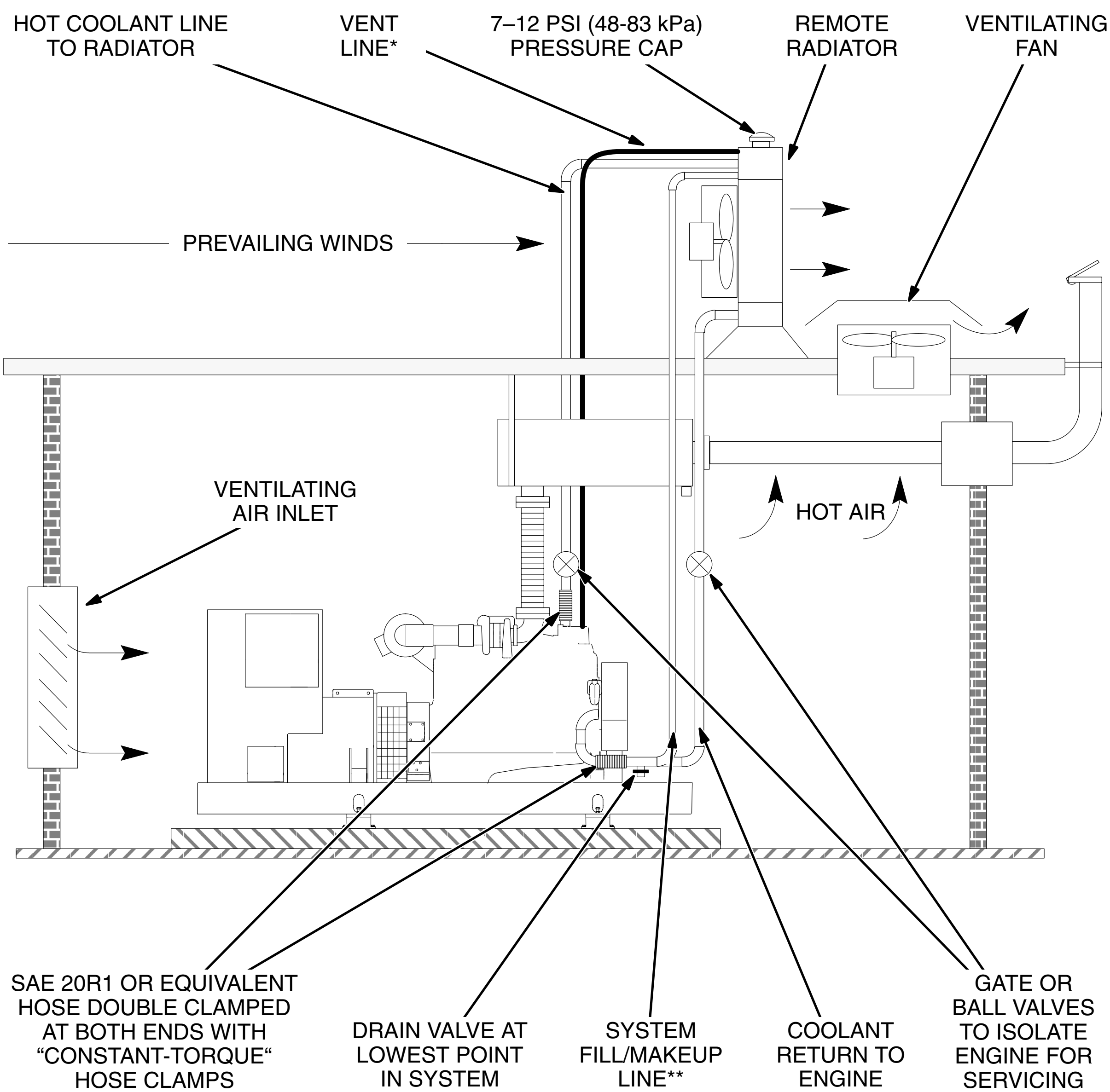
If the friction head is exceeded, but static head is not, a remote radiator system with auxiliary coolant pump can be used. See **Figure 6–33** and Remote Radiator With Auxiliary Coolant Pump, in this section.

If both the static and friction head limitations of the engine are exceeded, an isolated cooling system is needed for the generator set. This might include a remote radiator with hot well, or a liquid–to–liquid heat exchanger–based system.

Whichever system is used, application of a remote radiator to cool the engine requires careful design. In general, all the recommendations for skid mounted radiators also apply to remote radiators. For any type of remote radiator system, consider the following:

- It is recommended that the radiator and fan be sized on the basis of a maximum radiator top tank temperature of 200° F (93° C) and a 115 percent cooling capacity to allow for fouling. The lower top tank temperature (lower than described in Engine Cooling) compensates for the heat loss from the engine outlet to the remote radiator top tank. Consult the engine manufacturer for information on heat rejected to the coolant from the engine, and cooling flow rates[11].
- The radiator top tank or an auxiliary tank must be located at the highest point in the cooling system. It must be equipped with: an appropriate fill/pressure cap, a system fill line to the lowest point in the system (so that the system can be filled from the bottom up), and a vent line from the engine that does not have any dips or traps. (Dips and overhead loops can collect coolant and prevent air from venting when the system is being filled.) The means for filling the system must also be located at the highest point in the system, and a low coolant level alarm switch must be located there.
- The capacity of the radiator top tank or auxiliary tank must be equivalent to at least 17 percent of the total volume of coolant in the system to provide a coolant “drawdown capacity” (11percent) and space for thermal expansion (6 percent). Drawdown capacity is the volume of coolant that can be lost by slow, undetected leaks and the normal relieving of the pressure cap before air is drawn into the coolant pump. Space for thermal expansion is created by the fill neck when a cold system is being filled. See **Figure 6–33.**

11 Information on Cummins Power Generation products is provided in the Cummins Power Suite.



* – THE VENT LINE MUST NOT HAVE ANY DIPS OR TRAPS THAT WILL COLLECT COOLANT AND PREVENT AIR FROM VENTING WHEN THE SYSTEM IS BEING FILLED WITH COOLANT.

** – THE FILL/MAKEUP LINE MUST BE ROUTED DIRECTLY TO THE LOWEST POINT IN THE PIPING SYSTEM SO THAT THE SYSTEM CAN BE FILLED FROM THE BOTTOM UP AND NOT TRAP AIR.

Figure 6–35. Remote Radiator Cooling (Deaeration Type System, See **Figure 6–33**)

- To reduce radiator fin fouling, radiators that have a more open fin spacing (nine fins or less per inch) should be considered for dirty environments.

- Coolant friction head external to the engine (pressure loss due to pipe, fitting, and radiator friction) and coolant static head (height of liquid column measured from crankshaft centerline) must not exceed the maximum values recommended by the engine manufacturer[12]. See the example calculation in this section for a method of calculating coolant friction head. If a system configuration cannot be found that allows the engine to operate within static and friction head limitations, another cooling system type should be used.

NOTE: Excessive coolant static head (pressure) can cause the coolant pump shaft seal to leak. Excessive coolant friction head (pressure loss) will result in insufficient engine cooling.

- Radiator hose 6 to 18 inches (152 to 457mm) long, complying with SAE 20R1, or an equivalent standard, should be used to connect coolant piping to the engine to take up generator set movement and vibration.
- It is highly recommended that the radiator hoses be clamped with two premium grade “constant–torque” hose clamps at each end to reduce the risk of sudden loss of engine coolant due to a hose slipping off under pressure. Major damage can occur to an engine if it is run without coolant in the block for just a few seconds.
- A drain valve should be located at the lowest part of the system.
- Ball or gate valves (globe valves are too restrictive) are recommended for isolating the engine so that the entire system does not have to be drained to service the engine.
- Remember that the generator set must electrically drive remote radiator fan, ventilating fans, coolant pumps, and other accessories required for operation in remote cooling applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system. Remember to add these electrical loads to the total load requirement for the generator set.
- See Ventilation General Guidelines and Heat Exchanger or Remote Radiator Applications, both in this section, concerning generator room ventilation when remote cooling is used.

Deaeration Type Remote Radiator System

A deaeration type of radiator top tank (also know as a sealed top tank) or auxiliary tank must be provided. In this system, a portion of the coolant flow (approximately 5 percent) is routed to the radiator top tank, above the baffle plate. This allows air entrained in the coolant to separate from the coolant before the coolant returns to the system. Consider the following:

- Engine and radiator vent lines must rise without any dips or traps that will collect coolant and prevent air from venting when the system is being filled. Rigid steel or high density polystyrene tubing is recommended for long runs, especially if they are horizontal, to prevent sagging between supports.
- The fill/makeup line should also rise without any dips from the lowest point in the piping system to the connection at the radiator top tank or auxiliary tank. No other piping should be connected to it. This arrangement allows the system to be filled from bottom up without trapping air and giving a false indication that the system is full. With proper vent and fill line connections, it should be possible to fill the system at a rate of at least 5 gpm (19 L/Min) (approximately the flow rate of a garden hose).

12 Data for Cummins engines is in the Power Suite.

Remote Radiator with Auxiliary Coolant Pump

A remote radiator with an auxiliary coolant pump (**Figure 6–36**) can be used if coolant friction exceeds the engine manufacturer's maximum recommended value, and static head is within specifications. In addition to the considerations under Remote Radiators, consider the following:

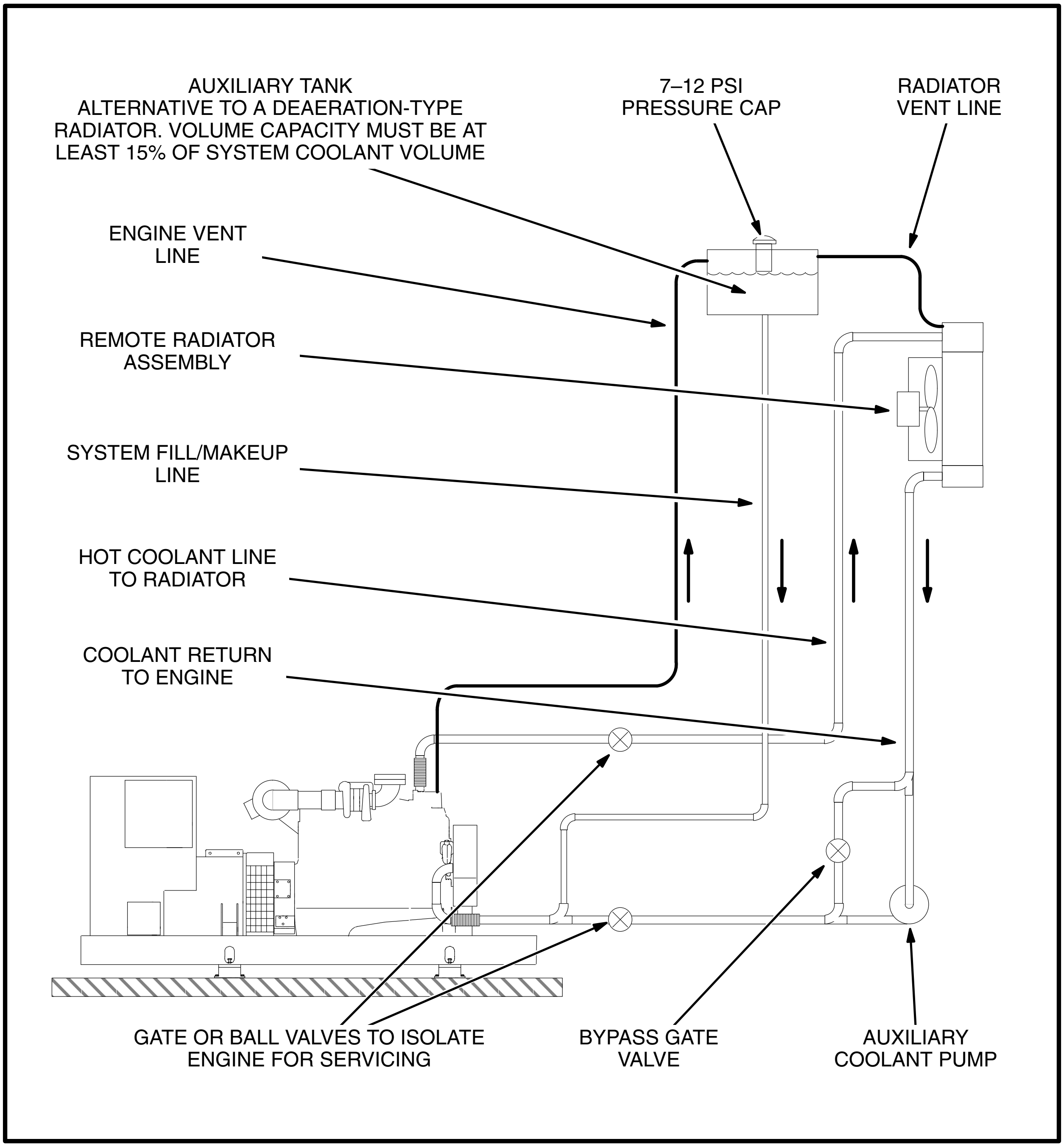


Figure 6–36. Remote Radiator With Auxiliary Coolant Pump and Auxiliary Tank

- An auxiliary pump and motor must be sized for the coolant flow recommended by the engine manufacturer and develop enough pressure to overcome the excess coolant friction head calculated by the method shown in the previous example.

NOTE: One foot of pump head (pump manufacturer's data) is equivalent to 0.43 PSI of coolant friction head (pressure loss) or one foot of coolant static head (height of liquid column).

- A bypass gate valve (globe valves are too restrictive) must be plumbed in parallel with the auxiliary pump, for the following reasons:
  - To allow adjustment of the head developed by the auxiliary pump (the valve is adjusted to a partially–open position to recirculate some of the flow back through the pump).
  - To allow operation of the generator set under partial load if the auxiliary pump fails (the valve is adjusted to a fully open position).
- Coolant pressure at the inlet to the engine coolant pump, measured while the engine is running at rated speed, must not exceed the maximum allowable static head shown on the recommended generator set Specification Sheet. Also, for deaeration type cooling systems (230/200 kW and larger generator sets), auxiliary pump head must not force coolant through the make–up line into the radiator top tank or auxiliary tank. In either case, the pump bypass valve must be adjusted to reduce pump head to an acceptable level.
- Since the engine of the generator set does not have to mechanically drive a radiator fan, there may be additional kW capacity on the output of the generator set. To obtain the **net power** available from the generator set, add the fan load indicated on the generator set Specification Sheet to the power rating of the set. Remember that the generator set must electrically drive the remote radiator fan, ventilating fans, coolant pumps, and other accessories required for the set to run for remote radiator applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system.

Remote Radiator with Hot Well

A remote radiator with a hot well (**Figure 6–37)** can be used if the elevation of the radiator above the crankshaft centerline exceeds the allowable coolant static head on the recommended generator set Specification Sheet. In a hot well system, the engine coolant pump circulates coolant between engine and hot well and an auxiliary pump circulates coolant between hot well and radiator. A hot well system requires careful design.

In addition to the considerations under Remote Radiator, consider the following:

- The bottom of the hot well should be above the engine coolant outlet.
- Coolant flow through the hot well/radiator circuit should be approximately the same as coolant flow through the engine. The radiator and the auxiliary pump must be sized accordingly. Pump head must be sufficient to overcome the sum of the static and friction heads in the hot well/radiator circuit.

NOTE: One foot of pump head (pump manufacturer's data) is equivalent to 0.43 PSI of coolant friction head (pressure loss) or one foot of coolant static head (height of liquid column).

- The liquid holding capacity of the hot well should not be less than the sum of the following volumes:
  - ¼ of the coolant volume pumped per minute through the engine (e.g., 25 gallons if the flow is 100 gpm) (100 liters if the flow is 400 l/min), plus
  - ¼ of the coolant volume pumped per minute through the radiator (e.g., 25 gallons if the flow is 100 gpm) (100 liters if the flow is 400 l/min), plus
  - Volume required to fill the radiator and piping, plus 5 percent of total system volume for thermal expansion.

- Careful design of the inlet and outlet connections and baffles is required to minimize coolant turbulence, allow free deaeration and maximize blending of engine and radiator coolant flows.
- Coolant must be pumped to the bottom tank of the radiator and returned from the top tank, otherwise the pump will not be able to completely fill the radiator.
- The auxiliary pump must be lower than the low level of coolant in the hot well so that it will always be primed.
- The radiator should have a vacuum relief check valve to allow drain down to the hot well.
- The hot well should have a high volume breather cap to allow the coolant level to fall as the auxiliary pump fills the radiator and piping.

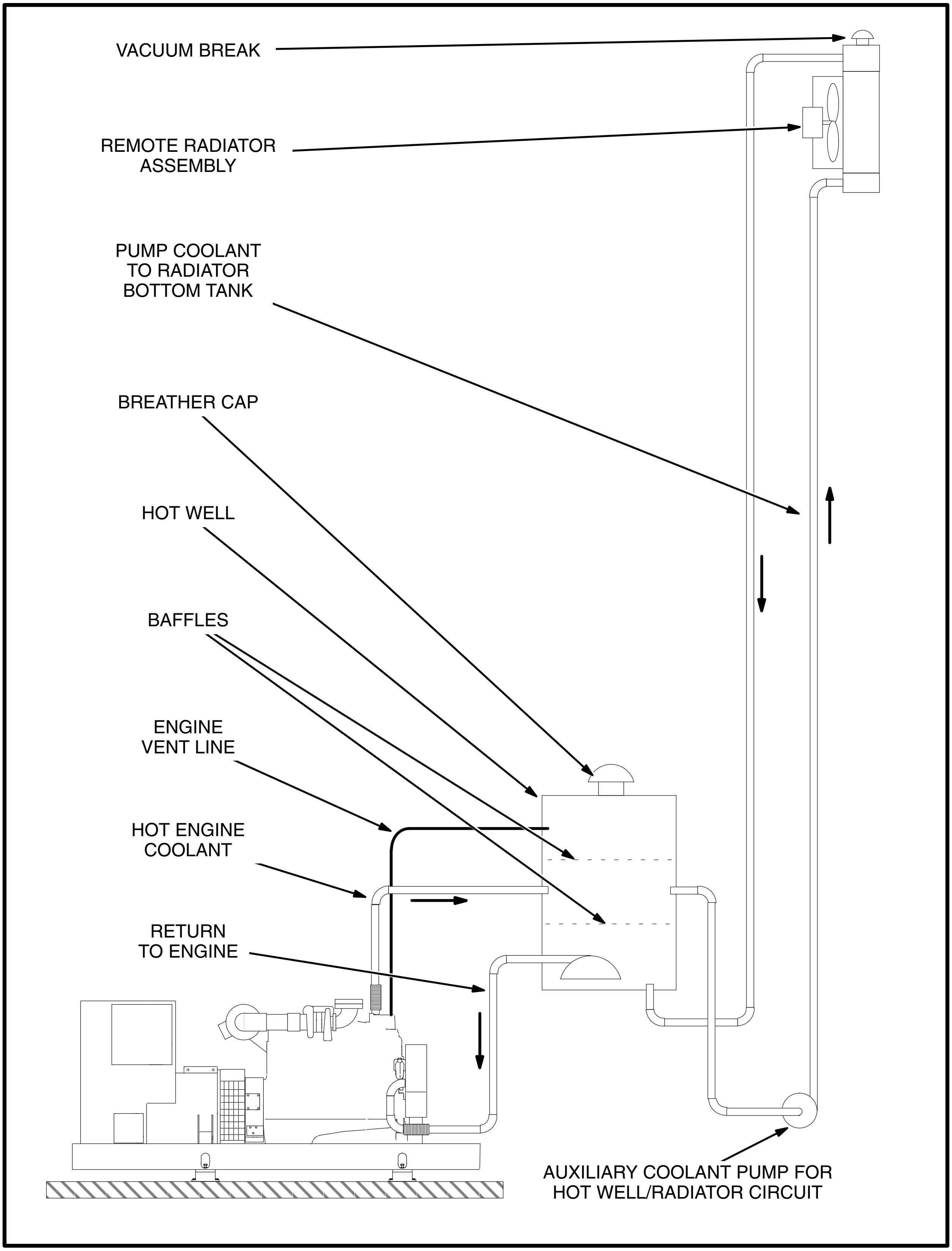


Figure 6–37. Remote Radiator With Hot Well and Auxiliary Coolant Pump

- Remember that the generator set must electrically drive remote radiator fan, ventilating fans, coolant pumps and other accessories required for operation in remote cooling applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system. Remember to add these electrical loads to the total load requirement for the generator set.

Multi–Loop Engine Cooling – Remote Radiators

Some engine designs incorporate more than one cooling loop and therefore require more than one remote radiator or heat exchanger circuit for remote cooling applications. These engines utilize various approaches to achieve Low Temperature Aftercooling (LTA) of the intake air for combustion. A primary reason behind the creation of these designs is their affect on improvement of exhaust emissions levels. Not all of these engine designs however are easily adaptable for remote cooling.

Two–Pump, Two–Loop

A common approach for low temperature aftercooling is to have two complete and separate cooling circuits with two radiators, two coolant pumps and separate liquid coolant for each. One circuit cools the engine water jackets, the other cools the intake combustion air after turbocharging. For remote cooling, these engines require two complete separate remote radiators or heat exchangers. Each will have its own specifications of temperatures, pressure restrictions, heat rejection, etc. that must be met in the remote systems. This data is available from the engine manufacturer. Essentially, two circuits must be designed, each **require** all the considerations of, and **must meet** all the criteria of a single remote system. See **Figure 6–38**.

Note: Radiator placement for the LTA circuit can be critical to achieving adequate removal of heat energy required for this circuit. When the LTA and jacket water radiators are placed back to back with a single fan, the LTA radiator should be placed upstream in the air flow so as to have the coolest air traveling over it.

One–Pump, Two–Loop

Occasionally engine designs accomplish low temperature aftercooling through the use of two cooling circuits within the engine, two radiators but only one coolant pump. These systems are not recommended for remote cooling applications due to the difficulty of achieving balanced coolant flows and thus proper cooling of each circuit.

Air–to–Air Aftercooling

Another approach to achieving low temperature aftercooling is to use an air–to–air radiator cooling circuit instead of an air–to–liquid design as described above. These designs route the turbocharged air through a radiator to cool it before entering the intake manifold(s). These systems are not generally recommended for remote cooling for two reasons. First, the entire system piping and radiator are operate under turbocharged pressure. Even the smallest pinhole leak in this system will significantly decrease turbo charger efficiency and is unacceptable. Second, the length of the air tube run to the radiator and back will create a time lag in turbocharging performance and potentially result in pressure pulses that will impede proper performance of the engine.

Radiators for Remote Radiator Applications

Remote Radiators

Remote radiators are available in a number of configurations for generator set applications. In all cases, the remote radiator uses an electric motor–driven fan that should be fed directly from the output terminals of the generator set. A surge tank must be installed at the highest point in the cooling system. The capacity of the surge tank must be at least 5% of the total system cooling capacity. The pressure cap installed there is selected based on the radiator sizing. Vent lines may also need to be routed to the surge tank. A sight glass is a desirable feature to display level of coolant in the system. It should be marked to show normal level cold and hot. A coolant level switch is a desirable feature to indicate a potential system failure when coolant level is low.

Some remote radiator installations operate with thermostatically controlled radiator fans. If this is the case, the thermostat is usually mounted at the radiator inlet.

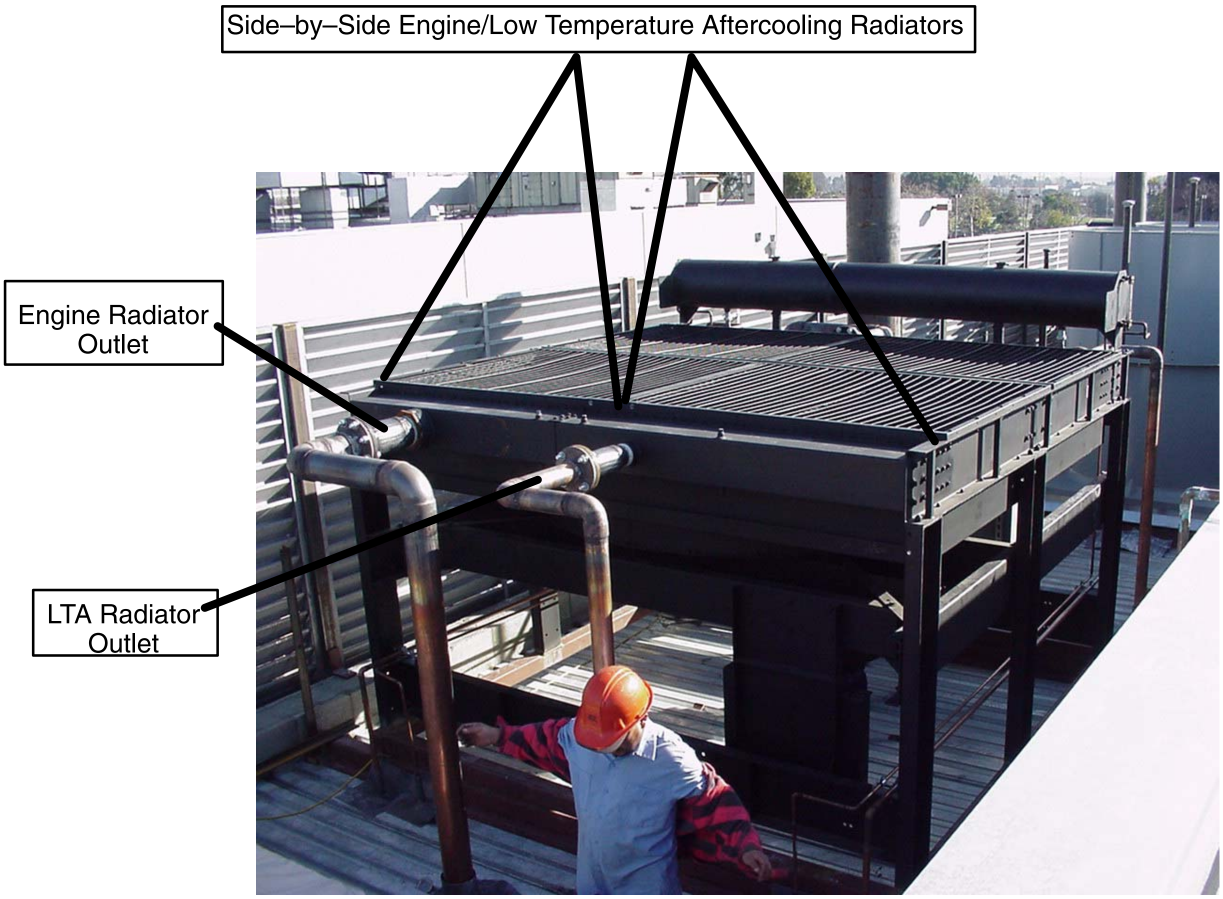


Figure 6–38. A Horizontal Remote Radiator and Aftercooler Radiator

Radiators may be either horizontal type (radiator core is parallel to mounting surface) or vertical type (radiator core is perpendicular to mounting surface) (**Figure 6–38**). Horizontal radiators are often selected because they allow the largest noise source in the radiator (the mechanical noise of the fan) to be directed up, where it is likely that there are no receivers that may be disturbed by the noise. However, horizontal radiators can be disabled by snow cover or ice formation, so they are often not used in cold climates.

Remote radiators require little maintenance, but when they are used, if they are belt driven, annual maintenance should include inspection and tightening of the fan belts. Some radiators may use re–greasable bearings that require regular maintenance. Be sure that the radiator fins are clean and unobstructed by dirt or other contaminants.

Skid–Mounted Heat Exchanger

The engine, pump and liquid–to–liquid heat exchanger form a closed, pressurized cooling system (**Figure 6–39**). The engine coolant and raw cooling water (the “cold” side of the system) do not mix. Consider the following:

- The generator set equipment room will require a powered ventilating system. See Ventilation in this section for information on the volume of air required for proper ventilation.

- Since the engine of the generator set does not have to mechanically drive a radiator fan, there may be additional kW capacity on the output of the generator set. To obtain the **net power** available from the generator set, add the fan load indicated on the generator set Specification Sheet to the power rating of the set. Remember that the generator set must electrically drive remote radiator fan, ventilating fans, coolant pumps and other accessories required for the set to run for remote radiator applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system.

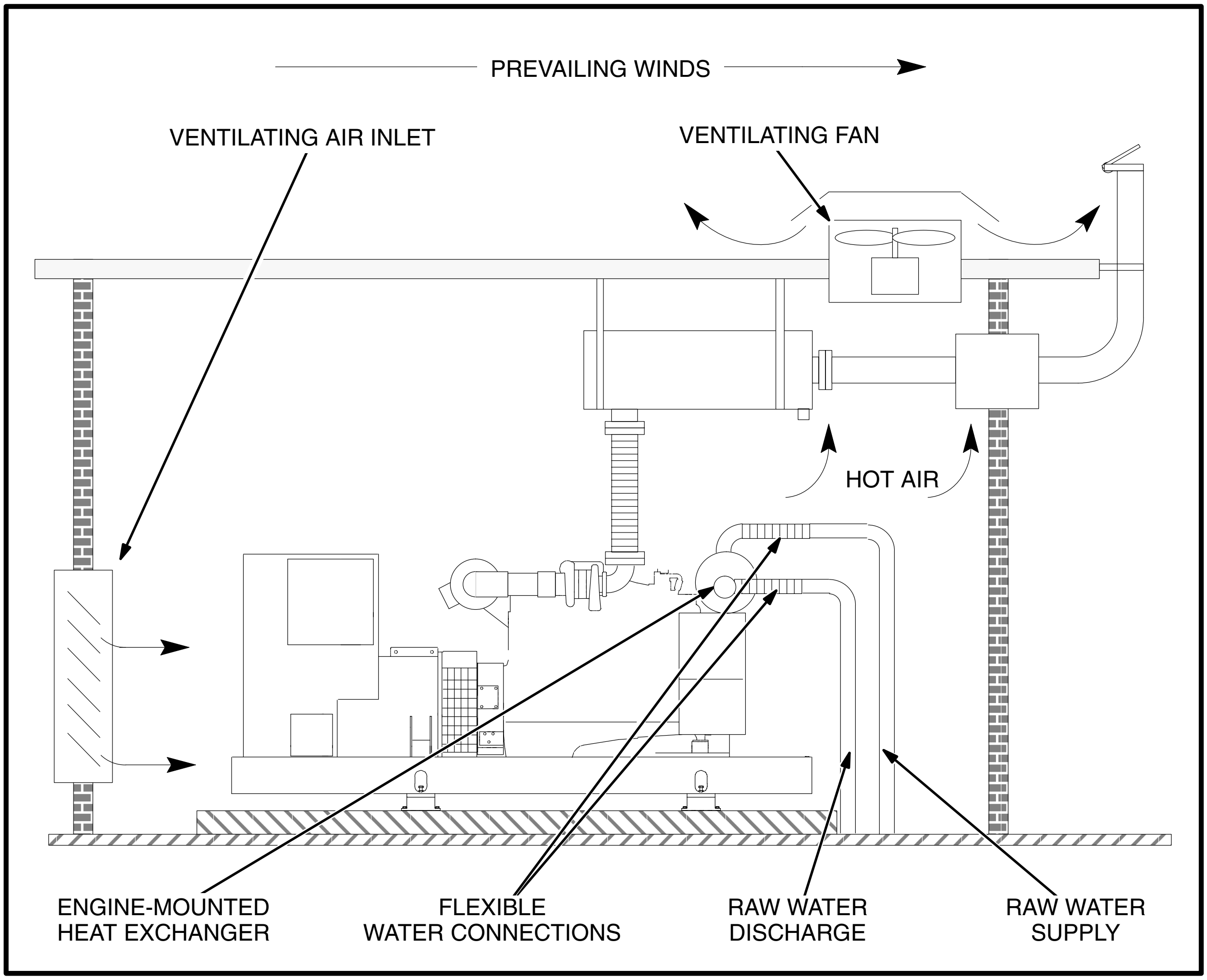


Figure 6–39. Factory-Mounted Heat Exchanger Cooling

- A pressure–reducing valve must be provided if water source pressure on the cold side of the system exceeds the pressure rating of the heat exchanger. Consult heat exchanger manufacturer for heat exchanger information[13].
- The heat exchanger and water piping must be protected from freezing if the ambient temperature can fall below 32 F (0 C).

13 Data for heat exchangers provided on Cummins Power Generation products that are provided with factory–mounted heat exchangers is available in the Cummins Power Suite.

- Recommended options include a thermostatic water valve (non–electrical) to modulate water flow in response to coolant temperature and a normally closed (NC) battery–powered shut off valve to shut off the water when the set is not running.
- There must be sufficient raw water flow to remove the **Heat Rejected To Coolant** indicated on the generator set Specification Sheet. Note that for each 1° F rise in temperature, a gallon of water absorbs approximately 8 BTU (specific heat). Also, it is recommended that the raw water leaving the heat exchanger not exceed 140° F (60° C). Therefore:

$$\text{Raw Water Required (gpm)} = \frac{\text{Heat Rejected}\left(\frac{\text{Btu}}{\text{min}}\right)}{\Delta\,\text{T (F)} \bullet \text{c}\left(\frac{\text{8 Btu}}{\text{F–Gallon}}\right)}$$

Where:
Δ T = Temperature rise of water across core
c = Specific heat of water

- If a set rejects 19,200 BTU per minute and the raw water inlet temperature is 80° F, allowing a water temperature rise of 60° F:

$$\text{Raw Water Required} = \frac{19{,}200}{60 \bullet 8} = 40 \text{ gpm}$$

Dual Heat Exchanger Systems

Dual heat exchanger cooling systems (**Figure 6–40**) can be difficult to design and implement, especially if a secondary cooling system such as a radiator is used to cool the heat exchanger. In these situations the remote device might be significantly larger than expected, since the change in temperature across the heat exchanger is relatively small. These systems should be designed for the specific application, considering the requirements of the engine, liquid to liquid heat exchanger, and remote heat exchanger device[14].

14 Skid–mounted heat exchangers provided by Cummins Power Generation are typically not suitable for use in dual heat exchanger applications. Dual heat exchanger arrangements require carefully matched components.

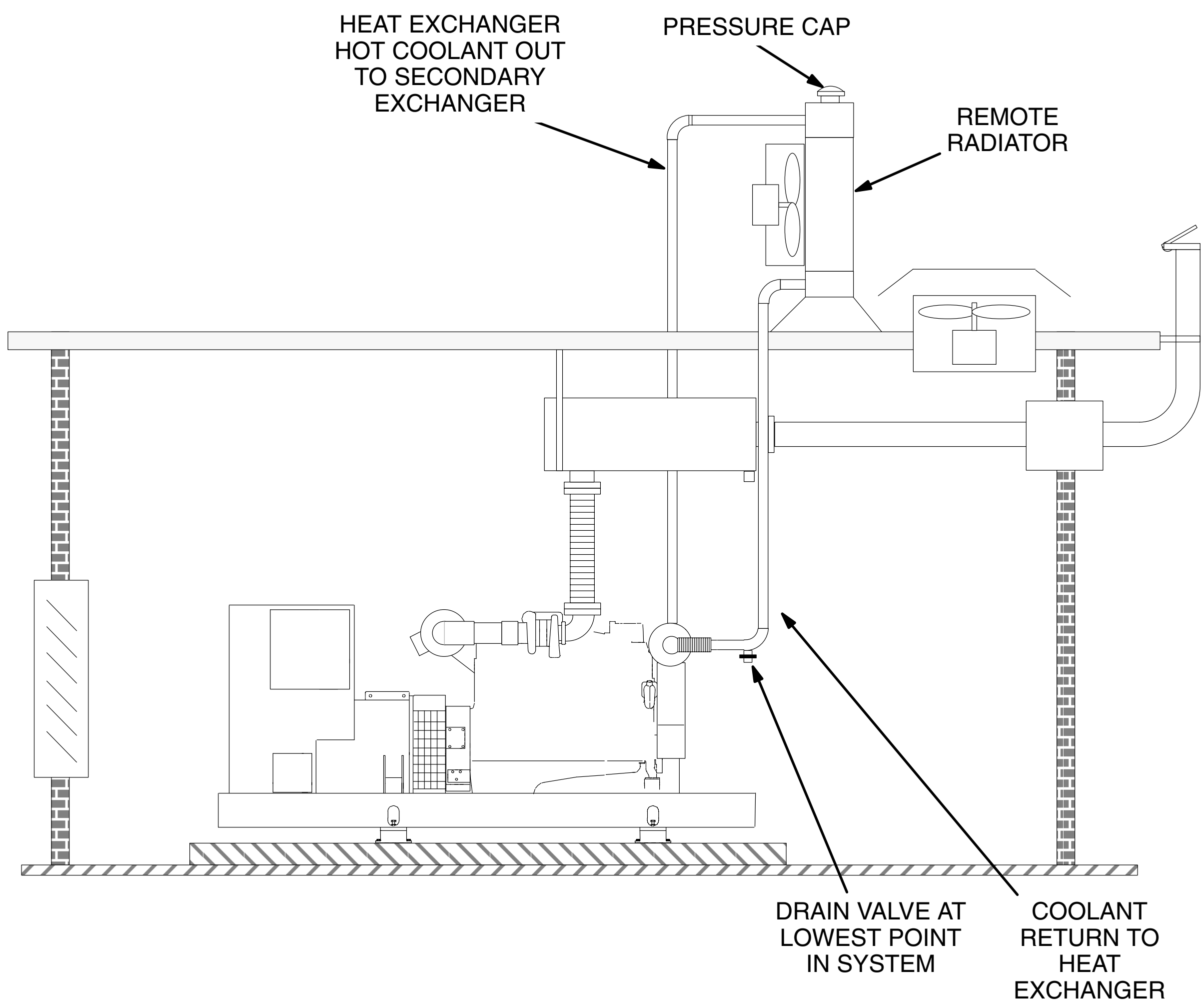


Figure 6–40. Dual Heat Exchanger System (With Secondary Liquid–to–Air Cooler)

Cooling Tower Applications

Cooling tower systems can be used in applications where the ambient temperature does not drop below freezing, and where the humidity level is low enough to allow efficient system operation. Typical arrangement of equipment is shown in **Figure 6–41.**

Cooling tower systems typically utilize a skid–mounted heat exchanger whose “cold” side to plumbed to the cooling tower. The balance of the system is composed of a “raw” water pump (the engine cooling pump circulates coolant on the “hot” side of the system) to pump the cooling water to the top of the cooling tower, where it is cooled by evaporation, and then returned to the generator set heat exchanger. Note that the system requires make–up water provisions, since evaporation will continuously reduce the amount of cooling water in the system. The “hot” side of the heat exchanger system is similar to that described earlier under skid mounted heat exchanger.

Fuel Cooling with Remote Radiators

Generator sets occasionally include fuel coolers to meet the requirements for specific engines. If an engine is equipped with a separate fuel cooler, these cooling requirements must be accommodated in the cooling system design. It is not often feasible to, and often against code to pipe fuel to a remote location. One approach would be to include a radiator and fan for fuel cooling within the generator space and account for the heat rejection in the room ventilation design. Another might be a heat exchanger type fuel cooling system utilizing a remote radiator or separate water supply for the coolant side.

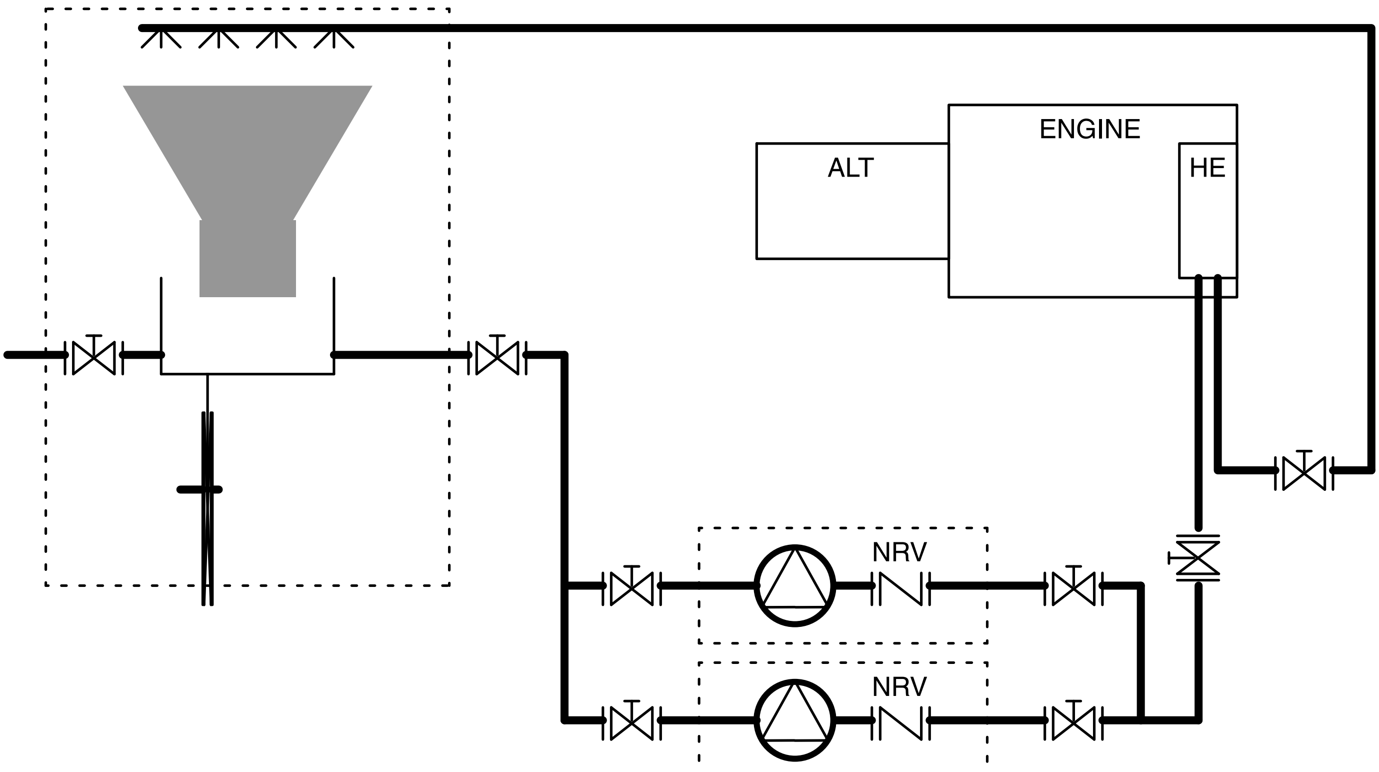


Figure 6–41. Diagram of Representative Cooling Tower Application

Cooling Pipe Sizing Calculations

The preliminary layout of piping for a remote radiator cooling system shown in **Figure 6–35** calls for 60 feet of 3–inch diameter pipe, three long sweep elbows, two gate valves to isolate the radiator for engine servicing and a tee to connect the fill/makeup line. The recommended generator set Specification Sheet indicates that coolant flow is **123 GPM** and that the allowable friction head is **5 PSI**.

This procedure involves determining the pressure loss (friction head) caused by each element and then comparing the sum of the pressure losses with the maximum allowable friction head.

1. Determine the pressure loss in the radiator by referring to the radiator manufacturer's data. For this example, assume the pressure loss is 1 psi at a flow of 135 gpm.
2. Find the equivalent lengths of all fittings and valves by using **Table 6–5** and add to the total run of straight pipe.

Three Long Sweep Elbows–3 x 5.2	15.6
Two Gate Valves (Open)–2 x 1.7	3.4
Tee (Straight Run)	5.2
60 Feet Straight Pipe	60.0
Equivalent Length of Pipe (Feet)	84.2

3. Find the back pressure at the given flow per unit length of pipe for the nominal pipe diameter used in the system. In this example, 3 inch nominal pipe is used. Following the dashed lines in **Figure 6–42**, 3 inch pipe causes a pressure loss of approximately **1.65 psi per 100 foot of pipe.**

4. Calculate the pressure loss in the piping as follows:

   $$\text{Piping Loss} = 84.2 \text{ feet} \times \frac{1.65 \text{ psi}}{100 \text{ feet}} = 1.39 \text{ psi}$$

5. The total system loss is the sum of the piping and radiator losses:

   Total Pressure Loss = 1.39 psi piping + 1.00 psi radiator = 2.39 psi

6. The calculation for this example indicates that the layout of the remote radiator cooling system is adequate in terms of coolant friction head since it is not greater than the allowable friction head. If a calculation indicates excessive coolant friction head, repeat the calculation using the next larger pipe size. Compare the advantages and disadvantages of using larger pipe with that of using an auxiliary coolant pump.

TYPE OF FITTING	NOMINAL INCH (MILLIMETER) PIPE SIZE										
	1/2 (15)	3/4 (20)	1 (25)	1-1/4 (32)	1-1/2 (40)	2 (50)	2-1/2 (65)	3 (80)	4 (100)	5 (125)	6 (150)
90 deg. Std. Elbow or Run of Tee Reduced ½.	1.7 (0.5)	2.1 (0.6)	2.6 (0.8)	3.5 (1.1)	4.1 (1.2)	5.2 (1.6)	6.2 (1.9)	7.7 (2.3)	10 (3.0)	13 (4.0)	15 (4.6)
90 deg Long Sweep Elbow or Straight Run Tee	1.1 (0.3)	1.4 (0.4)	1.8 (0.5)	2.3 (0.7)	2.7 (0.8)	3.5 (1.1)	4.2 (1.3)	5.2 (1.6)	6.8 (2.1)	8.5 (2.6)	10 (3.0)
45 deg Elbow	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.6 (0.5)	1.9 (0.6)	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)
Close Return Bend	4.1 (1.2)	5.1 (1.6)	6.5 (2.0)	8.5 (2.6)	9.9 (3.0)	13 (4.0)	15 (4.6)	19 (5.8)	25 (7.6)	31 (9.4)	37 (11.3)
TEE, Side Inlet or Outlet	3.3 (1.0)	4.2 (1.3)	5.3 (1.6)	7.0 (2.1)	8.1 (2.5)	10 (3.0)	12 (3.7)	16 (4.9)	20 (6.1)	25 (7.6)	31 (9.4)
Foot Valve and Strainer	3.7 (1.1)	4.9 (1.5)	7.5 (2.3)	8.9 (2.7)	11 (3.4)	15 (4.6)	18 (5.5)	22 (6.7)	29 (8.8)	36 (11.0)	46 (14.0)
Swing Check Valve, Fully Open	4.3 (1.3)	5.3 (1.6)	6.8 (2.1)	8.9 (2.7)	10 (3.0)	13 (4.0)	16 (4.9)	20 (6.1)	26 (7.9)	33 (10.1)	39 (11.9)
Globe Valve, Fully Open	19 (5.8)	23 (7.0)	29 (8.8)	39 (11.9)	45 (13.7)	58 (17.7)	69 (21.0)	86 (26.2)	113 (34.4)	142 (43.3)	170 (51.8)
Angle Valve, Fully Open	9.3 (2.8)	12 (3.7)	15 (4.6)	19 (5.8)	23 (7.0)	29 (8.8)	35 (10.7)	43 (13.1)	57 (17.4)	71 (21.6)	85 (25.9)
Gate Valve, Fully Open	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.6 (0.5)	1.9 (0.6)	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)

Table 6-5. Equivalent Lengths of Pipe Fittings and Valves in Feet (Meters)

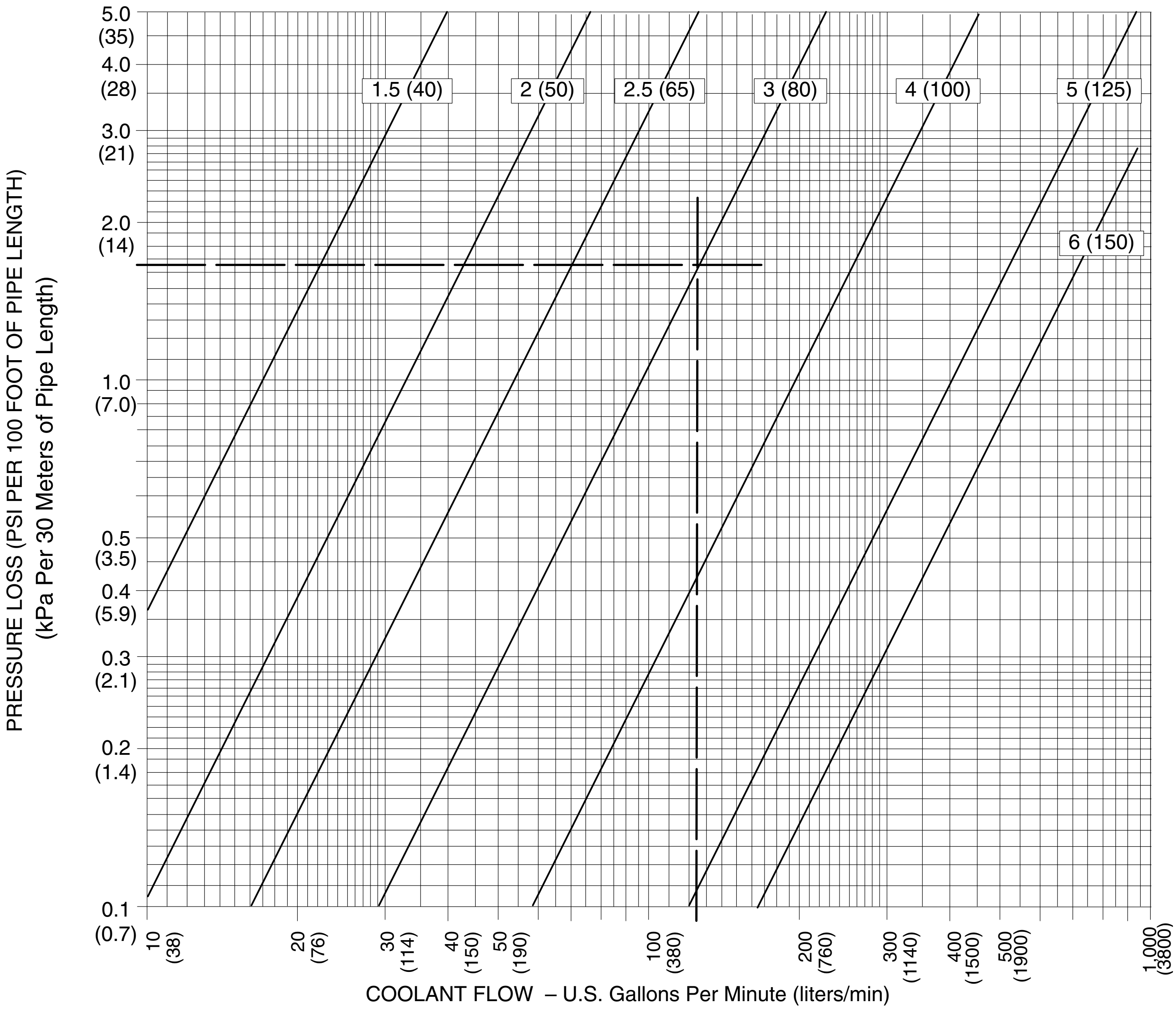


Figure 6–42. Frictional Pressure Losses for Inch (mm) Diameter Pipes

Coolant Treatment

Antifreeze (ethylene or propylene glycol base) and water are mixed to lower the freezing point of the cooling system and to raise the boiling point. Refer to **Table 6–7** for determining the concentration of ethylene or propylene glycol necessary for protection against the coldest ambient temperature expected. Antifreeze/water mixture percentages in the range of 30/70 to 60/40 are recommended for most applications.

NOTE: Propylene glycol based antifreeze is less toxic than ethylene based antifreeze, offers superior liner protection and eliminates some fluid spillage and disposal reporting requirements. However, it is not as effective coolant as ethylene glycol, so cooling system capacity (maximum operating temperature at full load) will be diminished somewhat by use of propylene glycol.

Cummins Power Generation generator sets, 125/100 kW and larger, are equipped with replaceable coolant filtering and treating elements to minimize coolant system fouling and corrosion. They are compatible with most antifreeze formulations. For smaller sets, the antifreeze should contain a corrosion inhibitor.

Generator sets with engines that have replaceable cylinder liners require supplemental coolant additives (SCAs) to protect against liner pitting and corrosion, as specified in the engine and generator set operator's manuals.

Ventilation

Overview

Ventilation of the generator set room is necessary to provide combustion air to the engine, remove the heat emitted from the generator set and any other equipment in the room, and to remove any fumes.

NOTE: The phrase "generator set room" and the term "room" are used throughout this section. However, the principles discussed here are applicable to any means of enclosing the generator set. For the purposes of this section, consider "room" synonymous with "powerhouse," "housing," "container," "enclosure," etc.

Poor ventilation system design and/or installation can lead to the following problems:

- Hazardous conditions for generator set room personnel (if applicable)
- High temperatures around the set that can lead to poor performance and overheating
- Poor operation in cold climates if the installation permits exposure of the unit to cold temperatures
- Issues with other equipment in the room that may be sensitive to high or low temperature.

Requirements

- Engine exhaust manifolds and turbochargers shall not be insulated. (See **Determining Airflow Requirements**, page 6–66.)
- Rigid insulation shall not be used on expansion joints. (See **Determining Airflow Requirements**, page 6–66.)
- Heat from other sources shall be considered in the ventilation system design. (See **Determining Airflow Requirements**, page 6–66.)
- Room inlet / outlet shall:
  - Accommodate the total combustion and ventilation airflow through the room. (See **Room Ventilation Inlet and Outlet Design Requirements**, page 6–73.)
  - Permit airflow across entire generator set from alternator end to radiator end. (See **Inlet and Outlet Design Guidelines**, page 6–74.)
  - Draw/discharge ventilation air directly from/to outdoors. (See **Inlet and Outlet Design Guidelines**, page 6–74.)
  - Permit the required amount of fresh air flow across each set in a multiple set installation. (See **Ventilating Multiple Generator Sets**, page 6–78.)
- The louver manufacturer shall be consulted for air velocity limits. (See **Calculating Inlet / Outlet Effective Flow Area,** page 6–74.)
- Radiator discharge ducts shall be self–supporting (See **Inlet and Outlet Design Guidelines**, page 6–74.).
- Ventilation system shall be designed for acceptable operation with all entry / service doors closed. All doors shall remain closed during generator set operation to maintain the designed ventilation flow. (See **Negative Pressure in the Generator Set Room**, page 6–75.)

- The crankcase breather line shall be routed such that vapors will not foul equipment. (See **Engine Crankcase Ventilation**, page 6–76.)
- If the crankcase breather is modified, crankcase pressure shall be measured at rated power. Pressure must be positive but not exceed 3 inches of water (0.75 kPa). (See **Engine Crankcase Ventilation**, page 6–76.)
- For set–mounted radiator / fan packages, generator set room total airflow restriction shall not exceed the maximum value listed on the **Generator Set Data Sheet.** (See **Airflow Restriction**, page 6–76.)
- Louvers shall open immediately upon generator set start–up for emergency / standby installations. In cold climates, louvers may open partially for combustion air only and controlled to modulate the temperature in the room. (See **Louver Operation**, page 6–78.)
- If a blocking wall is installed, it shall be located no closer than a distance equal to 1X the discharge louver height away from the building. For optimal performance, the wall should be located approximately 3X the discharge louver height away from the building. (See **Blocking Walls**, page 6–80.)
- A turning vane and drain shall be included with any blocking wall installation. (See **Blocking Walls**, page 6–80.)
- If ventilation system filters are installed, a system for detecting plugged filters shall be in place. (See **Ventilation Air Filtration**, page 6–81.)

Recommendations

- Exhaust piping and mufflers should be insulated. (See above requirement regarding manifolds and turbochargers – **Determining Airflow Requirements**, page 6–66.)
- Maximum outdoor temperature should be measured near the air inlet. (See **Determining Airflow Requirements**, page 6–66.)
- Air velocity should be limited to 500 – 700 feet/minute (150 – 220 meters/minute) to prevent rainwater / snow ingress. See above requirement regarding louver limits on air velocity. (See **Calculating Inlet / Outlet Effective Flow Area,** page 6–74.)
- Room inlet / outlet location recommendations (See **Inlet and Outlet Design Guidelines**, page 6–74.):
  - Inlet should not be located near engine exhaust outlet.
  - Inlet and outlet should not be located on the same wall.
  - Outlet should be located as high as possible and inlet should be located as low as possible, while maintaining fresh air flow across the entire set.
  - Outlet should be located on downwind side of the building.
- Additional combustion equipment should not be located in the generator set room. (See **Negative Pressure in the Generator Set Room**, page 6–75.)

Determining Airflow Requirements

Use the following method to determine the generator set room airflow requirements.

STEP 1: Determine Heat Emitted to Room from Generator Set

The engine and alternator will emit heat to the generator set room. In **Figure 6–43**, this heat is labeled Q_{GS}. Consult the **Generator Set Data Sheet** to determine the amount of heat, as shown in **Figure 6–44**. For the standby DFXX Cummins generator set example shown in **Figure 6–44**, Q_{GS} is 5530.0 Btu/min (5.9 MJ/min).

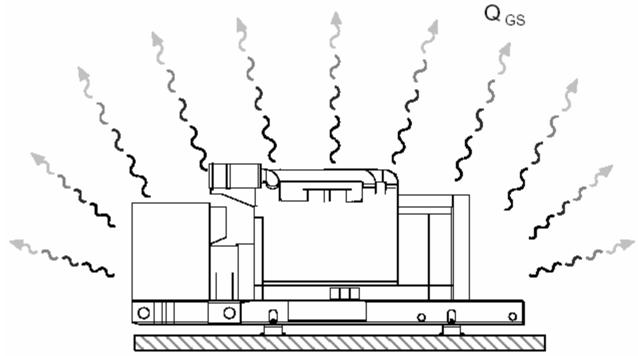


Figure 6–43. Heat Emitted To The Room From A Generator Set (Q_{GS})

STEP 2: Determine Heat Emitted to Room from Muffler and Exhaust Piping

The muffler and exhaust piping will emit heat to the generator set room, as shown in **Figure 6–45**. Use **Table 6–6** to estimate the amount.

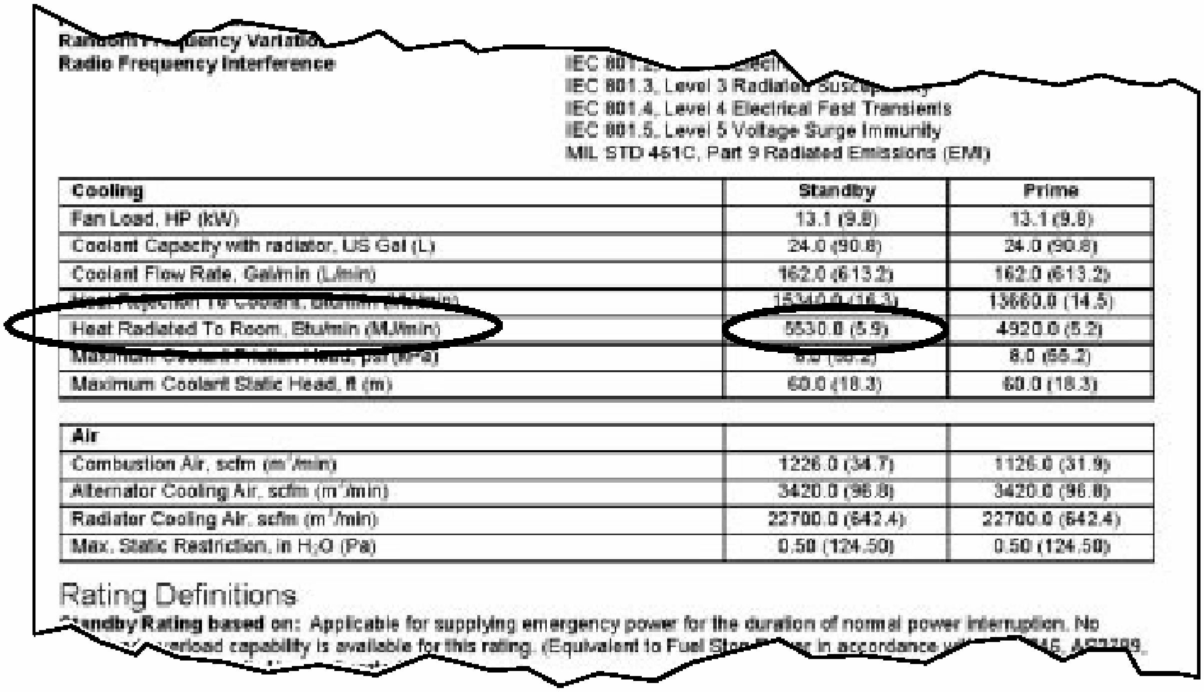
For the system shown in **Figure 6–45**, assume there is 10 feet of uninsulated 5–inch diameter (3 meters of 127 mm diameter) exhaust piping and an uninsulated muffler located in the generator set room. From **Table 6–6**, heat emitted from the piping (Q_P) and muffler (Q_M) can be determined:

$$Q_P = 10 feet * 139 \frac{Btu}{\min * ft} = 1390 Btu/\min$$

OR $$Q_P = 3.0 m * 481 \frac{kJ}{\min * m} = 1443 kJ/\min = 1.44 MJ/\min$$

$$Q_M = 1501 Btu/\min$$

OR $$Q_M = 1584 kJ/\min = 1.58 MJ/\min$$



Random Frequency Variation
Radio Frequency Interference — IEC 801.2, ... Electr...
IEC 801.3, Level 3 Radiated Susceptibility
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
Heat Rejection To Coolant, Btu/min (MJ/min)	15340.0 (16.3)	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
Maximum Coolant Friction Head, psi (kPa)	[illegible]	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
Alternator Cooling Air, scfm (m^3/min)	3420.0 (96.8)	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
Max. Static Restriction, in H_2O (Pa)	0.50 (124.50)	0.50 (124.50)

Rating Definitions

Standby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No ... overload capability is available for this rating. (Equivalent to Fuel Stop Power in accordance with ...

Figure 6–44. Example DFXX Generator Set Specification Sheet

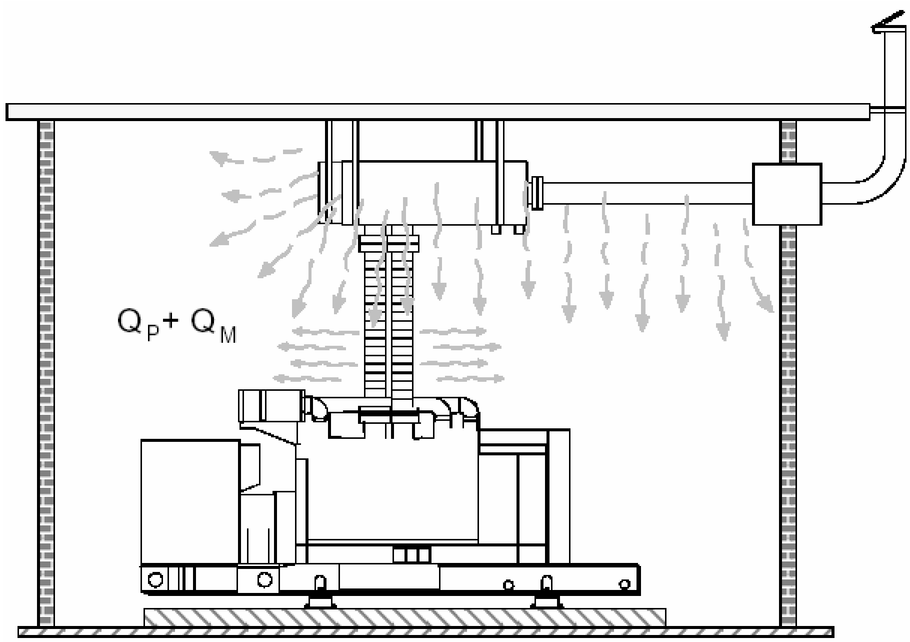


Figure 6–45. Heat Emitted to the Room from the Muffler and Exhaust Piping

Note that the values given in **Table 6–6** and the example equations are for uninsulated exhaust piping and mufflers. Cummins recommends insulating exhaust piping and mufflers to reduce the amount of heat emitted to the room. Factory–supplied, set–mounted radiator packages are designed and developed under the assumption that exhaust pipework will be lagged / insulated. As a rule of thumb, use 30% of the heat values given in **Table 6–6** for insulated systems[1].

Insulating engine exhaust manifolds and turbochargers can cause damage. In addition, rigid insulation cannot be used on expansion joints. For additional details, see the **Exhaust System** section of this manual, or contact the local Cummins distributor for access to AEB 60.05.

- Exhaust piping and mufflers should be insulated.
- Engine exhaust manifolds and turbochargers shall not be insulated.
- Rigid insulation shall not be used on expansion joints.

Pipe Diameter Inches (mm)	Heat From Pipe Btu/min/ft (kJ/min/m)	Heat From Muffler Btu/min (kJ/min)
3 (76)	87 (301)	922 (973)
3.5 (98)	99 (343)	1047 (1105)
4 (102)	112 (388)	1175 (1240)
5 (127)	139 (481)	1501 (1584)
6 (152)	164 (568)	1944 (2051)
8 (203)	213 (737)	2993 (3158)
10 (254)	268 (928)	3668 (3870)
12 (305)	318 (1101)	5463 (5764)
14 (356)	367 (1270)	8233 (8686)

Table 6–6. Estimated Heat Emitted from Uninsulated Exhaust Piping and Mufflers[15]

STEP 3: Determine Heat Emitted to Room from Other Heat Sources

- Heat from other sources shall be considered in the ventilation system design.

Other sources include switchgear, pumps, compressors, lighting, solar heat through windows, and any other heat–producing equipment. In the following equations, this heat is identified as Q_{AUX}.

For the example system, assume that there are no additional heat sources in the generator set room.

STEP 4: Calculate the Total Heat Emitted to Room from All Sources

To find the total heat emitted to the generator set room, sum all of the values from steps 1–3:

$$Q_{TOT} = Q_{GS} + Q_P + Q_M + Q_{AUX}.$$

For the example system,

$$Q_{TOT} = 5530 \, {}^{Btu}\!/_{\min} + 1390 \, {}^{Btu}\!/_{\min} + 1501 \, {}^{Btu}\!/_{\min} + 0 \, {}^{Btu}\!/_{\min} = 8421 \, {}^{Btu}\!/_{\min}.$$

STEP 5: Determine the Maximum Acceptable Room Temperature Rise

To determine the maximum acceptable generator set room temperature rise, first determine the maximum outdoor temperature (MAX T_{OUT}) and the maximum acceptable room temperature (MAX T_{ROOM}). The maximum outdoor temperature is the highest likely outdoor temperature in the geographic region. Ideally, this temperature will be measured near the generator set room air inlet. Temperatures near buildings can be significantly higher than temperatures in open spaces.

- Maximum outdoor temperature should be measured near the air inlet.

[15] Cummins employees can access Cummins Technical Report 9051–2005–003 for documentation of these values.

To determine the maximum acceptable room temperature, consult building codes, local ordinances, fire detection specifications, maximum generator set operating temperature before de–rate, cooling system capability, and other factors. Keep in mind that the generator set may not be the most temperature–sensitive equipment in the room. Maximum acceptable room temperatures may be defined by the operating limits of other equipment.

The maximum acceptable generator set room temperature rise is:

$$\Delta T = MaxT_{ROOM} - MaxT_{OUT}.$$

For the example system, assume that the generator set is located in a region where the highest outdoor temperature at the room inlet is 90 °F (32.2 °C), and the maximum acceptable room temperature is 104 °F (40 °C). The maximum acceptable generator set room temperature rise is:

$$\Delta T = 104°F - 90°F = 14°F \quad \text{OR} \quad \Delta T = 40°C - 32.2°C = 7.8°C$$

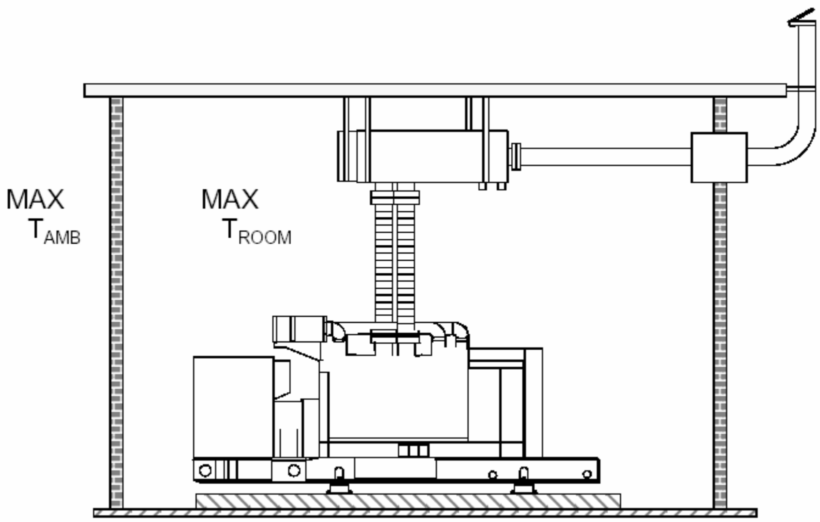


Figure 6–46. Maximum Acceptable Room And Ambient Temperatures

STEP 6: Determine the Combustion Airflow Requirement

Find the combustion airflow requirement on the **Generator Set Data Sheet**, as shown in **Figure 6–47**. For the standby DFXX Cummins generator set example shown, this value is 1226.0 cfm (34.7 m^3/min).

STEP 7: Calculate the Total Airflow Required through the Generator Set Room

First, the airflow required to provide the designed room temperature rise is calculated:

$$V_{ROOM} = \frac{Q_{TOT}}{(c_p)(\Delta T)(d)},$$

where V_{ROOM} = minimum forced ventilation airflow; cfm (m^3/min)

Q_{TOT} = total heat emitted to room (step 4); Btu/min (MJ/min)

c_p = specific heat; 0.241 Btu/lb/°F (1.01×10^{-3} MJ/kg/°C)

ÄT = generator set room temperature rise (step 5); °F (°C)

d = density of air; 0.0750 lb/ft^3 (1.20 kg/m^3).

For the example system,

$$V_{ROOM} = \frac{8421 \, {}^{Btu}\!/_{\min}}{(0.241 \, {}^{Btu}\!/_{lb \cdot {}^\circ F})(14^\circ F)(0.075 \, {}^{lb}\!/_{ft^3})} = 33278 \, cfm$$

OR

$$V_{ROOM} = \frac{8.92 \, {}^{MJ}\!/_{\min}}{(1.01x10^{-3} \, {}^{MJ}\!/_{kg \cdot {}^\circ C})(7.8^\circ C)(1.20 \, {}^{kg}\!/_{m^3})} = 944 \, {}^{m^3}\!/_{\min}$$

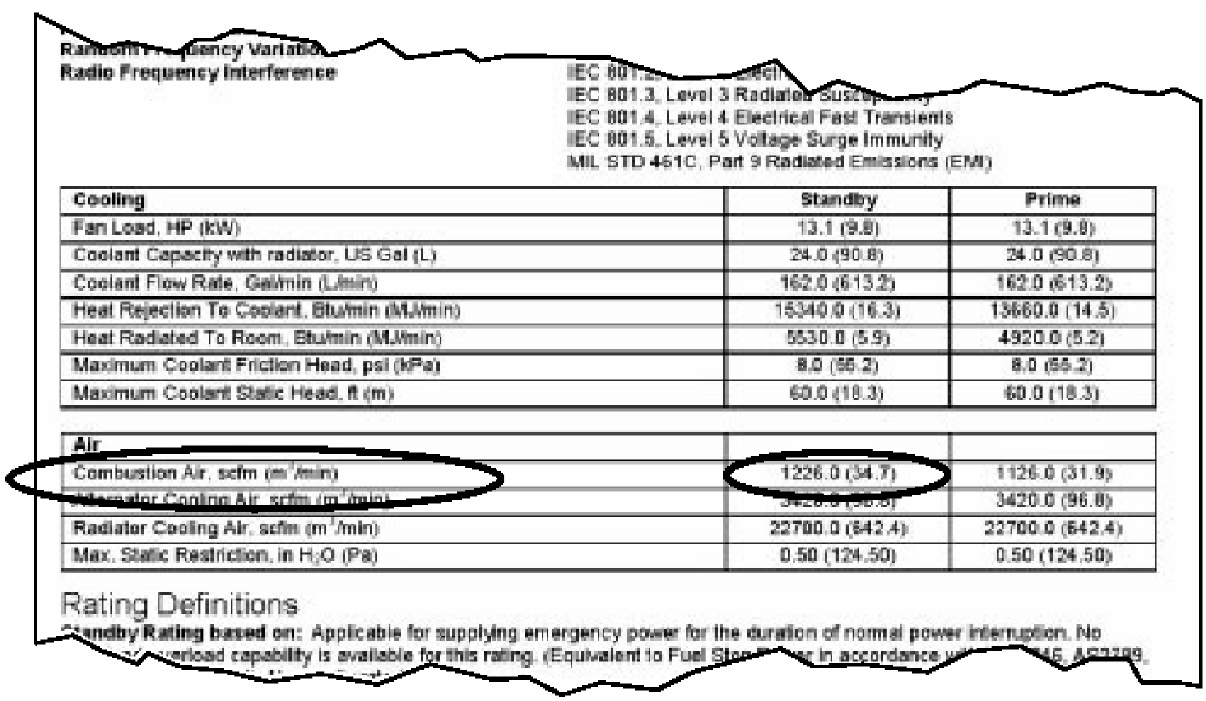
Next, add this value to the combustion air requirement from Step 6 to determine the required total airflow:

$$V_{TOT} = V_{ROOM} + V_{COMB}$$

For the example system,

$$V_{TOT} = 33278 \, cfm + 1226 \, cfm = 34504 \, cfm.$$ OR

$$V_{TOT} = 944 \, {}^{m^3}\!/_{\min} + 34.7 \, {}^{m^3}\!/_{\min} = 979 \, {}^{m^3}\!/_{\min}$$



Ran[illegible]quency Variation
Radio Frequency Interference — IEC 801.[illegible]
IEC 801.3, Level 3 Radiated Susc[illegible]
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
Heat Rejection To Coolant, Btu/min (MJ/min)	15340.0 (16.3)	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
Maximum Coolant Friction Head, psi (kPa)	8.0 (55.2)	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
[illegible] Cooling Air, scfm (m^3/min)	[illegible]	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
Max. Static Restriction, in H_2O (Pa)	0.50 (124.50)	0.50 (124.50)

Rating Definitions
[illegible]ndby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No [illegible]verload capability is available for this rating. (Equivalent to Fuel Sto[illegible] in accordance [illegible], AS2789,

Figure 6–47. Example DFXX Generator Set Specification Sheet

STEP 8: Adjust Airflow for Altitude

Air density decreases as altitude increases. A generator set operating at high altitude requires more volumetric airflow than a generator set operating at sea level in order to maintain equivalent air mass flow. Increase airflow from Step 7 by 3% for every 1000 feet (305 meters) above sea level to maintain adequate ventilation. Use the following equation:

$$V_{ADJ} = \left(\frac{Alt}{Alt_{REF}}\right)(.03)(V_{TOT}) + V_{TOT},$$

where V_{ADJ} = airflow adjusted for altitude; cfm (m^3/min)

Alt = altitude at installation site; ft (m)

Alt_{REF} = reference altitude; 1000 ft (305 m)

V_{TOT} = total airflow required from Step 7; cfm (m^3/min).

Assume the example system is to be installed at an altitude of 5000 feet (1524 meters).

$$V_{ADJ} = \left(\frac{5000ft}{1000ft}\right)(.03)(34504\ cfm) + 34504\ cfm = 39680\ cfm.$$

OR

$$V_{ADJ} = \left(\frac{1524\ m}{305\ m}\right)(.03)(979\ m^3/min) + 979\ m^3/min = 1126\ m^3/min.$$

This final value (V_{ADJ}) is the actual airflow required at the site conditions. Ventilation equipment suppliers may require additional details to specify appropriate equipment for the installation.

STEP 9: Determine Auxiliary Ventilation Fan Requirements

If the generator set has a factory-installed radiator and fan, obtain the "Radiator Cooling Air" or "Cooling System Airflow" value from the **Generator Set Data Sheet**. This is the airflow that the set-mounted fan will provide. For the standby DFXX Cummins generator set example shown in **Figure 6-48**, this value is 22700.0 cfm (642.4 m^3/min).

Random Frequency Variation
Radio Frequency Interference

IEC 801.3, Level 3 Radiated Susceptibility
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
Heat Rejection To Coolant, Btu/min (MJ/min)	15340.0 (16.3)	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
Maximum Coolant Friction Head, psi (kPa)	8.0 (55.2)	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
Alternator Cooling Air, scfm (m^3/min)	3420.0 (96.8)	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
Max. Static Restriction, in H_2O (Pa)	[illegible]	0.50 (124.50)

Rating Definitions

Standby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No overload capability is available for this rating. (Equivalent to Fuel Stop Power in accordance with ...

Figure 6-48. Example DFXX Generator Set Specification Sheet

Compare the total airflow requirement (V_{ADJ}) obtained in Step 8 with the "Cooling System Airflow" value from the generator set technical information.

If V_{ADJ} is less than the “Radiator Cooling Air” value, the set–mounted fan will provide more than the necessary ventilation airflow, and no auxiliary fans are required. This assumes that the total airflow restriction is within limits. (See **Airflow Restriction**, page 6–76.)

If V_{ADJ} is greater than the “Radiator Cooling Air” value, the set–mounted fan will not provide the necessary ventilation airflow, and auxiliary fans are required. The auxiliary fans must make up the airflow difference between V_{ADJ} and the “Cooling System Airflow” value. The auxiliary fan must be sized and located such that it will complement the set–mounted fan, not compete with it for air.

If the example system were equipped with a factory–installed radiator and fan, V_{ADJ} = 39680 cfm (1126 m^3/min) is greater than the “Radiator Cooling Air” value of 22700.0 cfm (642.4 m^3/min), so auxiliary fans would be required for the generator set room. These fans would need to deliver 39680 cfm – 22700.0 cfm = 16980 cfm (1126 m^3/min – 642.4 m^3/min = 483.6 m^3/min).

Note: This example presents extreme circumstances. In most applications, set–mounted fans will be capable of providing the required airflow. However, these calculations must be done to verify that the fan is adequate.

If the generator set does not have a factory–installed radiator and fan, fans installed in the generator set room will be required to provide the total airflow calculated in Step 8.

If the example system were not equipped with a factory–installed radiator and fan, fans installed in the generator set room would need to provide 39680 cfm (1126 m^3/min) air flow.

Room Ventilation Inlet and Outlet Design Requirements

- Room inlet(s) and outlet(s) must accommodate the total airflow through the room.

If the generator set has a factory–installed radiator and fan, the total airflow through the generator set room is either the required ventilation airflow from Step 8 above (V_{ADJ}) or the “Cooling System Airflow” from Step 9, whichever value is greater. An example system is shown in Figure NO TAG.

If the generator set does not have a factory–installed radiator and fan, the total airflow through the generator set room is the required ventilation airflow from Step 8 above (V_{ADJ}). An example system is shown in **Figure 6–50**.

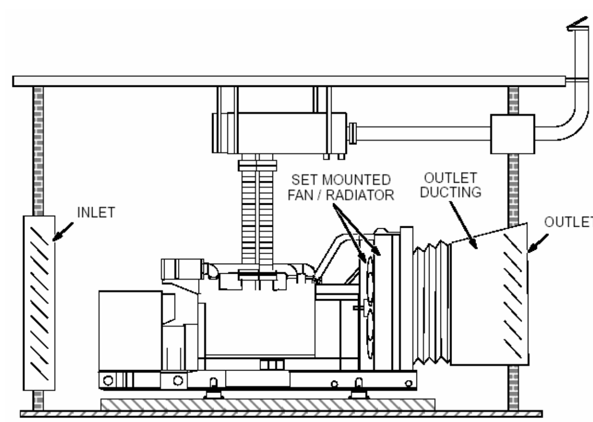


Figure 6–49. Example Ventilation System For Factory–installed Radiator and Fan

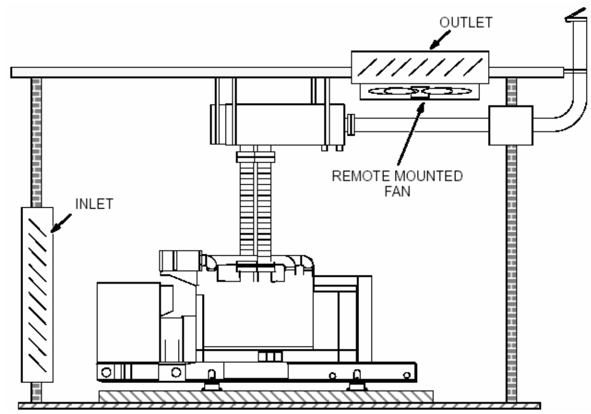


Figure 6–50. Example Ventilation System For Remote–cooled, Non–factory–installed Radiator and Fan (NOTE: cooling system is not shown in this illustration)

Calculating Inlet/Outlet Effective Flow Area

- Air velocity should be limited to 500 – 700 feet/minute (2.5 – 3.6 meters/second) to prevent rainwater / snow ingress.
- For louver installations, default to louver manufacturer for air velocity limits.

Typically, limiting the air velocity to 500 – 700 feet/minute (2.5 – 3.6 meters/second) will help keep rain and snow from entering the generator set room. For louver installations, be sure to check with louver manufacturer for specific air velocity requirements.

Louvers and screens over air inlet and outlet openings restrict airflow and vary widely in performance. A louver assembly with narrow vanes, for example, tends to be more restrictive than one with wide vanes. The effective open area specified by the louver or screen manufacturer should be used.

The required effective flow area of the inlet and/or outlet can be calculated:

$$A = \frac{V}{S},$$

where A = effective flow area; ft^2 (m^2)

V = volumetric flow; cfm (m^3/min)

S = air velocity; ft/min (m/min).

For the example system from part 1, assume inlet and outlet louvers are used, and the louver manufacturer requires the airflow velocity be limited to 400 feet/minute (122 meters/minute).

$$A = \frac{V}{S} = \frac{39680\,cfm}{400\,ft/\min} = 99.2\,ft^2 \quad \text{OR} \quad A = \frac{V}{S} = \frac{1126\,m^3/\min}{122\,m/\min} = 9.2\,m^2$$

Louvers with an effective flow area of 99.2 ft^2 (9.2 m^2) would be required.

Inlet and Outlet Design Guidelines

These requirements and recommendations will help deliver the required amount of air across the generator set and maintain system integrity.

- Inlets and outlets shall be located such that air will flow across the entire generator set from alternator end to radiator end.
- Ventilation air shall be drawn directly from / discharged directly to the outdoors.
- Radiator discharge ducts shall be self–supporting.

- Inlet and outlet should not be located on the same wall.
- Inlet should not be located near the engine exhaust outlet.
- Outlets should be located as high as possible and inlets as low as possible, while maintaining fresh air flow across the entire set.
- Outlet should be located on the downwind side of the building.

"Top" views of recommended, acceptable, and unacceptable room layouts are shown in **Figure 6–51**. "Side" views of recommended and unacceptable room layouts are shown in **Figure 6–52**.

*Note: For generator sets with factory–supplied, set–mounted radiator packages, it will not be possible to locate the outlet high in the room. The recommended layout in **Figure 6–52** applies only to remote–cooled systems.*

Negative Pressure in the Generator Set Room

- Ventilation system shall be designed for acceptable operation with all entry / service doors closed. All doors shall remain closed during generator set operation to maintain the designed ventilation flow.
- Additional combustion equipment should not be located in the generator set room.

The ventilation system may cause a slight negative pressure in the generator set room. It is recommended that combustion equipment such as the building heating boilers not be located in the generator set room due to the possibility of negative pressure. If this is unavoidable, the possibility of impacts on cooling system performance and other detrimental effects such as flue backdraft must be examined. Extra large room inlet openings and/or ducts, pressurizing fans, etc. may be required to reduce the negative pressure to an acceptable level.

Regardless of the pressure in the generator set room, it must always be possible for personnel to open the door(s) to the room in case of emergency.

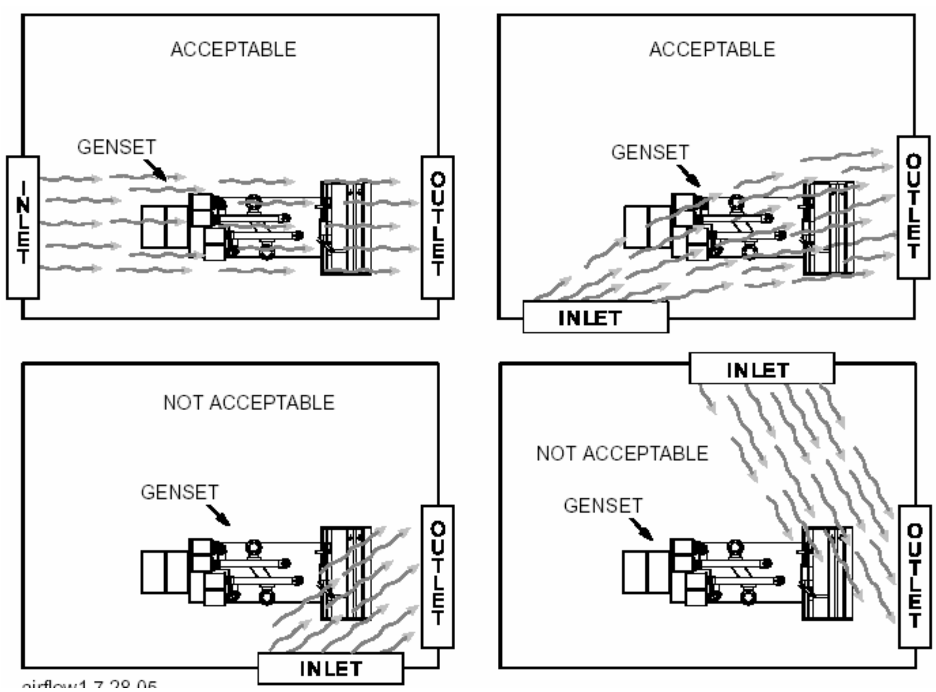


Figure 6–51. "Top" Views of Generator Set Room Layouts

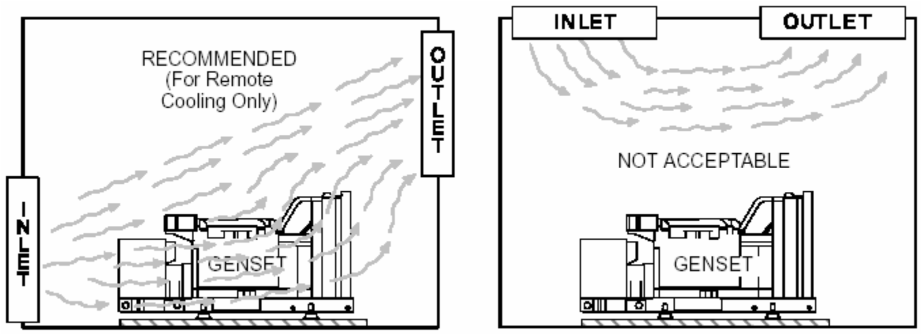


Figure 6–52. ”Side” Views Of Generator Set Room Layouts

Engine Crankcase Ventilation

- The crankcase breather line shall be routed such that vapors will not foul equipment.
- If the crankcase breather is modified, crankcase pressure shall be measured at rated power. Pressure must be positive but not exceed 3 inches of water (0.75 kPa).

Open engine crankcase ventilation systems will exhaust crankcase vapors into the generator set room. These vapors may contain an oil mist. The crankcase breather line shall be routed such that crankcase vapors cannot foul the radiator core, alternator, air cleaner, or any other equipment that may be sensitive to an oil mist. The potential for environmental pollution must also be considered when routing the line. Low spots or dips in the breather line are not permitted, and the line must be protected from freezing. The breather line must not add significant restriction to the system. If the breather is modified, the crankcase pressure must be measured at rated power. This value must be positive and not exceed 3 inches of water (0.75 kPa). Excessively long lines may cause over pressurization of the crankcase. A shorter route or larger diameter line may be required.

Airflow Restriction

- For set–mounted radiator / fan packages, generator set room total airflow restriction shall not exceed the listed maximum value.

If a set–mounted radiator/fan is used, the generator set room total airflow restriction cannot exceed the value listed in the generator set technical information. See **Figure 6–53**. For the DFXX generator set example, this value is 0.50 in H_20 (124.50 Pa).

Radio Frequency Interference

IEC 801.3, Level 3 Radiated Susceptibility
IEC 801.4, Level 4 Electrical Fast Transients
IEC 801.5, Level 5 Voltage Surge Immunity
MIL STD 461C, Part 9 Radiated Emissions (EMI)

Cooling	Standby	Prime
Fan Load, HP (kW)	13.1 (9.8)	13.1 (9.8)
Coolant Capacity with radiator, US Gal (L)	24.0 (90.8)	24.0 (90.8)
Coolant Flow Rate, Gal/min (L/min)	162.0 (613.2)	162.0 (613.2)
Heat Rejection To Coolant, Btu/min (MJ/min)	15340.0 (16.3)	13660.0 (14.5)
Heat Radiated To Room, Btu/min (MJ/min)	5530.0 (5.9)	4920.0 (5.2)
Maximum Coolant Friction Head, psi (kPa)	8.0 (55.2)	8.0 (55.2)
Maximum Coolant Static Head, ft (m)	60.0 (18.3)	60.0 (18.3)

Air		
Combustion Air, scfm (m^3/min)	1226.0 (34.7)	1126.0 (31.9)
Alternator Cooling Air, scfm (m^3/min)	3420.0 (96.8)	3420.0 (96.8)
Radiator Cooling Air, scfm (m^3/min)	22700.0 (642.4)	22700.0 (642.4)
Max. Static Restriction, in H_2O (Pa)	0.50 (124.50)	0.50 (124.50)

Rating Definitions

Standby Rating based on: Applicable for supplying emergency power for the duration of normal power interruption. No overload capability is available for this rating. (Equivalent to Fuel Stop Power in accordance with ... AS2789.

Figure 6–53. Example DFXX Generator Set Specification Sheet.

The generator set room inlet(s) and outlet(s) will cause airflow restriction. See **Figure 6–54**. The inlet restriction is the pressure drop labeled $ÄP_i$ in **Figure 6–54**. The outlet restriction is the pressure drop across the outlet and any installed ducting, labeled $ÄP_o$ in **Figure 6–54**. The sum of these two values must be less than the maximum allowed restriction listed in the generator set technical information:

$ÄP_i + ÄP_o <$ Max. Static Restriction (from **Generator Set Data Sheet**).

If the total system restriction exceeds the maximum allowed, reduced airflow will result. Reduced airflow will prevent the cooling system from performing to its rated ambient temperature. Overheating and shutdown are possible.

Additional cooling system performance details can be found on the generator set model's **Cooling System Data Sheet**. Consider the example shown in **Figure 6–55**. Assume an example 50 Hz standby generator set is installed in a room with a total airflow restriction of 0.25 in water (6.4 mm water). For the 50 °C ambient system shown, the actual ambient capability of this system is 47 °C.

Pressure drop data for inlets, outlets, louvers, dampers, ducting, etc., should be obtained from the manufacturer for the volume flow rates predicted. For installations in North America, refer to ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) publications for recommendations on duct design if air ducts are required.

Once all equipment is installed in the room, the airflow restriction must be verified to insure that it is within limits. See **Airflow Restriction** in **System Verification,** page 6–81.

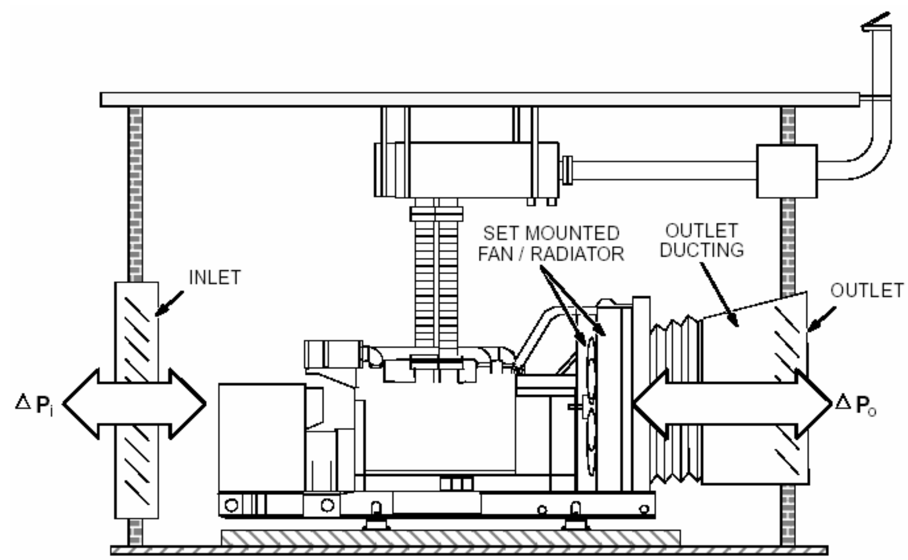


Figure 6–54. Room inlet and outlet airflow restriction.

50 Degree C Ambient Radiator Cooling System

Duty		Rating (kW)	Max Cooling @ Air Flow Static Restriction, Unhoused (inches water/mm water)				Housed in Free Air, No Air Discharge Restriction				
			0.0 /0.0	0.25 /6.4	0.5 /12.7	0.75/19.1	F183	F184	F200	F201	F202
			Maximum Allowable Ambient Temperature, Degree C								
60 Hz	Standby	300	50	50	48.2	N/A	43.9	N/A	45	45	44
	Prime	270	52.5	52	50.5	N/A	45	N/A	N/A	N/A	N/A
50 Hz	Standby	275	50	47	42.8	N/A	40	N/A	N/A	N/A	N/A
	Prime	250	51.6	51.3	46.2	N/A	40.8	N/A	N/A	N/A	N/A

Figure 6–55. Example DXXX Cooling System Data Sheet

If a set–mounted radiator/fan is not used, the auxiliary fans must deliver the required amount of air against the restrictions imposed by the inlets and outlets in order to maintain designed room temperature. Consult equipment suppliers for assistance.

Ventilating Multiple Generator Sets

- Each generator set in a multiple set installation shall receive the required amount of fresh air flow.

For applications where multiple generator sets are installed in the same room, the ventilation system must be designed so that the required amount of air will flow across each generator set. The goal in such installations is to have uniform flow across all units. There are several methods to achieve this, including:

- Proper location of room inlets and outlets
- Ducting.

With multiple set installations, additional care is required to make sure that hot expelled ventilation air from one set is not recirculated into the inlet of any other set. Examples of good and poor designs are shown in **Figure 6–56**.

Louver Operation

- Louvers shall open immediately upon generator set start–up for emergency / standby installations. In cold climates, louvers may open partially for combustion air only and controlled to modulate the temperature in the room.

Generator sets used for emergency or standby power are expected to handle full load immediately upon start–up. For these situations, make sure that the louvers are open and permit full air flow as soon as the set is started.

In cold climates, or when the generator set is operated or tested under light or no load, the full air flow through the site may result in overcooling. In these instances, louvers can be thermostatically controlled to keep the room temperature at an acceptable level and permit proper cooling. Be cautious of creating a negative pressure that may be a health hazard to generator set room personnel.

Ventilation air can be recirculated to modulate the temperature in the generator set room for cold climate operation. This will help the generator set warm up faster and keep fuel temperatures higher than the fuel cloud point. This recirculation system should be thermostatically controlled to maintain an appropriate temperature in the room. See **Figure 6–57**.

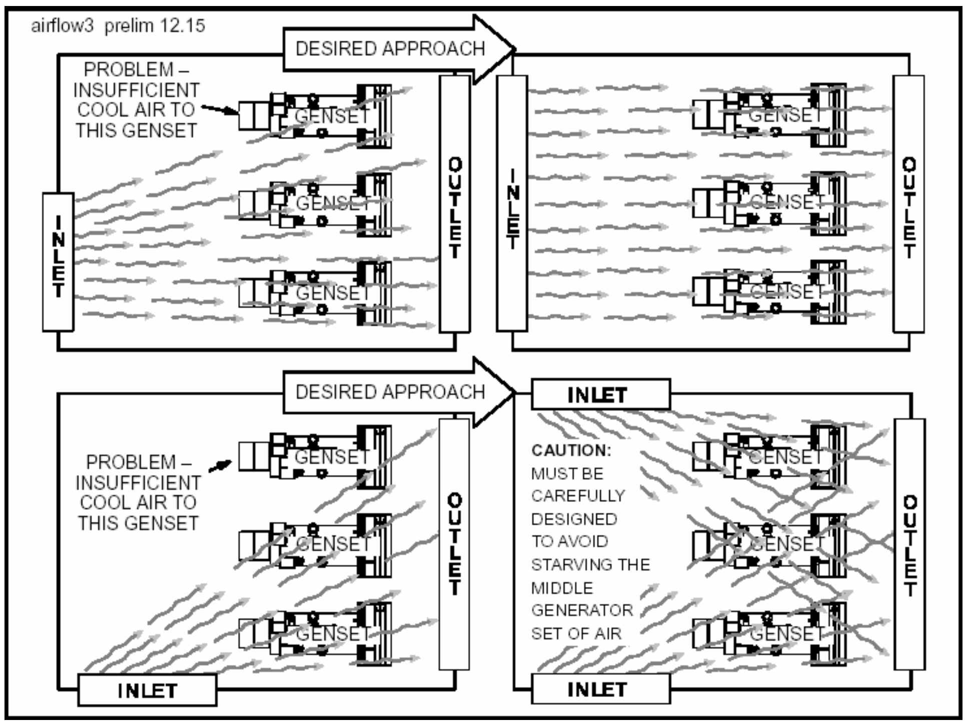


Figure 6–56. Multiple Generator Set Installation

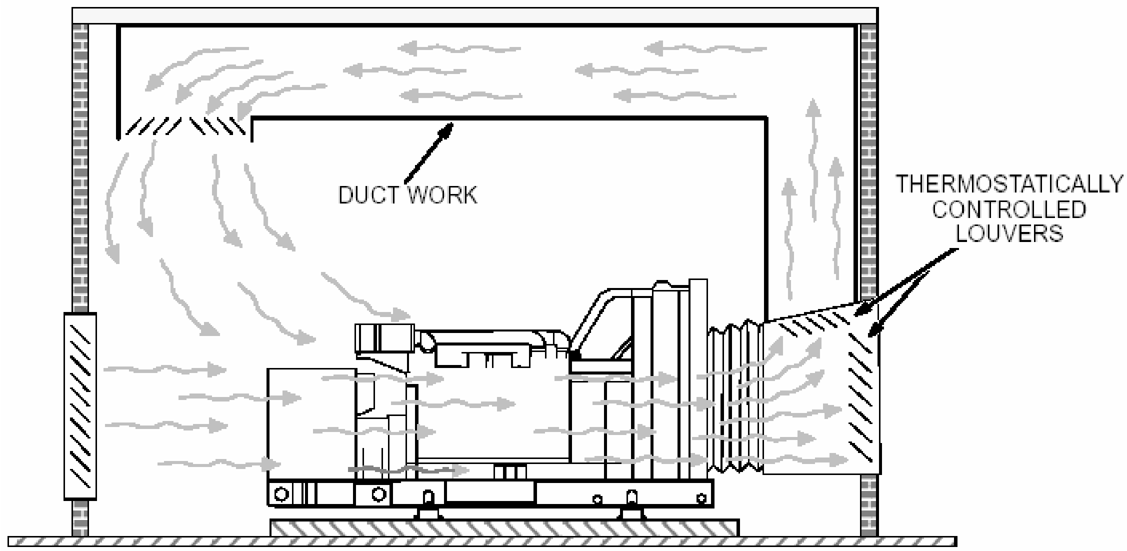


Figure 6–57. Room Recirculation System

Blocking Walls

- If a blocking wall is installed, it shall be located no closer than a distance equal to 1X the discharge louver height away from the building. For optimal performance, the wall should be located approximately 3X the discharge louver height away from the building.
- A turning vane and drain shall be included with any blocking wall installation.

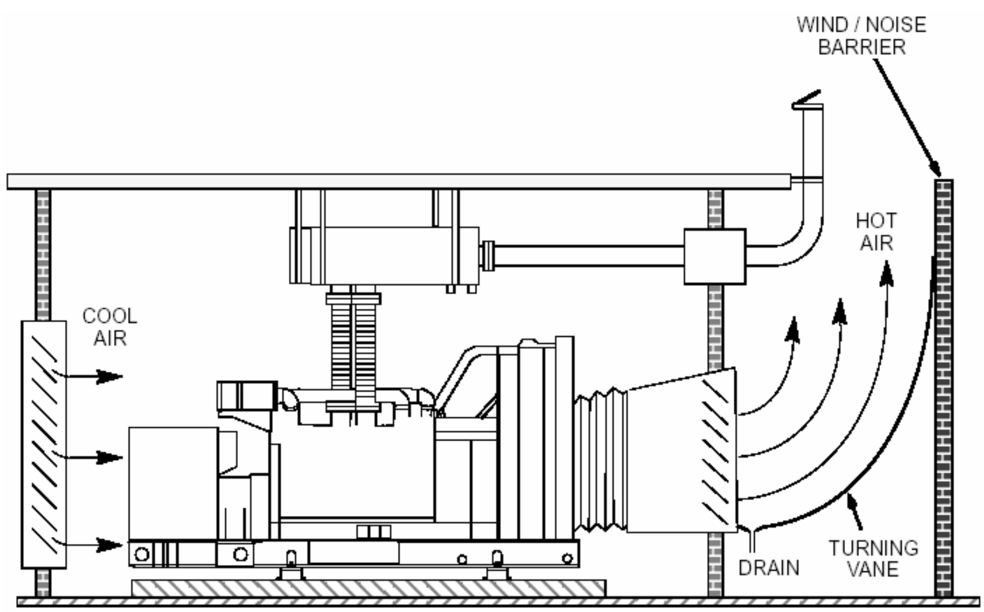


Figure 6–58. Blocking Wall and Turning Vane

Blocking walls can be constructed to prevent wind from blowing into the ventilation outlet. See **Figure 6–58**. The blocking wall should be located a distance at least equal to the radiator outlet away from the outlet. Better performance is achieved at a distance of approximately 3 times the radiator air outlet. A turning vane should be used to help reduce the restriction caused by the wall. A drain should be included with the turning vane to prevent rain water from entering the generator set room.

Ventilation Air Filtration

The generator set room must be kept free from dirt and debris. Ventilating air that is polluted with dust, fibers, salt, or other chemicals or materials may require special filters on the room ventilation system, engine, or alternator. If filters are used, their airflow restriction must be considered. For generator sets with set–mounted radiators, the filter restriction must be included in the total airflow restriction calculation. The total restriction, including filters, must remain below the total allowed restriction listed in the generator set technical information. (See **Airflow Restriction**, page 6–76.)

- If ventilation system filters are installed, a system for detecting plugged filters shall be in place.

If filters are used, there should be provisions in place to monitor their condition and detect clogged filters. Pressure drop indicators can be installed on the room ventilation system. Other solutions may also be acceptable.

Altitude and Ambient Temperature

Installation site altitude and temperature affect the density of the air surrounding the generator set, which in turn affects engine, alternator, and cooling system performance. For additional details, including a discussion of Limiting Ambient Temperature (LAT), see the **Generator Set Cooling Systems** and **Ambient Conditions** sections of this manual.

System Verification

Upon system installation, field tests should be performed to make sure that design criteria have been met.

Room Temperature Rise

The following procedure can be used to compare actual versus designed room temperature rise:

1. Run the generator set at full load (1.0 power factor is acceptable) long enough for the engine coolant or oil temperature to stabilize. This will take approximately 1 hour.
2. With the generator set still running at rated load, measure the air temperature of the generator set room at the air cleaner inlet.
3. Measure the outdoor air temperature in the same location that was used in Step 5 (from **Determining Airflow Requirements**, page 6–66.)
4. Calculate the temperature difference between the outdoors and the generator set room.
5. Verify that the design room temperature rise is not exceeded.

If the design room temperature rise is exceeded, more detailed testing of the facility or corrections in the system design will be required.

Airflow Restriction

Before the generator set is placed in service, the room airflow restriction should be measured to confirm that the system does not exceed the maximum allowed airflow restriction listed in the generator set technical information. Room airflow restriction should be measured according to **Figure 6–59** and **Figure 6–60**.

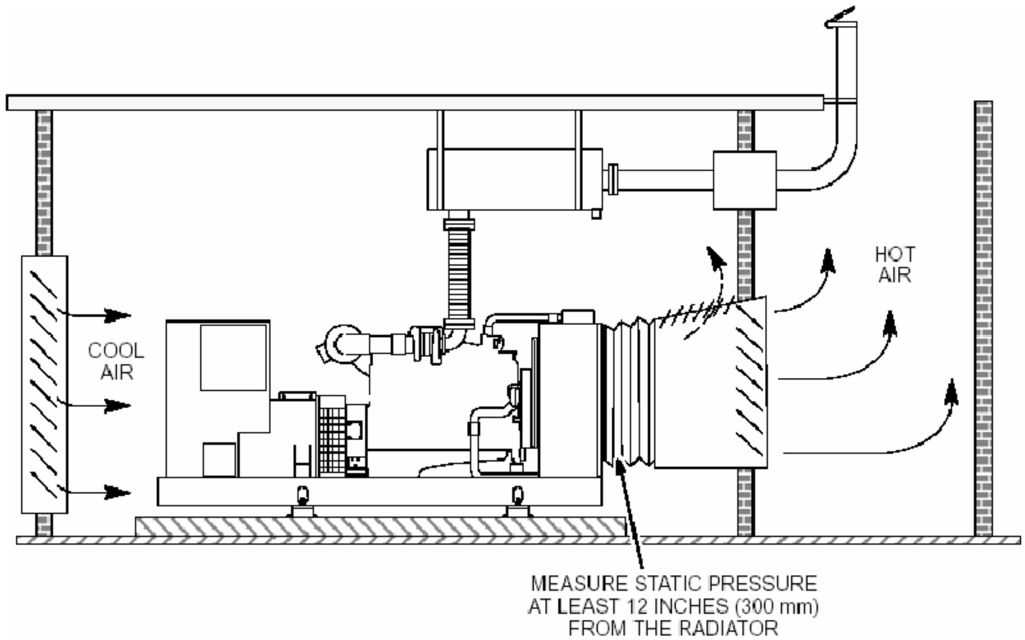


Figure 6-59. Measuring Airflow Restriction

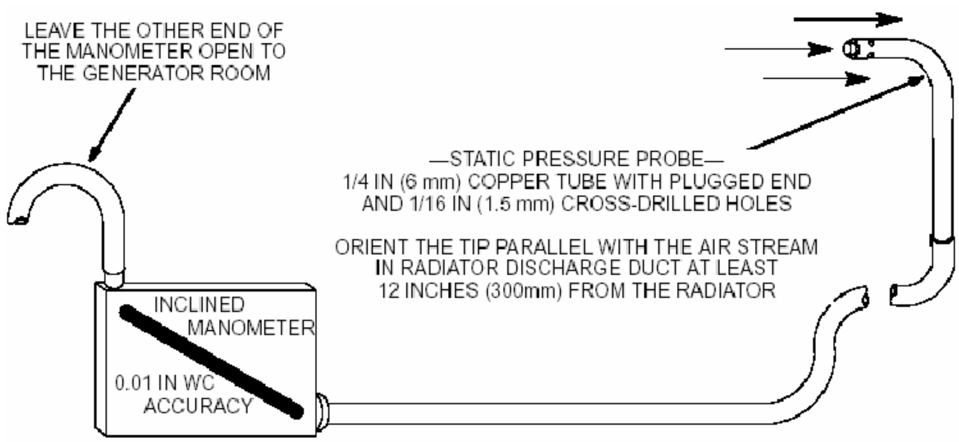


Figure 6-60. Measuring Airflow Restriction

General Guidelines

Ventilation of the generator room is necessary to remove the heat expelled from the engine, alternator and other heat generating equipment in the genset room, as well as to remove potentially dangerous exhaust fumes and to provide combustion air. Poor ventilation system design leads to high ambient temperatures around the generator set that can cause poor fuel efficiency, poor generator set performance, premature failure of components, and overheating of the engine. It also results in poor working conditions around the machine.

Selection of the intake and exhaust ventilation locations is critical to the proper operation of the system. Ideally, the inlet and exhaust allow the ventilating air to be pulled across the entire generator room. The effects of prevailing winds must be taken in to consideration when determining exhaust air location. These effects can seriously degrade skid-mounted radiator performance. If there is any question as to the wind speed and direction, blocking walls can be used to prevent wind blowing into the engine exhaust air outlet (See **Figure 6-61**). Care should also be taken to avoid ventilation exhausting into a recirculation region of a building that forms due to prevailing wind direction.

MIXTURE BASE		MIXTURE PERCENTAGES (ANTIFREEZE/WATER)					
		0/100	30/70	40/60	50/50	60/40	95/5
ETHYLENE GLYCOL	FREEZING POINT	32° F (0° C)	4° F (–16° C)	–10° F (–23° C)	–34° F (–36° C)	–65° F (–54° C)	8° F (–13° C)
	BOILING POINT	212° F (100° C)	220° F (104° C)	222° F (106° C)	226° F (108° C)	230° F (110° C)	345° F (174° C)
PROPYLENE GLYCOL	FREEZING POINT	32° F (0° C)	10° F (–12° C)	–6° F (–21° C)	–27° F (–33° C)	–56° F (–49° C)	–70° F (–57° C)
	BOILING POINT	212° F (100° C)	216° F (102° C)	219° F (104° C)	222° F (106° C)	225° F (107° C)	320° F (160° C)

Table 6–7. Freezing and Boiling Points vs. Concentration of Antifreeze

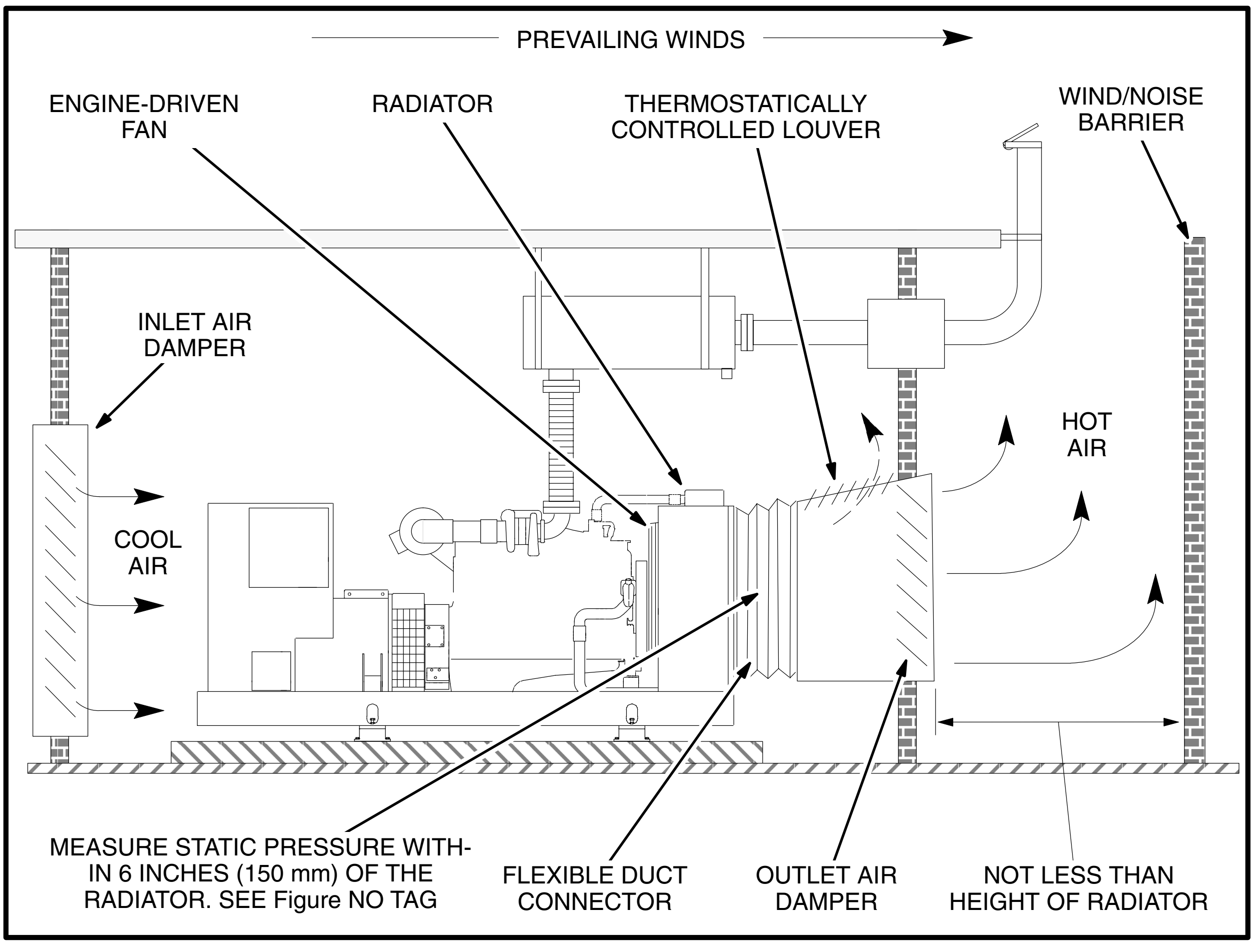


Figure 6–61. Factory-Mounted Radiator Cooling

Ventilating air that is polluted with dust, fibers, or other materials may require special filters on the engine and/or alternator to allow proper operation and cooling, particularly in prime power applications. Consult the factory for information on use of generator sets in environments that include chemical contamination.

Engine crankcase ventilation systems can exhaust oil–laden air into the generator set room. The oil can then be deposited on radiators or other ventilation equipment, impeding their operation. Use of crankcase ventilation breather traps or venting of the crankcase to outdoors is best practice.

Attention should be give to the velocity of intake air brought into the generator set room. If the air flow rate is too high, the generator sets will tend to pull rain and snow into the generator set room when they are running. A good design goal is to limit air velocity to between 500–700 f/min (150–220 m/min).

In cold climates, the radiator exhaust air can be recirculated to modulate the ambient air temperature in the generator set room. This will help the generator set warm up faster, and help to keep fuel temperatures higher than the cloud point of the fuel. If recirculation dampers are used, they should be designed to “fail closed”, with the main exhaust dampers open, so that the generator set can continue to operate when required. Designers should be aware that the generator set room operating temperature will be very close to the outdoor temperature, and either not route water piping through the generator set room, or protect it from freezing.

As ventilating air flows through an equipment room, it gradually increases in temperature, particularly as it moves across the generator set. See **Figure 6–62**. This can lead to confusion as to temperature ratings of the generator set and the overall system. Cummins Power Generation practice is to rate the cooling system based on the ambient temperature around the alternator. The temperature rise in the room is the difference between the temperature measured at the alternator, and the outdoor temperature. The radiator core temperature does not impact the system design, because radiator heat is moved directly out of the equipment room.

A good design goal for standby applications is to keep the equipment room at not more than 125° F (50° C). However, limiting generator set room temperature to 100° F (40° C) will allow the generator set to be provided with a smaller, less expensive skid–mounted radiator package, and eliminate the need for engine de–rating due to elevated combustion air temperatures[16]. Be sure that the design specifications for the generator set fully describe the assumptions used in the design of the ventilation system for the generator set.

The real question then becomes, “What is the maximum temperature of outdoor air when the generator set will be called to operate?” This is simply a question of the maximum ambient temperature in the geographic region where the generator set is installed.

In some areas of the northern United States for example, the maximum temperature is likely to not exceed 90° F. So, a designer could select the ventilation system components based on a 10° F temperature rise with a 100° F generator set cooling system, or based on a 35° F temperature rise with a 125° F generator cooling system.

The key to proper operation of the system is to be sure that the maximum operating temperature and temperature rise decisions are carefully made, and that the generator set manufacturer designs the cooling system (not just the radiator) for the temperatures and ventilation required.

The result of improper system design is that the generator set will overheat when ambient temperatures and load on the generator set is high. At lower temperatures or lower load levels the system may operate properly.

16 .Check the engine manufacturer’s data for information on derating practice for a specific engine. Information on Cummins Power Generation products is on the Power Suite.

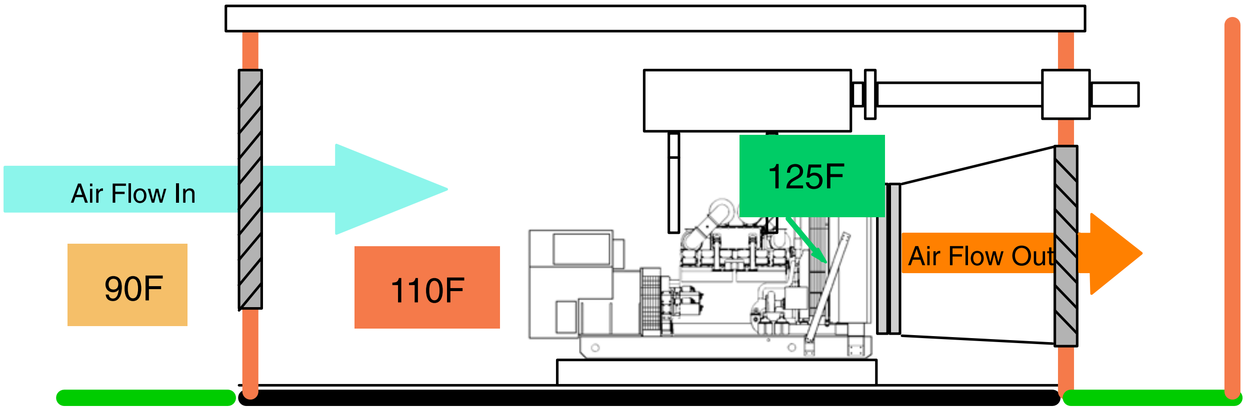


Figure 6–62. Typical Air Temperature Surrounding an Operating Genset

Air Flow Calculations

The required air flow rate to maintain a specific temperature rise in the generator room is described by the formula:

$$m = \frac{Q}{c_p \, T \, d}$$

Where: m = Mass flow rate of air into the room; ft^3/min (m^3/min)

Q = Heat rejection into the room from the genset and other heat sources; BTU/min (MJ/min).

c_p = Specific heat at constant pressure; 0.241 BTU/lb–° F (1.01×10^{-3} MJ/kg–° C).

ΔT = Temperature rise in the generator set room over outdoor ambient; ° F (° C).

d = Density of air; 0.0754 lb/ft^3 (1.21 kg/m^3).

Which can be reduced to:

$$m = \frac{Q}{0.241 \bullet 0.0754 \bullet \Delta T} = \frac{55.0Q}{\Delta T} \; (ft^3/min)$$

OR:

$$m = \frac{Q}{(1.01 \bullet 10^{3)} \bullet 1.21 \bullet \Delta T} = \frac{818Q}{\Delta T} \; (m^3/min)$$

The total airflow required in the room is the calculated value from this equation, plus the combustion air required for the engine[17].

In this calculation the major factors are obviously the heat radiated by the generator set (and other equipment in the room) and the allowable maximum temperature rise.

17 Data required for calculations for specific Cummins Power Generation generator sets can be found on the Cummins Power Suite. There may be significant differences in the variables used in these calculations for various manufacturer's products.

Since the heat rejection to the room is fundamentally related to the kW size of the generator set and that rating is controlled by building electrical load demand, the major decision to be made by the designer regarding ventilation is what allowable temperature rise is acceptable in the room.

Field Testing of Ventilation Systems

Since it is difficult to test for proper operation, one factor to view in system testing is the temperature rise in the room under actual operating conditions, vs. the design temperature rise. If the temperature rise at full load and lower ambient temperatures is as predicted, it is more probable that it will operate correctly at higher ambients and load levels.

The following procedure can be used for preliminary qualification of the ventilation system design:

1. Run the generator set at full load (1.0 power factor is acceptable) long enough for the engine coolant temperature to stabilize. This will take approximately 1 hour.
2. With the generator set still running at rated load, measure the ambient air temperature of the generator set room at the air cleaner inlet.
3. Measure the outdoor air temperature (in the shade).
4. Calculate the temperature difference between the outdoor temperature and the generator set room.
5. Verify that the design temperature rise of the generator room is not exceeded, and that the maximum top tank temperature of the engine is not exceeded.

If either the design temperature rise or top tank temperature is exceeded, more detailed testing of the facility or corrections in the system design will be required to verify proper system design.

Skid–Mounted Radiator Ventilation

In this configuration (**Figure 6–61**), the fan draws air through inlet air openings in the opposite wall and across the generator set and pushes it through the radiator which has flanges for connecting a duct to the outside of the building.

Consider the following:

- The location of the generator room must be such that ventilating air can be drawn directly from the outdoors and discharged directly to the outside of the building. Ventilation air should not be drawn from adjacent rooms. Exhaust should also discharge on the radiator air discharge side of the building to reduce the likelihood of exhaust gases and soot being drawn into the generator room with the ventilating air.
- Ventilating air inlet and discharge openings should be located or shielded to minimize fan noise and the effects of wind on airflow. When used, the discharge shield should be located not less than the height of the radiator away from the ventilation opening. Better performance is achieved at approximately 3 times the radiator height. In restricted areas, turning vanes will help to reduce the restriction caused by the barriers added to the system. When these are used, make provisions for precipitation run–off so that it is not routed into the generator room.
- The airflow through the radiator is usually sufficient for generator room ventilation. See the example calculation (under Air Flow Calculations in this section) for a method of determining the airflow required to meet room air temperature rise specifications.

- Refer to the recommended generator set Specification Sheet for the design airflow through the radiator and allowable airflow restriction. **The allowable air flow restriction must not be exceeded.** The static pressure (air flow restriction) should be measured, as shown in **Figures 6–61, 6–63, and 6–64**, to confirm, before the set is placed in service, that the system is not too restrictive This is especially true when ventilating air is supplied and discharged through long ducts, restrictive grilles, screens, and louvers.
- Rules of thumb for sizing ventilation air inlets and outlets have been applied or even published in the past but have more recently been largely abandoned. Due to large variation in louver performance and greater demands on installations for space, noise, etc., these rules of thumb have proven to be unreliable at best. Generally, louver manufacturers have charts of restriction versus airflow readily available. These charts combined with duct design and any other restriction can be easily compared to the published specifications for the generator set for a reliable method of determing acceptable restriction levels.
- For installations in North America, refer to the ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) publications for recommendations on duct design if air ducts are required for the application. Note that the inlet duct must handle combustion airflow (see the Specification Sheet) as well as ventilating airflow and must be sized accordingly.
- Louvers and screens over air inlet and outlet openings restrict airflow and vary widely in performance. A louver assembly with narrow vanes, for example, tends to be more restrictive than one with wide vanes. The effective open area specified by the louver or screen manufacturer should be used.
- Because the radiator fan will cause a slight negative pressure in the generator room, it is highly recommended that combustion equipment such as the building heating boilers not be located in the same room as the generator set. If this is unavoidable, it will be necessary to determine whether there will be detrimental effects, such as backdraft, and to provide means (extra large room inlet openings and/or ducts, pressurizing fans, etc.) to reduce the negative pressure to acceptable levels.
- In colder climates, automatic dampers should be used to close off the inlet and outlet air openings to reduce heat loss from the generator room when the generator set is not running. A thermostatic damper should be used to recirculate a portion of the radiator discharge air to reduce the volume of cold air that is pulled through the room when the set is running. The inlet and outlet dampers must fully open when the set starts. The recirculating damper should close fully at 60° F (16° C).
- Other than recirculating radiator discharge air into the generator room in colder climates, all ventilating air must be discharged directly outside the building. It must not be used to heat any space other than the generator room.
- A flexible duct connector must be provided at the radiator to prevent exhaust air recirculation around the radiator, to take up generator set movement and vibration, and prevent transmission of noise.

Note: Duct adapters or radiator shrouds may not be designed to support weight or structure beyond that of the flexible duct adatper. Avoid supporting additional weight/equipment with the duct adapter or radiator shroud without sufficient analysis of strength and vibration considerations.

- Typically a generator set with a Skid–Mounted radiator is designed for full–power cooling capability in an ambient temperature of 40° C while working against an external cooling air flow resistance of 0.50 inch WC (Point A, **Figure 6–64**). External airflow resistance is that caused by ducts, screens, dampers, louvers, etc. Operation in ambient temperatures higher than the design temperature can be considered (Point B, **Figure 6–64**, for example) if derating is acceptable and/or resistance to cooling airflow is less than the resistance under which the cooling capability was tested. (Less resistance means greater airflow through the radiator, offsetting the effect of higher air temperature on radiator cooling capability.) Close consultation with the factory is required to attain acceptable generator set cooling capability in an elevated ambient temperature.

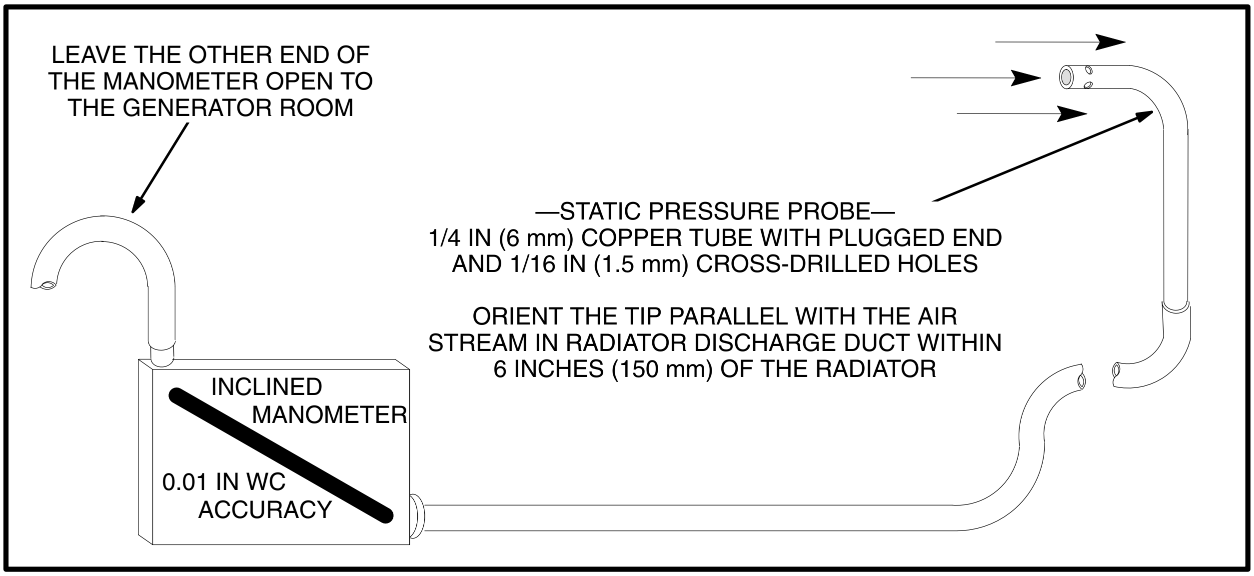


Figure 6–63. Recommended Instrumentation for Measuring Air Flow Restriction

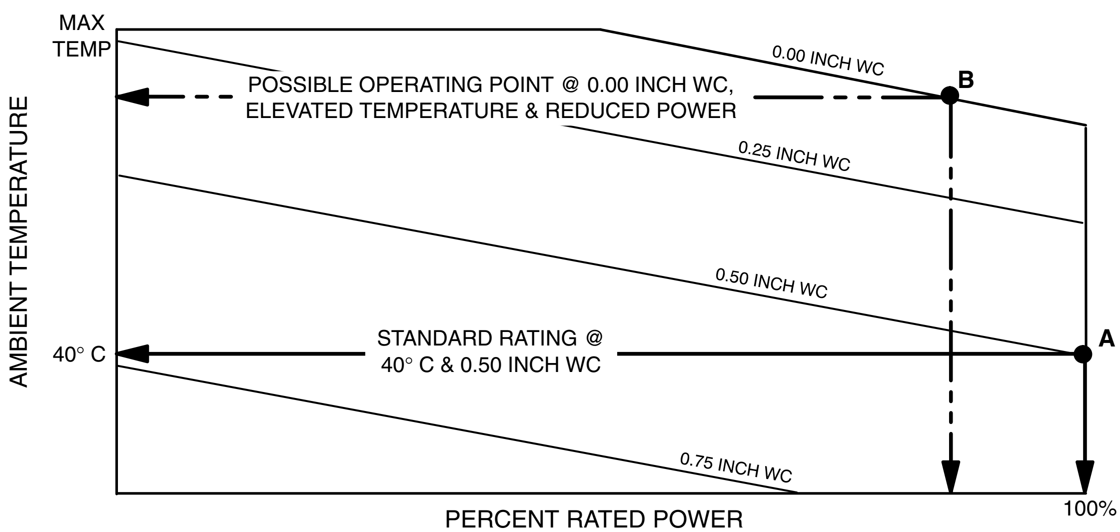


Figure 6–64. Figure Cooling Capability in Elevated Ambients

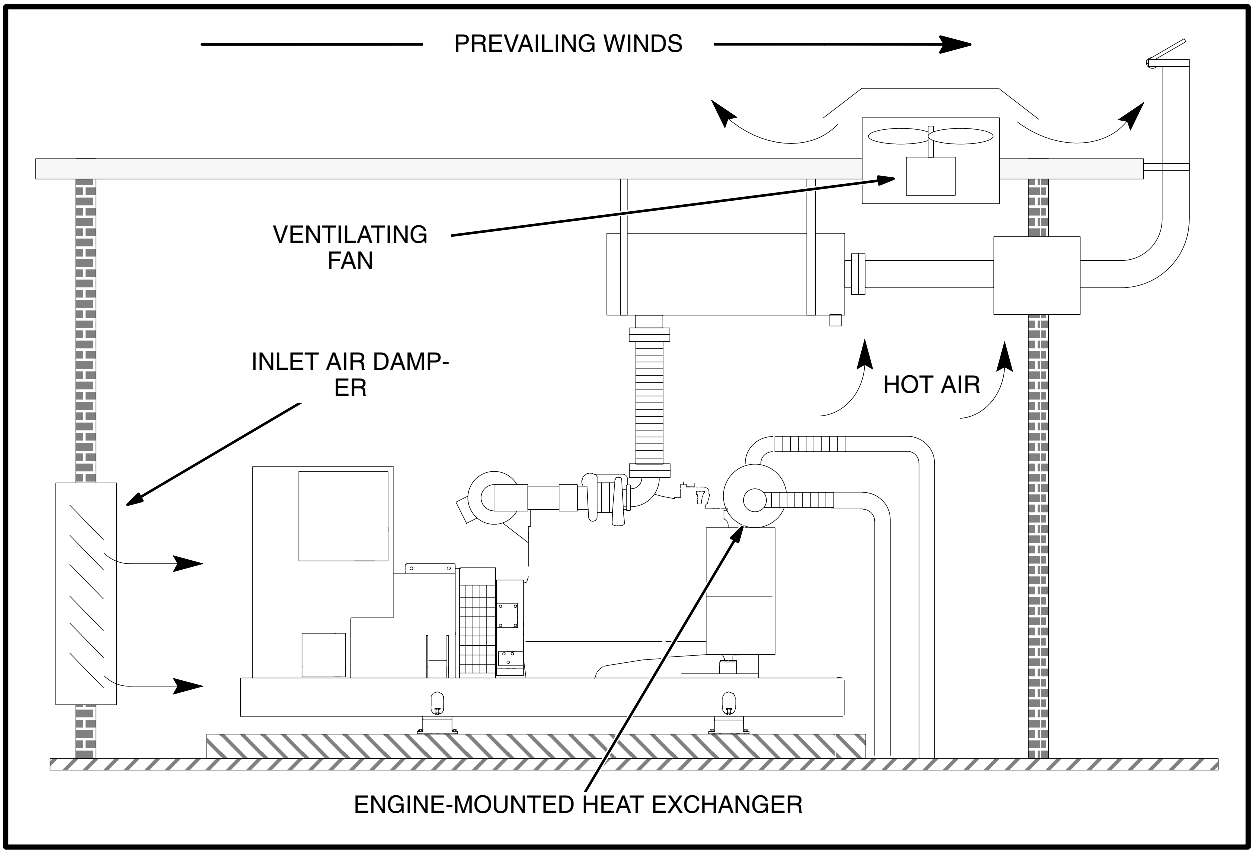


Figure 6–65. Ventilation for a Heat Exchanger Cooling System

Ventilating Heat Exchanger or Remote Radiator Applications

A heat exchanger (**Figure 6–65)**, or remote radiator cooling system might be selected because of noise considerations or because the air flow restriction through long ducts would be greater than that allowed for the engine–driven radiator fan. Consider the following:

- Ventilating fans must be provided for the generator room. The ventilating fans must have the capacity of moving the required flow of ventilating air against the airflow restriction. See the following example calculation for a method of determining the airflow required for ventilation.
- A remote radiator fan must be sized primarily to cool the radiator. Depending on its location, it might also be used to ventilate the generator room.
- The fan and air inlet locations must be such that the ventilating air is drawn forward over the set.

In general, remote cooling systems have more parasitic loads, so slightly less kW capacity is available from the generator set in those applications. Remember to add the parasitic loads to the total load requirements for the generator set.

Example Ventilating Air Flow Calculation

The recommended generator set Specification Sheet indicates that the heat radiated to the room from the generator set (engine and generator) is 4,100 BTU/min. The muffler and 10 feet of 5–inch diameter exhaust pipe are also located inside the generator room. Determine the airflow required to limit the air temperature rise to 30° F.

1. Add the heat inputs to the room from all sources. **Table 6–8** indicates that the heat loss from 5–inch exhaust pipe is 132 BTU/min per foot of pipe and 2,500 BTU/min from the muffler. Add the heat inputs to the room as follows:

Heat rejection from generator set	4,100
Heat from Exhaust Pipe–10 x 132	1,320
Heat from Muffler	2,500
Total Heat to Generator Room (BTU/Min)	7,920

PIPE DIAMETER INCHES (mm)	HEAT FROM PIPE BTU/MIN-FOOT (kJ/Min-Meter)	HEAT FROM MUFFLER BTU/MIN (kJ/Min)
1.5 (38)	47 (162)	297 (313)
2 (51)	57 (197)	490 (525)
2.5 (64)	70 (242)	785 (828)
3 (76)	84 (291)	1,100 (1,160)
3.5 (98)	96 (332)	1,408 (1,485)
4 (102)	108 (374)	1,767 (1,864)
5 (127)	132 (457)	2,500 (2,638)
6 (152)	156 (540)	3,550 (3,745)
8 (203)	200 (692)	5,467 (5,768)
10 (254)	249 (862)	8,500 (8,968)
12 (305)	293 (1,014)	10,083 (10,638)

Table 6–8. Heat Losses From Uninsulated Exhaust Pipes and Mufflers

2. The required airflow to account for heat rejection in the room is proportional to the total heat input divided by the allowable room air temperature rise (See Ventilation earlier in this section):

$$m = \frac{55 \bullet Q}{\Delta T} = \frac{55 \bullet 7920}{30} = 14{,}520 \text{ ft}^3\text{/min}$$

Fuel Supply

Diesel Fuel Supply

Diesel engine–driven generator sets are generally designed to operate on ASTM D975 number 2 diesel fuel. Other fuels may be suitable for short term operation, if the fuel meets the quality and physical characteristics described in **Table 6–9**. Consult engine manufacturer for use of other fuels.

Care should be taken in the purchase of fuel and filling of tanks to prevent ingress of dirt and moisture into the diesel fuel system. Dirt will clog injectors and cause accelerated wear in the finely machined components of the fuel system. Moisture can cause corrosion and failure of these components.

Diesel generator sets consume approximately 0.07 gal/hr per rated–kW (0.26 liters/hr per rated–kW) of fuel at full load, based on their standby rating. For example, a 1000 kW standby generator set will consume approximately 70 gal/hr (260 liters/hr) of fuel. The main fuel tank for a diesel generator set may be either a sub–base tank (mounted under the generator set skid), or a remote fuel tank. If the main (bulk) fuel tank is remote from the generator set, an intermediate (day) tank may be required to properly supply the generator set. There are considerable differences in engine capabilities between suppliers, so the fuel system design should be reviewed for the specific generator set installed at a site.

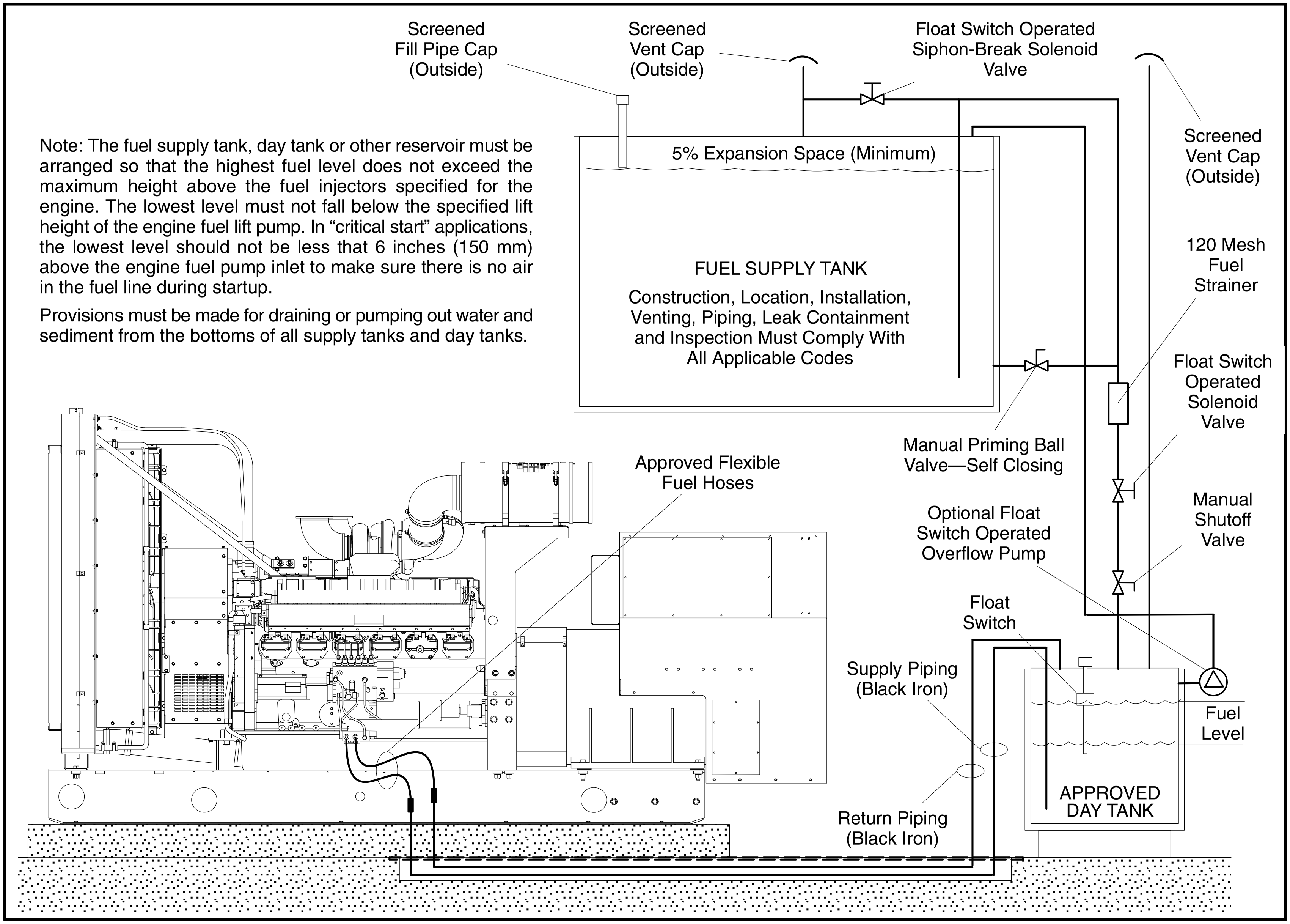
The primary advantage of sub–base fuel tanks is that the system can be factory designed and assembled to minimize site work. However, they may not be a practical (or possible) selection based on main fuel tank capacity requirements and code limitations, and the ability to access the tank for re–filling. When selecting a sub–base fuel tank, be aware that the generator set control system and other service maintenance points may be raised to an impractical height. This may require structures to be added to the installation to allow convenient service or meet operational requirements.

Because of the limitations of the mechanical fuel pumps on most engines, many installations that require remote main (bulk) fuel tanks will also require intermediate (day) tanks. The main tank may be either above the generator set, or below it, and each of these installations will require slightly different intermediate tank designs and fuel control systems.

Figures 6–66 and 6–67 illustrate typical diesel fuel supply systems.

PROPERTY	SPECIFICATIONS	GENERAL DESCRIPTION
Viscosity (ASTM D445)	1.3–1.5 centisokes (mm/sec) at 40° C (104° F)	The injection system works most effectively when the fuel has the proper "body" or viscosity. Fuels that meet the requirements of ASTM 1–D or 2–D fuels are satisfactory with Cummins fuel systems.
Cetane Number (ASTM D613)	42 minimum above C (32° F) 45 minimum below 0° C (32° F)	Cetane number is a measure of the starting and warm–up characteristics of a fuel. In cold weather or in service with prolonged low loads, a higher cetane number is desirable.
Sulphur Content (ASTM D129 or 1552)	Not to exceed 0.5 mass percent (see note)	Diesel fuels contain varying amounts of various sulphur compounds which increase oil acidity. A practical method of neutralizing high acids from higher sulphur is to change oil more frequently or use a higher TBN oil (TBN = 10 to 20) or both. The use of high sulphur fuel (above 0.5 mass percent)will result in sulfate formation in the exhaust gas under high load continuous conditions. High sulphur fuel will also shorten the life of certain components in the exhaust system, including the oxidation catalyst.
Active Sulphur (ASTM D130)	Copper strip corrosion not to exceed No.2 rating after three hours at 50° C (122° F)	Some sulphur compounds in fuel are actively corrosive. Fuels with a corrosion rating of three or higher can cause corrosion problems.
Water and Sediment (ASTM D1796)	Not to exceed 0.05 volume percent	The amount of water and solid debris in the fuel is generally classified as water and sediment. It is good practice to filter the fuel while it is being put into the fuel tank. More water vapor condenses in partially filled tanks due to tank breathing caused by temperature changes. Filter elements, fuel screens in the fuel pump, and fuel inlet connections on injectors, must be cleaned or replaced whenever they become dirty. These screens and filters, in performing their intended function, will become clogged when using a poor or dirty fuel and will need replacing more often.
Carbon Residue (Ramsbottom, ASTM D254 or Conradson, ASTM D189)	Not to exceed 0.35 mass percent on 10 volume percent residuum	The tendency of a diesel fuel to form carbon deposits in an engine can be estimated by determining the Ramsbottom or Conradson carbon residue of the fuel after 90 percent of the fuel has been evaporated.
Density (ASTM D287)	42–30 degrees API gravity at 60° F (0.816–0.876 g/cc at 15° C)	Gravity is an indication of the high density energy content of the fuel. A fuel with a high density (low API gravity) contains more BTUs per gallon than a fuel with a low density (higher API gravity). Under equal operating conditions, a higher density fuel will yield better fuel economy than a low density fuel.
Cloud Point (ASTM D97)	6° C (10° F) below lowest ambient temperature at which fuel expected to operate.	The cloud point of the fuel is the temperature at which crystals of paraffin wax first appear. Crystals can be detected by a cloudiness of the fuel. These crystals will cause a filter to plug.
Ash (ASTM D482)	Not to exceed 0.02 mass percent (0.05 percent with lubricating oil blending)	The small amount of non–combustible metallic material found in almost all petroleum products is commonly called ash.
Distillation (ASTM D86)	The distillation curve must be smooth and continuous.	At least 90 percent of the fuel must evaporate at less than 360° C (680° F). All of the fuel must evaporate at less than 385° C (725° F).
Acid Number (ASTM D664)	Not to exceed 0.1 Mg KOH per 100ML	Using fuel with higher acid numbers can lead to higher levels of wear than is desirable. The total acid number is located in ASTM D664
Lubricity	3100 grams or greater as measured by US Army scuffing BOCLE test or Wear Scar Diameter (WSD) less than 0.45mm at 60° C (WSD less than 0.38mm at 25° C) as measured by HFRR method.	Lubricity is the ability of a liquid to provide hydrodynamic and/or boundary lubrication to prevent wear between moving parts.
NOTE: Federal or local regulations may require a lower sulphur content than is recommended in this table. Consult all application regulations before selecting a fuel for a given engine application.		

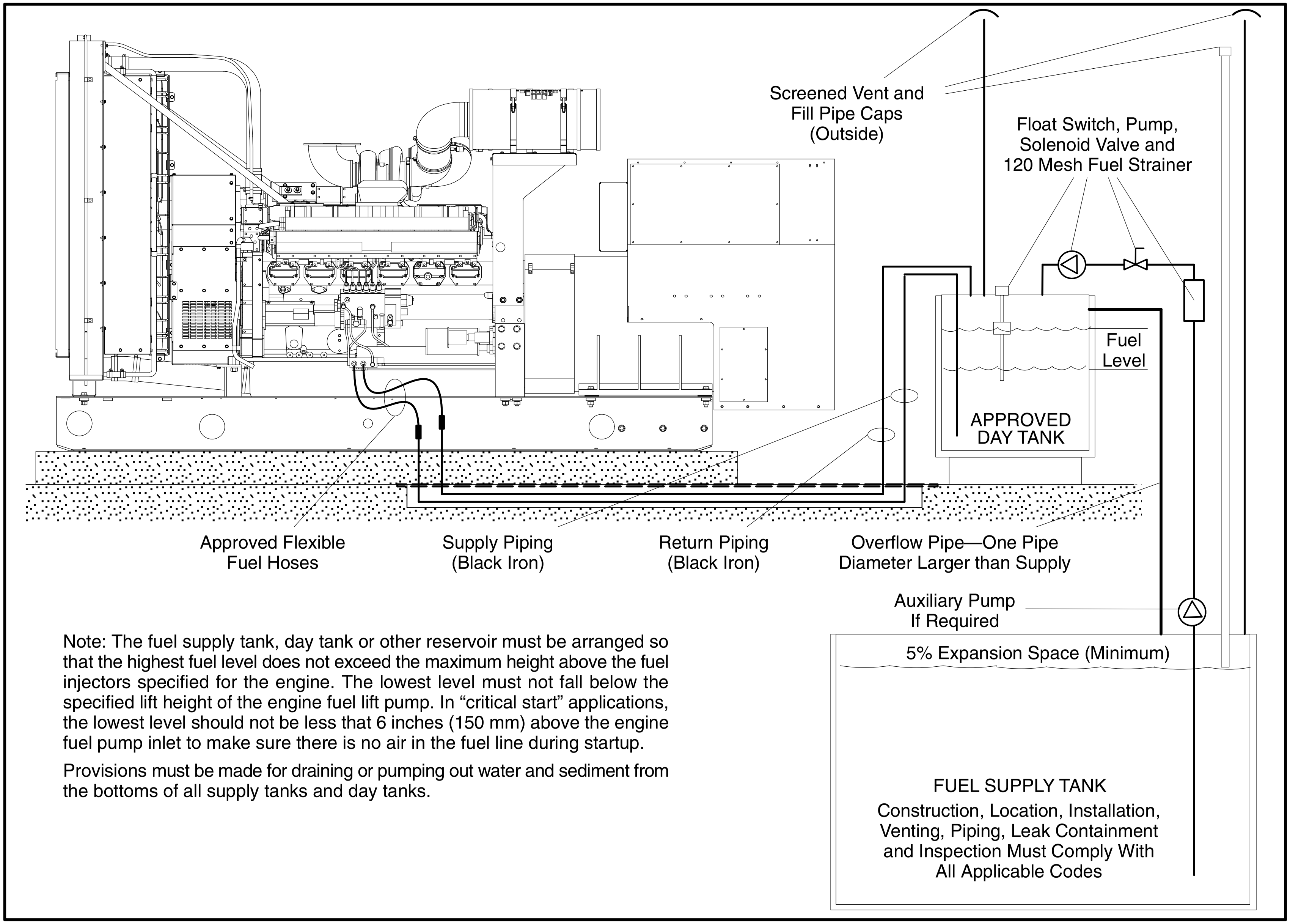
Table 6–9. Diesel Fuel Specifications



Note: The fuel supply tank, day tank or other reservoir must be arranged so that the highest fuel level does not exceed the maximum height above the fuel injectors specified for the engine. The lowest level must not fall below the specified lift height of the engine fuel lift pump. In “critical start” applications, the lowest level should not be less that 6 inches (150 mm) above the engine fuel pump inlet to make sure there is no air in the fuel line during startup.

Provisions must be made for draining or pumping out water and sediment from the bottoms of all supply tanks and day tanks.

Figure 6–66. Typical Fuel Supply System—Supply Tank Above Generator Set



Note: The fuel supply tank, day tank or other reservoir must be arranged so that the highest fuel level does not exceed the maximum height above the fuel injectors specified for the engine. The lowest level must not fall below the specified lift height of the engine fuel lift pump. In “critical start” applications, the lowest level should not be less that 6 inches (150 mm) above the engine fuel pump inlet to make sure there is no air in the fuel line during startup.

Provisions must be made for draining or pumping out water and sediment from the bottoms of all supply tanks and day tanks.

Figure 6–67. Typical Fuel Supply System—Supply Tank Below Generator Set

The following should be considered when designing and installing any diesel fuel supply system:

- Fuel supply tank capacity, construction, location, installation, venting, piping, testing, and inspection must comply with all applicable codes and their local interpretation[18]. Local environmental regulations generally require secondary containment (called a “rupture basin”, “dike”, or “bund”) to prevent leaking fuel from entering the soil or the sewer system. The secondary containment area will normally include features to sense and sound an alarm when the main tank is leaking.
- Location should be chosen with consideration for accessibility for refilling and whether supply lines will need to be heated (in cold climates).
- The fuel supply tank must hold enough fuel to run the set for the prescribed number of hours[19] without refueling. Tank sizing calculations can be based on the hourly fuel consumption rates, tempered with the knowledge that full load operation of most generator sets is rare. Other considerations for tank sizing include the duration of expected power outages vs. availability of fuel deliveries and the storage life of the fuel. The storage life for diesel fuel is 1–1/2 to 2 years, when properly maintained.
- Fuel supply tanks must be adequately vented to prevent pressurization. There may be both primary and emergency venting requirements in a tank, depending on local codes and interpretations. They also must have provisions for manually draining or pumping out water and sediment, and have at least a five–percent expansion space to prevent spillage when the fuel warms up.
- The fuel lift pump, day tank transfer pump or float valve seat should be protected from fuel supply tank debris by a pre–filter or sediment bowl with a 100 to 120 mesh element.
- For emergency power systems, codes might not permit the fuel supply to be used for any other purpose, or may specify a draw–down level for other equipment that guarantees the fuel supply for emergency power use.
- The Cetane rating of No. 2 heating oil is not high enough for dependable starting of diesel engines in cold weather. Therefore, separate supply tanks for emergency power and building heating systems might be required.
- Separate fuel return lines to the day tank or supply tank must be provided for each generator set in a multiple–set installation to prevent pressurizing the return lines of idle sets. Also, a fuel return line must not include a shutoff device. Engine damage will occur if the engine is run with the line shut off.
- A day tank is required whenever pipe friction and/or supply tank elevation, either below the fuel pump inlet or above the fuel injectors, would cause an excessive fuel inlet or return restriction. Some generator set models are available with an integral skid–mounted or sub–base day tank.

NOTE: Where generator sets are paralleled or must satisfy short emergency start–time requirements, it is a requirement that a fuel tank or reservoir be located such that the lowest possible fuel level is not less than 6 inches (150 mm) above the fuel pump inlet. This will prevent air from accumulating in the fuel line while the set is not running, eliminating the period during startup when the air has to be purged. Options are available on some models for eliminating this requirement.

18 **US CODE NOTE:** In North America, NFPA Standards No. 30 and No. 37 are typical.

19 **US CODE NOTE:** NFPA110 defines number of required operating hours as the *Class* of an installation. Typical requirements are 2 hours if for emergency egress from the building, 8 hours for the duration of most outages.

- Day tank fuel temperature limits may be exceeded in some applications when the warm fuel from the engine is returned to the day tank. As fuel temperature increases, fuel density and lubricity decrease, reducing maximum power output and lubrication of fuel handling parts such as pumps and injectors. One solution is to pipe the fuel back to the supply tank rather than to the day tank. Other designs might require a fuel cooler to reduce the return fuel temperature to a safe level for return to the day tank. Consult the engine manufacturer for more information on the engine used, and its return fuel requirements[20].
- The day tank fuel transfer pump capacity and supply piping should be sized on the basis of the maximum fuel flow indicated on the recommended generator set Specification Sheet.
- Use **Table 6–9** as a guide for diesel fuel selection to obtain best performance.
- All fuel systems should have provisions for containment of fuel if a tank leaks, and also for situations where it is "overfilled".
- Consider means to manually fill tanks if auto tank filling system fails.
- The supply pump from the main tank may be a duplex type to improve system reliability.
- Local fire codes may include specific requirements for the generator set, such as means to prevent fuel flow into the generator set room if a fire is sensed, and means to return fuel to the main tank if a fire occurs in the generator set room.

Diesel Fuel Piping

- Diesel fuel lines should be constructed from black iron pipe. Cast iron and aluminum pipe and fittings must not be used because they are porous and can leak fuel. Galvanized fuel lines, fittings, and tanks must not be used because the galvanized coating is attacked by the sulfuric acid that forms when the sulfur in the fuel combines with tank condensate, resulting in debris that can clog fuel pumps and filters. Copper lines should not be used because fuel polymerizes (thickens) in copper tubing during long periods of disuse and can clog fuel injectors. Also, copper lines are less rugged than black iron, and thus more susceptible to damage.

Note: Never use galvanized or copper fuel lines, fittings or fuel tanks. Condensation in the tank and lines combines with the sulfur in the diesel fuel to produce sulfuric acid. The molecular structure of the copper or galvanized lines or tanks reacts with the acid and contaminates the fuel.

- Approved flexible fuel hose must be used for connections at the engine to take up generator set movement and vibration.
- Piping from a day tank to the engine should run "down hill" all the way from the tank to the engine, with no overhead loops that can allow air to be entrained in the system.
- Fuel system piping should be properly supported to prevent vibration and breakage due to vibration. The piping should not run close to heating pipes, electrical wiring, or engine exhaust system components. The piping system design should include valves at appropriate locations to allow isolation of system components for repair without draining the entire fuel system.
- Piping systems should be regularly inspected for leaks and general condition. The piping system should be flushed before operation of the engine to remove dirt and other impurities that could damage the engine. Use of plugged "T" connections rather than elbows allows for easier cleaning of the piping system.

20 In general, Cummins engines may be installed with the fuel return plumbed to the day tank. The location of the return line varies with the engine provided.

- The engine manufacturer's data indicates the maximum fuel inlet and return restrictions, the maximum fuel flow, supply and return, and the fuel consumption. **Table 6–10** indicates minimum hose and pipe sizes for connections to a supply tank or day tank when it is within 50 feet (15 meters) of the set and at approximately the same elevation.

Hose and pipe size should be based on the maximum fuel flow rather than on the fuel consumption. It is highly recommended that the fuel inlet and return restrictions be checked before the generator set is placed in service.

Max Fuel Flow Rate GPH (L/hr)	Flex Hose No.*	NPS Pipe Size (in)	DN Pipe Size (mm)
Less than 80 (303)	10	½	15
81–100 (304–378)	10	½	15
101–160 (379–604)	12	¾	20
161–230 (605–869)	12	¾	20
231–310 (870–1170)	16	1	25
311–410 (1171–1550)	20	1–1/4	32
411–610 (1550–2309)	24	1–1/2	40
611–920 (2309–3480)	24	1–1/2	40

* Generic fuel hose suppliers' size specification.

Table 6–10. Minimum Fuel Hose and Pipe Sizes; Up to 50 Feet (15 Meters) Equivalent Length.

Sub–Base Fuel Tank

When a generator set is mounted on a sub–base fuel tank, the vibration isolators must be installed between the generator set and the fuel tank. The fuel tank must be able to support the weight of the set and resist the dynamic loads. It is required that the tank be mounted such that an air space is provided between the bottom of the tank and the floor underneath to reduce corrosion and permit visual inspections for leaks.

Day Tanks

When an intermediate day tank is required in an application, it is typically sized for approximately 2 hours of operation for the generator set at full load. (Subject to code limitations for fuel in the generator set equipment room.) Multiple generator sets may be fed from one day tank, but it is preferred that there be one day tank for each generator set in the system. The day tank should be located as close to the generator set as is practical. Position the tank to allow for manually filling the tank, should it become necessary.

The height of the day tank should be sufficient to put a positive head on the engine fuel pump. (Minimum level in tank not less than 6 inches [150 mm] above engine fuel inlet.) The maximum height of fuel in the day tank should not be sufficient to put a positive head on the engine fuel return lines.

Fuel return line location in the day tank is different depending on the type of engine used. Some engines require the fuel to be returned above the maximum tank level, others require fuel to be returned to the tank at the bottom (or below the minimum tank level). The engine manufacturer supplies these specifications.

Important features, either required or desired, of day tanks include:

- Rupture basin or bund. (Option, but required by law in many areas.)
- Float switch used for tank filling to control: a solenoid valve, if the bulk tank is above the day tank, or a pump, if the bulk tank is below the day tank.
- Vent pipe, same size as fill, routed to highest point in system.
- Drain valve.

- Level gage or sight glass.
- Low level alarm (option).
- High level float switch to control: the solenoid, if the bulk tank is above the day tank, or the pump control, if the bulk tank is below the day tank.
- Overflow to bulk tank if the tank is below the day tank.

Local laws and standards often control day tank construction as well as federal codes so it is essential to check with the local authority.

Gaseous Fuel Supply

See section 2 of this manual for information regarding general advantages and disadvantages of gaseous fuel systems compared to other available alternatives.

Gaseous fueled generator sets (also called “spark–ignited generator sets”) may utilize natural gas or liquid–propane (LP) gas, or both. Dual fuel systems with natural gas as primary fuel and propane as a backup can be used in seismic risk areas and where there is concern that a natural event could disrupt a public utility gas system.

Regardless of the fuel used, the primary factors in successful installation and operation of a gas fuel system are:

- The gas supplied to the generator set must be of acceptable quality.
- The gas supply must have sufficient pressure. Care must be taken to be sure that the gas supply *at the generator set*, not just at the source, is of proper pressure for operation. The specified pressure must be available while the generator set is running at full load.
- The gas must be supplied to the genset in sufficient volume to support operation of the generator set. This is normally a matter of selecting fuel line size to be large enough to transport the volume of fuel needed. For LP vapor–withdrawal fuel systems the size and temperature of the fuel tank also affects this requirement.

Failure to meet the minimum requirements of the generator set in these areas will result in the inability of the generator set to operate, or inability to carry rated load, or poor transient performance.

Gaseous Fuel Quality

Gaseous fuels are actually a mixture of several different hydrocarbon gases such as methane, ethane, propane, and butane; other gaseous elements such as oxygen and nitrogen; vaporized water; and various contaminants, some of which are potentially damaging to an engine over time. The quality of the fuel is based on the amount of energy per unit volume in the fuel and the amount of contaminants in the fuel.

Energy Content

One of the most important characteristics of the gaseous fuel used in a generator set is the heat value of the fuel. The heat value of a fuel describes how much energy is stored in a specific volume of the fuel. Gaseous fuel has a low heat value (LHV) and a high heat value (HHV). The low heat value is the heat available to do work in an engine after the water in the fuel is vaporized. If the low heat value of a fuel is too low, even if a sufficient volume of fuel reaches the engine, the engine will not be able to maintain full output power, because sufficient energy is not available in the engine to convert to mechanical energy. If the LHV is below 905 BTU/ft^3 the engine may not produce rated power at standard ambient temperature conditions.

If the local fuel has a higher energy content than 1000 BTU/ft^3, the actual flow requirements in cu ft/min will be lower and the pressure requirements drop slightly. Conversely if the local fuel has a lower energy content than 1000 BTU/ ft^3, the actual flow requirements in ft^3/min will be higher and a higher minimum supply pressure will be needed to meet published performance for any given generator set

Each engine may have slightly different performance characteristics based on the type of fuel provided, due to differences in engine compression ratio, and whether the engine is naturally aspirated or turbocharged.

Pipeline Natural Gas

The most common fuel for generator sets is called “Pipeline natural gas”. In the US, “dry pipeline natural gas” has specific qualities, based on federal requirements. In other countries, pipeline gas may vary in content, so fuel characteristics should be verified prior to use with a generator set. US pipeline gas is a mixture composed of approximately 98% methane and ethane with the other 2% being hydrocarbons such as propane and butane, nitrogen, carbon dioxide, and water vapor. “Dry” means that it is free of liquid hydrocarbons such as gasoline, but NOT that it is free of water vapor. Dry pipeline gas typically has a LHV of 936 BTU/ft^3, and a HHV of 1,038 BTU/ft^3.

Field Gas

The composition of “Field natural gas” varies considerably by region and by continent. Careful analysis is necessary prior to using field natural gas in an engine. Field natural gas can contain “heavier” hydrocarbon gases such as pentane, hexane, and heptane, which may require derating of the output of the engine. Other contaminants, such as sulfur, may also be present in the fuel. A typical field gas might have a LHV of 1203 BTU/ft^3, and a HHV of 1,325 BTU/ft^3.

Propane (LPG)

Propane is available in two grades, either commercial, or special duty. Commercial propane is used where high volatility is required. Not all spark–ignition engines will operate acceptably with this fuel due to its volatility. Special duty propane (also called HD5) is a mixture of 95% propane and other gases such as butane that allow better engine performance due to the reduction pre–ignition due to reduced volatility. Special duty propane fuel gas that meets the ASTM D 1835 specification for special–duty propane (equivalent to HD–5 propane of Gas Producers Association Standard 2140) is suitable for most engines. Propane has a LHV of approximately 2,353 BTU/ft^3, and an HHV of 2,557 BTU/ft^3. The higher heating value of the fuel necessitates mixing of different volumes of air in the fuel system for propane vs. natural gas applications, so dual fuel engines essentially have two fuel arrangements for this purpose.

Contaminants

The most harmful contaminants in gaseous fuels are water vapor and sulfur.

Water vapor is damaging to an engine because it may cause uncontrolled burning, pre–ignition, or other effects that can damage an engine. Liquid vapor or droplets must be removed from the fuel prior to entry into the engine by use of a “dry filter” that is mounted in the fuel system prior to the primary fuel pressure regulator. The dew point of fuel gas should be at least 20F (11C) below the minimum ambient temperature at the installation site.

Sulfur and hydrogen sulfides will cause corrosion and serious damage to an engine over a relative short period of time. Different engines have different levels of tolerance to sulfur contamination, and some engines simply should not be operated with fuel that contains significant sulfur content. Contact the engine manufacturer for approval of specific engines with specific fuels. The effects of sulfur in the fuel can be counteracted in part by use of high–ash natural gas lubricating oils. In general, engines should not be operated with fuels in excess of 10 parts per million (ppm).

Certain fuels, such as those derived from land fill applications, can have useful chemical energy content, but very high sulfur levels (>24 ppm). These fuels are often termed “sour gas”. If this fuel is scrubbed of the sulfur content, it can be used as a fuel for many engines, provided that it has sufficient BTU content.

Fuel Analysis

The gaseous fuel supplier can provide a fuel analysis that describes the chemical makeup of the fuel to be provided. This fuel analysis can be used to be certain that the fuel is suitable for use in the specific engine proposed for a specific application, and also to verify that the BTU content of the fuel is sufficient to provide necessary kW output of the machine. Gas suppliers may change the pipeline natural gas composition without notice, so there is no long–term guarantee of performance, but the process of evaluation of the fuel can be briefly described as:

1. List the percent of each gas constituent in the fuel.
2. Calculate the percent of the total fuel that is combustible. The combustible portion of the fuel is 100% less the inert component percentages. Inert components include oxygen, carbon dioxide and water vapor.
3. Calculate the percent of each combustible component of the fuel.
4. Verify acceptability of the fuel by checking the percent of each combustible element vs. the recommendations of the engine manufacturer.

   For example, for a gas analysis of:

   90% Methane
   6% Ethane
   2% Hydrogen
   1% Normal Pentane
   1% Nitrogen

   - Total percent inert elements = 1%.
   - Total combustible =100%–1% = 99%.
   - % Methane = 90%/99% = 91%.
   - % Ethane = 6%/99% = 6.1%.
   - % Hydrogen = 2%/99% = 2%.
   - % Normal Pentane = 1%/99% = 1%.

   See **Table 6–11** for a typical listing of Maximum Permissible Combustibles in Cummins Gas generator sets. Note that in this example, the analysis shows the fuel will be acceptable for a lower compression ratio engine (typically around 8.5:1) but not for a higher compression engine. A higher compression engine will have more stringent fuel composition requirements but may operate satisfactorily with a derating of its output – consult the engine manufacturer.
5. Verify the rating of the generator set based on use of the proposed fuel.

The total BTU content of the fuel will determine the rating of the generator set when using fuel of a specific composition. If any component of the fuel has more than the specific value allowed derating will be required. Consult the engine manufacturer for fuel requirements and derating instructions.

Note that the fuel derating and the altitude/temperature derating[21] are not additive. Only the maximum value of the fuel derate or the altitude/temperature derate need be applied.

Turbocharged engines have unique fuel composition requirements due to higher cylinder pressures. To avoid problems with pre–ignition or detonation, power output derating is required if propane and/or Iso–Butane content exceed the percentages listed in **Table 6–12**.

21 Consult the engine or generator set manufacturer for temperature/altitude derating factors.

	8.5:1 Compression Ratio	10.5:1 Compression Ratio
Methane (C_1)	100	100
Ethane (C_2)	100	100
Propane (C_3)	10	2
ISO–Butane (IC_4)	7	0.2
Hydrogen (H_2)	7	trace
Normal Butane (NC_4)	3	0.2
ISO–Pentane (IC_5)	3	0.2
Normal Pentane (NC_5)	1	0.1
Hexane (C_6)	1	0.1
Heptane (C_7)	1	0.1

Table 6–11. Maximum Allowable Percentages for Engine Fuel Combustibles

	8.5:1 Compression Ratio	10.5:1 Compression Ratio
Methane	NA	NA
Ethane	NA	NA
Propane	5%	*
Iso-butane	2%	*
*High compression ratio turbocharged engines cannot consume any propane or iso–butane.		

Table 6–12. Maximum Allowable Percentages of Constituent Gases Before Derating Turbocharged Engines

Generator Set Fuel System Design

Figure 6–68 illustrates the typical gas line components in an automatic–transfer, dual–fuel system (natural gas and LPG). Single fuel systems (natural gas or LPG) use the noted portions of the components on this drawing. Not shown is the LPG vaporizer supplied with Cummins Power Generation generator sets equipped for liquid withdrawal of LPG (engine–mounted on outdoor sets only). Service pressure regulators, dry gas filters and manual shutoff valves are typically provided by the installer but are available as accessories from Cummins Power Generation.

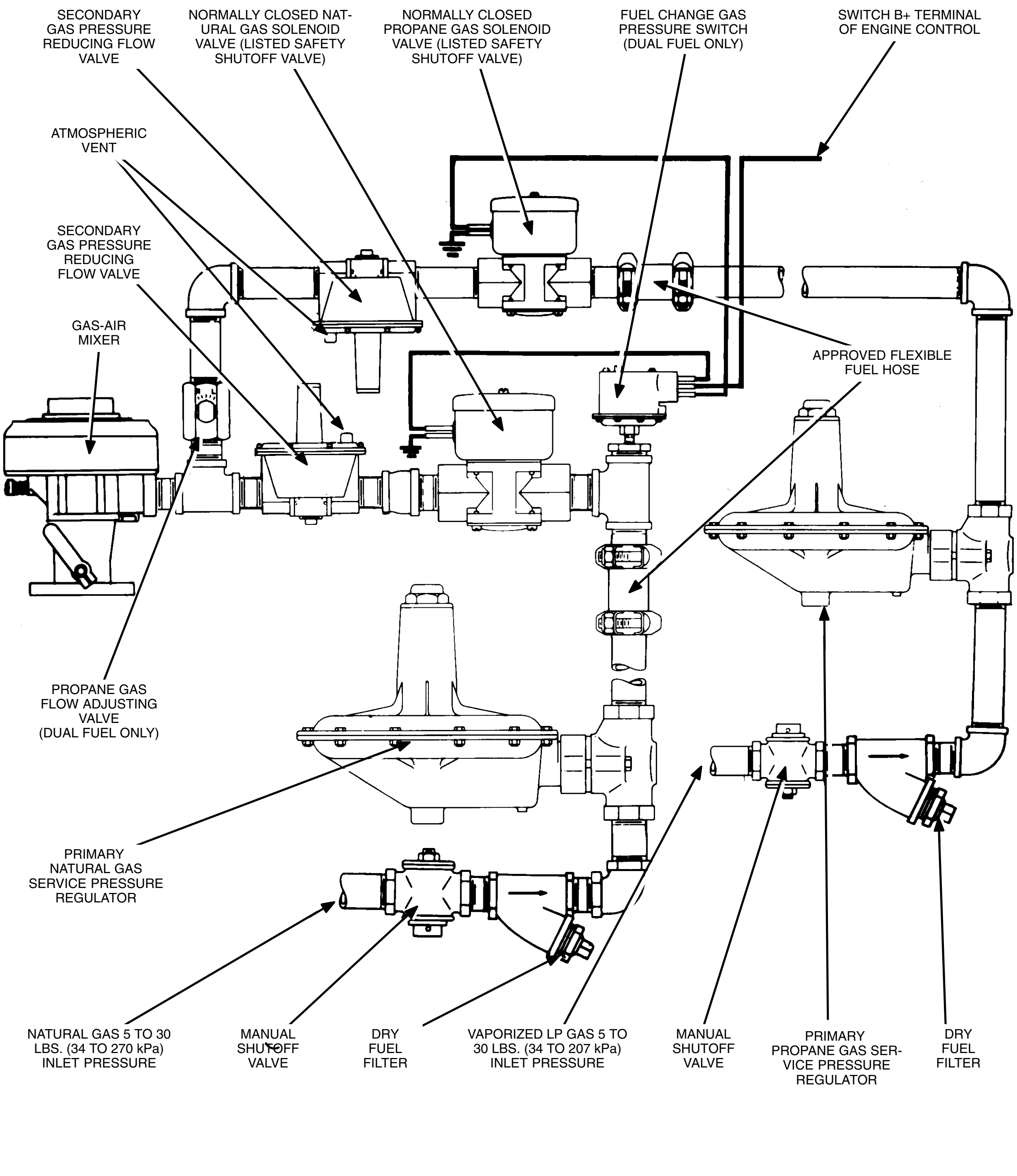
Site Fuel System Design

The following should be considered when installing a natural gas and/or LPG fuel system:

- Gaseous–fuel supply system design, materials, components, fabrication, assembly, installation, testing, inspection, operation and maintenance must comply with all applicable codes[22].
- The layout and sizing of gas piping must be adequate for handling the volume of gas required by the generator set and all other equipment, such as building heating boilers, supplied by the same source. Full–load gas flow (see the recommended generator set Specification Sheet) must be available at not less than the minimum required supply pressure, typically from 5 to 10 inches WC (water column), depending on model. Final determination of pipe sizes must, however, be based upon the method approved by the authority having jurisdiction (see NFPA No. 54).

22 In North America, NFPA Standards No. 30, No. 37, No. 54 and No. 58 are typical.

- Most installations will require a service gas pressure regulator. Gas supply pressure should not exceed 13.8 or 20 inches WC, depending on model, at the inlet to the generator set. Depending on distribution gas pressure, more than one stage of pressure regulation may be required. High–pressure gas piping is not permitted inside buildings (5 psig for natural gas and 20 psig for LPG, unless higher pressures are approved by the authority having jurisdiction). Gas pressure regulators must be vented to the outdoors according to code.



* THE GAS PRESSURE SWITCH CAUSES THE NATURAL GAS SOLENOID VALVE TO CLOSE AND THE PROPANE GAS SOLENOID VALVE TO OPEN UPON LOSS OF NATURAL GAS SUPPLY PRESSURE TO CONTINUE GENERATOR SET OPERATION WITHOUT INTERRUPTION. RETURN TO NATURAL GAS IS AUTOMATIC WHEN SUPPLY PRESSURE IS RESTORED.

Figure 6–68. Typical Gaseous Fuel System

- The pressure regulator installed on the supply line at the gas source for generator applications should never be a “pilot” regulator. A “pilot” style regulator is the type where the regulator requires a pressure line from the regulator housing to the downstream gas pipe to “sense” when downstream pressure has dropped. Pilot regulators do not work because the response time is unacceptable compared to the large–instantaneous changes in demand from the generator set.
- Approved flexible fuel hose must be used for connections at the engine to take up generator set movement and vibration.
- Most codes require both manual and electric (battery–powered) shutoff valves ahead of the flexible fuel hose(s). The manual valve should be of the indicating type.
- A dry fuel filter should be installed in each line as shown in **Figure 6–68** to protect the sensitive pressure regulating components and orifices downstream from harmful foreign substances carried along in the gas stream (rust, scale, etc.).
- An LPG fuel supply system must be dedicated for the emergency power system if it is the required alternative fuel.
- An LPG vaporizer heated by engine coolant is factory installed on Cummins Power Generation generator sets equipped for a liquid–withdrawal of LPG. Because high pressure (20 psig or greater) gas piping is not permitted inside buildings, generator sets equipped for liquid withdrawal of LPG must not be installed inside the building. (Weather–protective housings for outdoor installation are available for most LPG models.)
- The rate of vaporization in an LPG tank depends upon the outdoor air temperature, unless the tank is equipped with a heater, and the quantity of fuel in the tank. Even on cold days outdoor air heats and vaporizes LPG (mostly through the wetted tank surface) when air temperature is higher than LPG temperature. Withdrawing vapor causes tank temperature and pressure to drop. (At –37° F [–38° C] LPG has zero vapor pressure.) Unless there is enough fuel and enough heat available from ambient air, the vaporization rate will drop off, as the generator set runs, to less than that required to continue running properly.

Gaseous Fuel System Calculations Fuel Pressure

Tank Size

Use **Figure 6–69** as a quick reference for sizing an LPG tank on the basis of the lowest ambient temperature expected. For example, on a 40F day, withdrawal at 1000 ft^3/h requires a 2000 gallon tank at least half full. Note: In many instances the amount of fuel required for proper vaporization is far greater than that required for the number of hours of operation stipulated by code.

For instance, in an NFPA 110 Class 6 application, there must be enough fuel for the generator set to run for 6 hours before refilling the tank. LPG yields approximately 36.5 cubic feet of gas per gallon of liquid. If the generator set withdrawal rate is 1000 ft^3/h:

$$\text{Fuel Consumed in 6 hours} = \frac{1000\ ft^3/hr \bullet 6\ hours}{36.5\ ft^3/gal} = 164\ \text{gallons}$$

In this instance the tank must be sized for at least 2000 gallons based on the lowest expected temperature rather than on the fuel consumed in 6 hours (164 gallons).

Gas Pipe Sizing

Sizing of gas piping for proper fuel delivery, both flow and pressure, can become quite complex. However, a simplified method, as with other piping for exhaust and coolant, is to convert all fittings, valves, etc. to equivalent lengths of pipe in the diameter(s) being considered. The total equivalent length can then be related to flow capacity.

Table 6–5, Equivalent Lengths of Pipe Fittings and Valves applies to gas as well as liquid piping. **Tables 6–13 through 6–17** show maximum gas capacity for equivalent length for various pipe sizes. Tables 6–10 through 6–14 are reproduced from NFPA 54–2002, National Fuel Gas Code, and are selected considering the general fuel system operating requirements for generator sets. Tables are included for natural gas, propane liquid withdrawal and propane vapor withdrawal under specified conditions. Consult NFPA 54 or other applicable codes for other operating conditions or other fuel system installation requirements.

A calculation of minimum pipe size is fairly straightforward:

- Make a list of al the fittings and valves in a proposed system and sum their equivalent lengths using the table.
- Add to this total, all lengths of straight pipe to arrive at a total equivalent length.
- Choose the applicable table based on the fuel system.
- Obtain the maximum fuel requirements for the specific generator set(s) from the manufacturer's specification sheets. Convert to ft^3/hr as needed (Be cognizant of BTU content as discussed earlier in this section.)
- Locate the equivalent length of pipe (or next larger equivalent length) in the left hand column. Move across to the columns to where the number is as large or larger than the total equivalent length calculated above. At the top of that column is the minimum nominal pipe size or tubing size required for the system as designed.

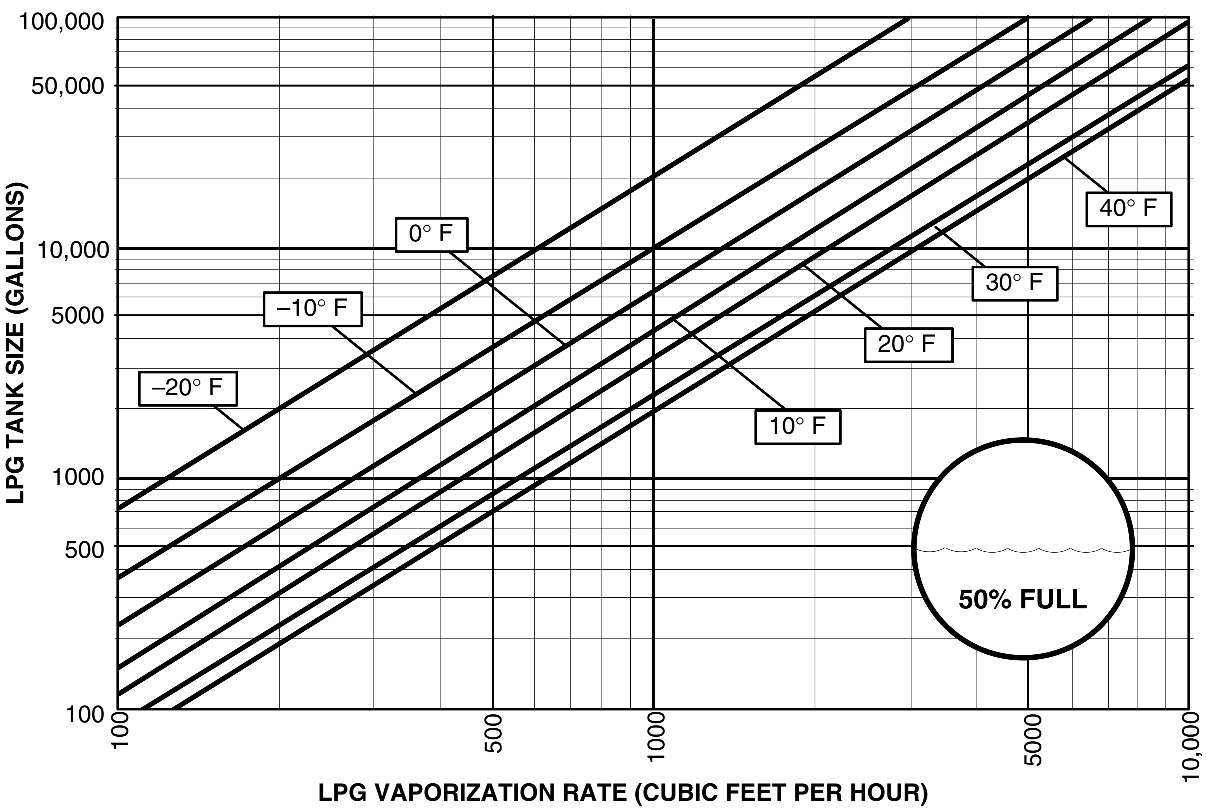


Figure 6–69. Minimum LPG Tank Size (50% Full) Required to Maintain 5 PSIG at Specific Withdrawal Rate and Minimum Expected Winter Temperature

Gas: Natural
Inlet Pressure: 0.5 psi or less
Pressure Drop: 0.5 in. w.c.
Specific Gravity: 0.60

	Pipe Size (in.)										
Nominal	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4
Actual ID	(0.364)	(0.493)	(0.622)	(0.824)	(1.049)	(1.380)	(1.610)	(2.067)	(2.469)	(3.068)	(4.026)
Length (ft)	**Maximum Capacity in Cubic Feet of Gas per Hour**										
10	43	95	175	360	680	1400	2100	3950	6300	11000	23000
20	29	65	120	250	465	950	1460	2750	4350	7700	15800
30	24	52	97	200	375	770	1180	2200	3520	6250	12800
40	20	45	82	170	320	660	990	1900	3000	5300	10900
50	18	40	73	151	285	580	900	1680	2650	4750	9700
60	16	36	66	138	260	530	810	1520	2400	4300	8800
70	15	33	61	125	240	490	750	1400	2250	3900	8100
80	14	31	57	118	220	460	690	1300	2050	3700	7500
90	13	29	53	110	205	430	650	1220	1950	3450	7200
100	12	27	50	103	195	400	620	1150	1850	3250	6700
125	11	24	44	93	175	360	550	1020	1650	2950	6000
150	10	22	40	84	160	325	500	950	1500	2650	5500
175	9	20	37	77	145	300	460	850	1370	2450	5000
200	8	19	35	72	135	280	430	800	1280	2280	4600

Table 6–13. Natural Gas Schedule 40 Iron Pipe Sizing[23]

23 Reprinted with permission from NFPA 54–2002, *National Fuel Gas Code*, Copyright © 2002, National Fire Protection Association, Quincy, MA 02169. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

Gas: Natural
Inlet Pressure: 0.5 psi or less
Pressure Drop: 0.5 in. w.c.
Specific Gravity: 0.6

		Tube Size (in.)									
Nominal	K & L	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2
	ACR	3/8	1/2	5/8	3/4	7/8	1 1/8	1 3/8	1 5/8	2 1/8	2 5/8
Outside		0.375	0.500	0.625	0.750	0.875	1.125	1.375	1.625	2.125	2.625
Inside*		0.305	0.402	0.527	0.652	0.745	0.995	1.245	1.481	1.959	2.435
Length (ft)		**Maximum Capacity in Cubic Feet of Gas per Hour**									
10		27	55	111	195	276	590	1062	1675	3489	6173
20		18	38	77	134	190	406	730	1151	2398	4242
30		15	30	61	107	152	326	586	925	1926	3407
40		13	26	53	92	131	279	502	791	1648	2916
50		11	23	47	82	116	247	445	701	1461	2584
60		10	21	42	74	105	224	403	635	1323	2341
70		9.3	19	39	68	96	206	371	585	1218	2154
80		8.6	18	36	63	90	192	345	544	1133	2004
90		8.1	17	34	59	84	180	324	510	1063	1880
100		7.6	16	32	56	79	170	306	482	1004	1776
125		6.8	14	28	50	70	151	271	427	890	1574
150		6.1	13	26	45	64	136	245	387	806	1426
175		5.6	12	24	41	59	125	226	356	742	1312
200		5.2	11	22	39	55	117	210	331	690	1221
250		4.7	10	20	34	48	103	186	294	612	1082
300		4.2	8.7	18	31	44	94	169	266	554	980

* Table capacities are based on Type K copper tubing inside diameter (shown), which has the smallest inside diameter of the copper tubing products.

Table 6–14. Natural Gas Semi–Rigid Copper Tubing Sizing[24]

24 Reprinted with permission from NFPA 54–2002, National Fuel Gas Code, Copyright © 2002, *National Fire Protection Association*, Quincy, MA 02169. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

Gas: Undiluted Propane
Inlet Pressure: 11.0 in. w.c.
Pressure Drop: 0.5 in. w.c.
Specific Gravity: 1.50
Special Use: Pipe sizing between single or second stage (low pressure regulator) and appliance.

	Pipe Size (in.)								
Nominal Inside	1/2	3/4	1	1 1/4	1 1/2	2	3	3 1/2	4
Actual:	0.622	0.824	1.049	1.38	1.61	2.067	3.068	3.548	4.026
Length (ft)	**Maximum Capacity in Thousands of Btu per Hour**								
10	291	608	1145	2352	3523	6786	19119	27993	38997
20	200	418	787	1616	2422	4664	13141	19240	26802
30	160	336	632	1298	1945	3745	10552	15450	21523
40	137	287	541	1111	1664	3205	9031	13223	18421
50	122	255	480	984	1475	2841	8004	11720	16326
60	110	231	434	892	1337	2574	7253	10619	14793
80	94	197	372	763	1144	2203	6207	9088	12661
100	84	175	330	677	1014	1952	5501	8055	11221
125	74	155	292	600	899	1730	4876	7139	9945
150	67	140	265	543	814	1568	4418	6468	9011
200	58	120	227	465	697	1342	3781	5536	7712
250	51	107	201	412	618	1189	3351	4906	6835
300	46	97	182	373	560	1078	3036	4446	6193
350	42	89	167	344	515	991	2793	4090	5698
400	40	83	156	320	479	922	2599	3805	5301

Table 6–15. Propane Vapor Schedule 40 Iron Pipe Sizing[25]

25 Reprinted with permission from NFPA 54–2002, National Fuel Gas Code, Copyright © 2002, *National Fire Protection Association*, Quincy, MA 02169. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

Gas: Undilute Propane
Inlet Pressure: 11.0 in w.c.
Pressure Drop: 0.5 in. w.c.
Specific Gravity: 1.50
Special Use: Sizing between single or second stage (low pressure regulator) and appliance

		Tube Size (in.)									
Nominal	K & L	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2
	ACR	3/8	1/2	5/8	3/4	7/8	1 1/8	1 3/8	1 5/8	2 1/8	2 5/8
Outside		0.375	0.500	0.625	0.750	0.875	1.125	1.375	1.625	2.125	2.625
Inside*		0.305	0.402	0.527	0.652	0.745	0.995	1.245	1.481	1.959	2.435
Length (ft)		Maximum Capacity in Thousands of Btu per Hour									
10		45	93	188	329	467	997	1795	2830	5895	10429
20		31	64	129	226	321	685	1234	1945	4051	7168
30		25	51	104	182	258	550	991	1562	3253	5756
40		21	44	89	155	220	471	848	1337	2784	4926
50		19	39	79	138	195	417	752	1185	2468	4366
60		17	35	71	125	177	378	681	1074	2236	3956
70		16	32	66	115	163	348	626	988	2057	3639
80		15	30	61	107	152	324	583	919	1914	3386
90		14	28	57	100	142	304	547	862	1796	3177
100		13	27	54	95	134	287	517	814	1696	3001
125		11	24	48	84	119	254	458	722	1503	2660
150		10	21	44	76	108	230	415	654	1362	2410
175		10	20	40	70	99	212	382	602	1253	2217
200		8.9	18	37	65	92	197	355	560	1166	2062
225		8.3	17	35	61	87	185	333	525	1094	1935
250		7.9	16	33	58	82	175	315	496	1033	1828
275		7.5	15	31	55	78	166	299	471	981	1736
300		7.1	15	30	52	74	158	285	449	936	1656

* Table capacities are based on Type K copper tubing inside diameter (shown), which has the smallest inside diameter of the copper tubing products.

Table 6–16. Propane Vapor Semi–Rigid Copper Tubing Sizing[26]

26 Reprinted with permission from NFPA 54–2002, National Fuel Gas Code, Copyright © 2002, *National Fire Protection Association*, Quincy, MA 02169. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

Equivalent Length of Pipe, ft.	Schedule 40 Iron Pipe Size, in.: Nominal (Inside Diameter)								
	1/2 (0.622)	3/4 (0.824)	1 (1.049)	1 1/4 (1.38)	1 1/2 (1.61)	2 (2.067)	3 (3.068)	3 1/2 (3.548)	4 (4.026)
30	733	1532	2885	5924	8876	17094	48164	70519	98238
40	627	1311	2469	5070	7597	14630	41222	60355	84079
50	556	1162	2189	4494	6733	12966	36534	53492	74518
60	504	1053	1983	4072	6100	11748	33103	48467	67519
70	463	969	1824	3746	5612	10808	30454	44589	62116
80	431	901	1697	3484	5221	10055	28331	41482	57787
90	404	845	1593	3269	4899	9434	26583	38921	54220
100	382	798	1504	3088	4627	8912	25110	36764	51216
150	307	641	1208	2480	3716	7156	20164	29523	41128
200	262	549	1034	2122	3180	6125	17258	25268	35200
250	233	486	916	1881	2819	5428	15295	22395	31198
300	211	441	830	1705	2554	4919	13859	20291	28267
350	194	405	764	1568	2349	4525	12750	18667	26006
400	180	377	711	1459	2186	4209	11861	17366	24193
450	169	354	667	1369	2051	3950	11129	16295	22700
500	160	334	630	1293	1937	3731	10512	15391	21442
600	145	303	571	1172	1755	3380	9525	13946	19428
700	133	279	525	1078	1615	3110	8763	12830	17873
800	124	259	488	1003	1502	2893	8152	11936	16628
900	116	243	458	941	1409	2715	7649	11199	15601
1000	110	230	433	889	1331	2564	7225	10579	14737
1500	88	184	348	713	1069	2059	5802	8495	11834
2000	76	158	297	611	915	1762	4966	7271	10128

Table 6–17. Propane Schedule 40 Iron Pipe Sizing, Liquid Withdrawal – Maximum Capacity of Pipe in Cubic Feet of Gas per Hour. Pipe size recommendations are based on schedule 40 black iron pipe.

Reducing Noise in Generator Set Applications

The Science of Noise

Noise Level Measurement and Decibel/dB(A) Units: One unit of measurement for sound is the decibel (dB). The decibel is a convenient number on a logarithmic scale expressing the ratio of two sound pressures, comparing the actual pressure to a reference pressure.

Noise regulations are generally written in terms of “decibels ‘A’ scale” or dB(A). The “A” denotes that the scale has been “adjusted” to approximate how a person perceives the loudness of sound. Loudness depends on sound pressure level (amplitude) and frequency. **Figure 6–70** shows typical noise levels associated with various surroundings and noise sources.

Accurate and meaningful sound level data are preferably measured in a “free field site” to collect noise data. A “free field”, as distinguished from a “reverberant field”, is a sound field in which the effects of obstacles or boundaries on sound propagated in that field are negligible. (Generally this means the objects or barriers are far away, do not reflect toward the test area and/or are covered with adequate sound absorption materials.) Accurate noise measurements also require that the microphone be placed outside the "near field." "Near field" is defined as the region within one wave length, or two times the largest dimension of the noise source, whichever is greater. Noise measurements for community regulations should not be made in the near field. Engineers' noise specifications should call for sound pressure level measurements in the free field, 7 meters (21 feet) or greater.

Noise measurements should be made using a sound level meter and an octave band analyzer for more detailed analysis by acoustical consultants. The microphones are placed in a circle of 7 meters (21 feet) radius centered on the generator set; a sufficient distance for this type and size of equipment. Refer to the Sound Performance data sheets available on the Power Systems Software Suite CD for data on Cummins Power Generation products.

Additive Sound Levels

The noise level at a given location is the sum of the noise levels from all sources, including reflecting sources. For example, the noise level at a point in a free field equidistant from two identical generator sets is double when both sets are running. A doubling of the noise level is represented as an increase of approximately 3 dB(A). In this case, if the noise level from either set is measured as 90 dB(A), one could expect to measure 93 dB(A) when both sets are running.

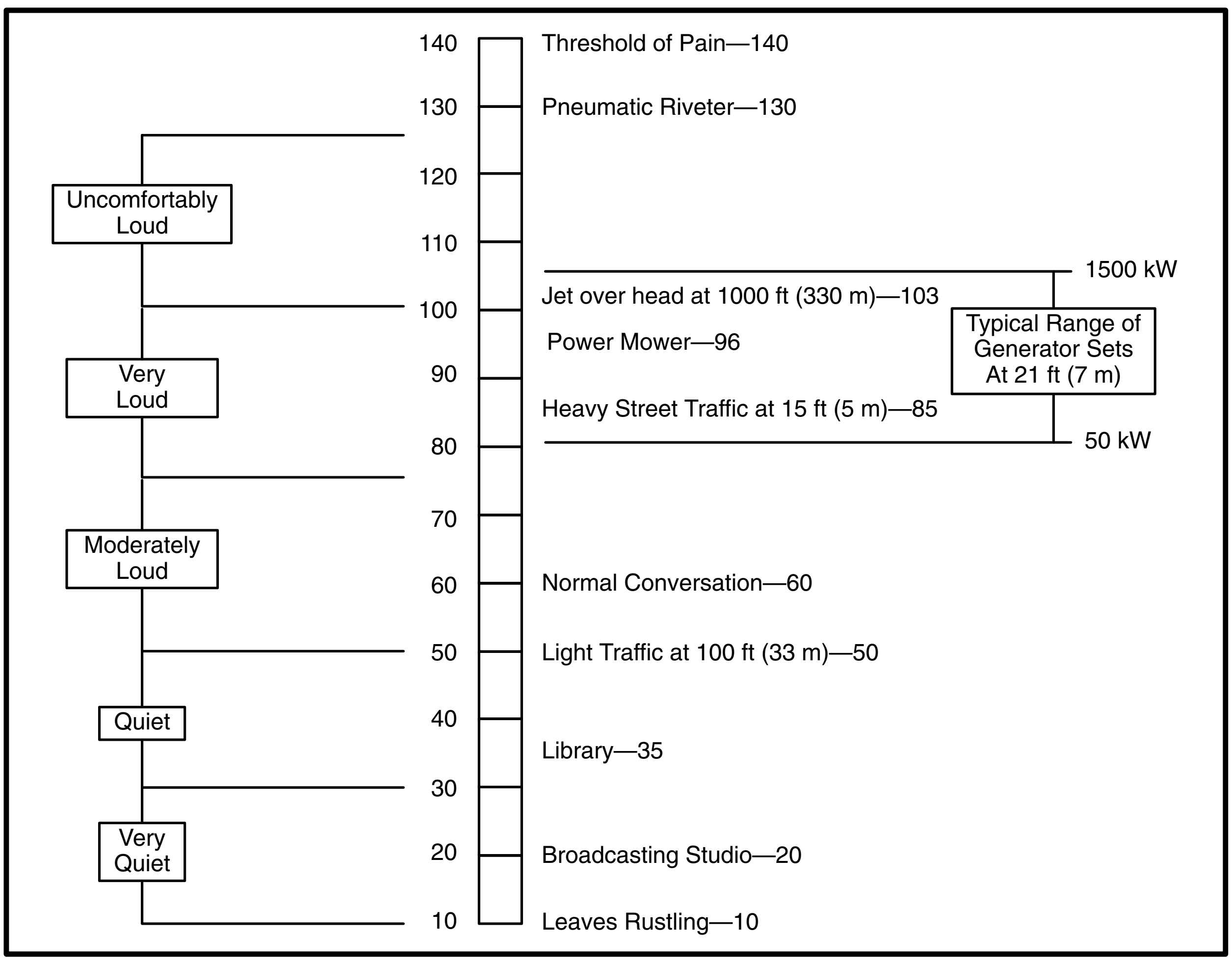


Figure 6–70. Typical Noise Levels

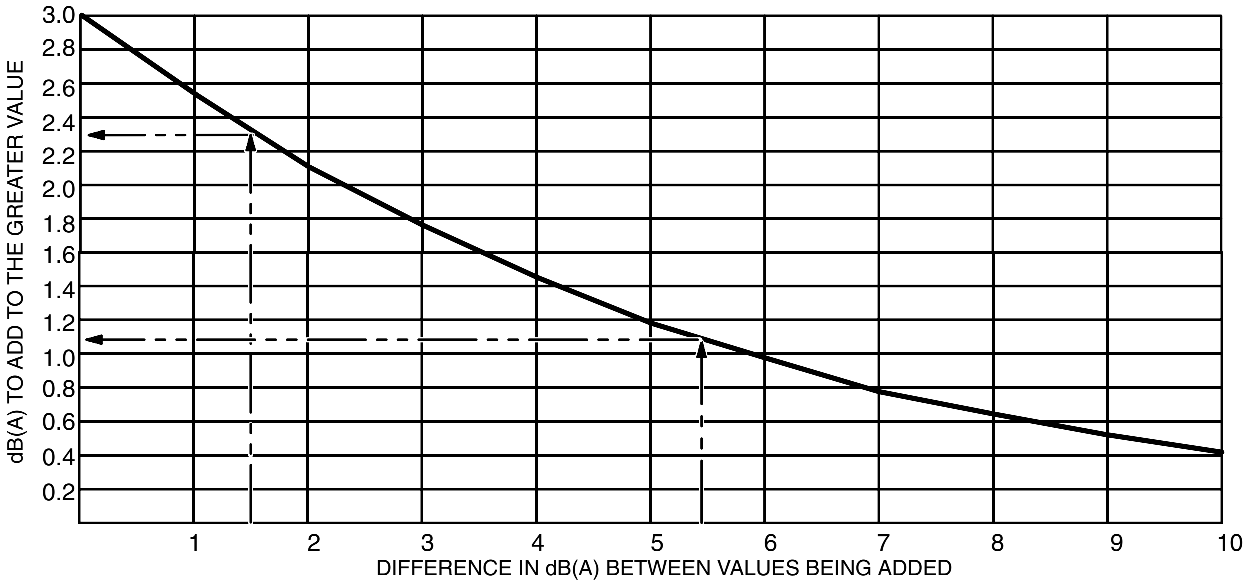


Figure 6–71. Graph Of Values For Adding Noise Levels

Figure 6–71 can be used, as follows, to estimate the noise level from multiple noise sources:

1. Find the difference in dB(A) between two of the sources (any pair). Locate that value on the horizontal scale as shown by the vertical arrow, move up to the curve and over to the vertical scale as shown by the horizontal arrow. Add this value to the larger dB(A) value of the pair.
2. Repeat Step 1 between the value just determined and the next value. Keep repeating the process until all sources have been accounted for.

For example, to add 89 dB(A), 90.5 dB(A), and 92 dB(A):

- Subtract 90.5 dB(A) from 92 dB(A) for a difference of 1.5 dB(A). As the arrows show in **Figure 6–71**, corresponding to the difference of 1.5 dB(A) is the value of 2.3 dB(A) which should be added to 92 dB(A) for a new value of 94.3 dB(A).
- Likewise, subtract 89 dB(A) from the new value of 94.3 dB(A) for a difference of 5.3 dB(A).
- Finally, add the corresponding value of 1.1 dB(A) to 94.5 dB(A) for a total of 95.6 dB(A).

Alternatively, the following formula can be used to add sound pressure levels measured in dB(A):

$$dBA_{total} = 10 \bullet \log_{10}\left(10^{\left(\frac{dBA_1}{10}\right)} + 10^{\left(\frac{dBA_2}{10}\right)} + \ldots + 10^{\left(\frac{dBA_n}{10}\right)}\right)$$

Effect of Distance

In a “free field,” sound level decreases as distance increases. If, for example, a second sound measurement is taken twice as far from the source, the second reading will be approximately 6 dB(A) less than the first (four times less). If the distance is cut in half, the second reading will be approximately 6 dB(A) greater (four times greater). For the more general case, if the sound pressure level (SPL_1) of a source at distance d_1 is known, the sound pressure level (SPL_2) at distance d_2 can be found as follows:

$$SPL_2 = SPL_1 - 20 \bullet \log_{10}\left(\frac{d_2}{d_1}\right)$$

For example, if the sound pressure level (SPL_1) at 21 meters (d_1) is 100 dB(A), at 7 meters (d_2), the sound pressure level (SPL_2) will be:

$$\begin{aligned} SPL_2 &= 100\text{dBA} - 20 \bullet \log_{10}\left(\frac{7}{21}\right) \\ &= 100 - 20 \bullet (-0.477) \\ &= 100 + 9.5 = 109.5\ \text{dBA} \end{aligned}$$

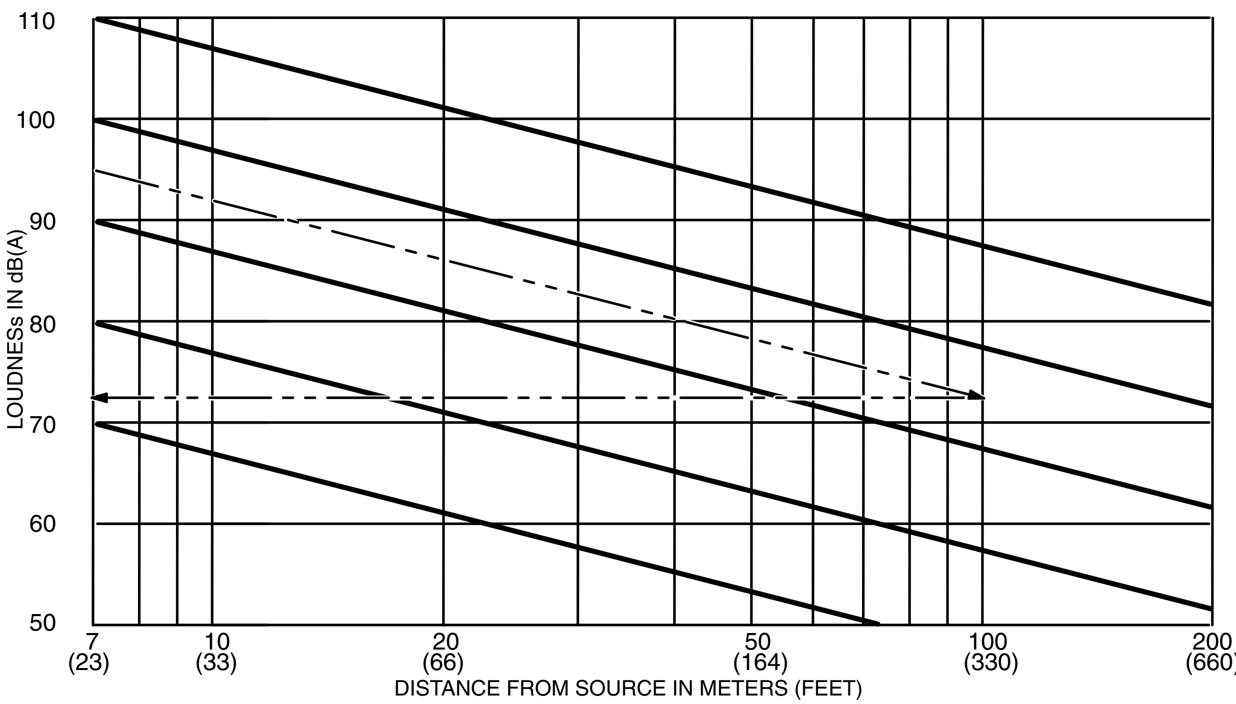


Figure 6–72. Decrease In Loudness As Distance Increases (Free Field)

To apply the distance formula (above) to generator set data published by Cummins Power Generation, the background noise level must be at least 10 dB(A) below the noise level of the generator set and the installation must approximate a free field environment.

Figure 6–72 can be used as an alternative to the formula for estimating the sound level at various distances, such as to the property line. For example, as shown by the dashed arrows, if the noise rating on the recommended generator set Specification Sheet is 95 dB(A) (at 7 meters), the noise level 100 meters away will be approximately 72 dB(A).

To use **Figure 6–72**, draw a line parallel to the slanted lines from the known dB(A) value on the vertical scale line to the vertical line for the specified distance. Then draw a horizontal line back to the vertical scale line and read the new dB(A) value.

Generator Set Noise

Generator set applications are susceptible to problems associated with noise levels, due to the inherent high levels of noise produced by operating generator sets. Codes and standards have been enacted to protect property owners or users from objectionable levels of noise from other properties.

In general, required noise levels at a property line are often in the low 60s or high 50s (depending on time of day), while untreated generator set noise levels can approach 100dBA. The generator set noise may be amplified by site conditions, or the ambient noise level existing at the site may prevent the generator set from meeting required noise performance levels. (In order to accurately measure the noise level of any source, the noise source must be more than 10 dBA louder than the ambient around it.)

The noise level produced by a generator set at a property line is predictable if the generator set is installed in a *free field* environment. In a free field environment, there are no reflecting walls to magnify the noise produced by the generator set, and the noise level follows the “6 dBA reduction for doubling distance” rule. If the property line is within the *near field* of a generator set the noise level may not be predictable. A near field environment is any measurement taken within twice the largest dimension of the noise source.

Reflecting walls and other hard surfaces magnify the noise level that may be sensed by a receiver. For example, if a generator set is placed next to a hard surfaced wall, the noise level perpendicular to the wall will be approximately twice the expected sound power of the generator set in a free field environment (i.e., a generator set operating with a 68 dBA noise level would measure 71 dBA next to a reflecting wall). Putting a generator set in a corner further magnifies the noise level sensed.

Noise ordinances are often only enforced by complaint, but the high cost of retrofitting a site for noise reduction makes it a good idea to assess noise performance requirements early in the design cycle, and designing into the site the most cost effective sound attenuation provisions.

See section **Table 2–2** for representative outside noise data.

Reducing Structure – Transmitted Noise

Vibrating structures create sound pressure waves (noise) in the surrounding air. Connections to a generator set can cause vibrations in the building structure, creating noise. Typically, these include the skid anchors, radiator discharge air duct, exhaust piping, coolant piping, fuel lines, and wiring conduit. Also, the walls of a generator set housing can vibrate and cause noise. **Figure 6–1** shows ways of minimizing structure–transmitted noise by proper vibration isolation.

Mounting a generator set on spring–type vibration isolators effectively reduces vibration transmission. Vibration isolation practice is described in Vibration Isolators at the beginning of this chapter.

Flexible connections to exhaust pipe, air duct, fuel line, coolant pipe (remote radiator or heat exchanger systems) and wiring conduit effectively reduce vibration transmission. All generator set applications require the use of flexible connections to the generator set.

Reducing Airborne Noise

Airborne noise has a directional characteristic and is usually the most apparent at the high end of the frequency range.

- The simplest treatment is to direct the noise, such as a radiator or exhaust outlet, away from receivers. For example, point the noise up vertically so that people at grade level will not be in the sound path.
- Line–of–sight barriers are effective in blocking noise. Barriers made of materials with high mass materials such as concrete, filled cement block, or brick, are best. Be careful to eliminate sound paths through cracks in doors or room (or enclosure) access points for exhaust, fuel, or electrical wiring.

- Sound absorbing (acoustic) materials are available for lining air ducts and covering walls and ceilings. Also, making noise travel through a 90–degree bend in a duct reduces high frequency noise. Directing noise at a wall covered with sound absorbing material can be very effective. Fiberglass or foam may be suitable, based on factors such as cost, availability, density, flame retardance, resistance to abrasion, aesthetics and cleanability. Care should be taken to select materials that are resistant to the effects of oil and other engine contaminants.
- A concrete block enclosure is an excellent barrier to all noise. The blocks may be filled with sand to increase the mass of the wall and thus increase noise attenuation.
- Remote radiator arrangements can be used to limit air flow and to move the radiator fan noise source to a location that is less likely to be objectionable to receivers. Remote radiator installations can be supplied with low speed fans to minimize noise from the assembly.

Sound Attenuated Enclosures (Canopies)

Generator sets that are installed out of doors may be provided with integral sound attenuated enclosures. These enclosures effectively form an enclosed space around the generator set and can effectively reduce the noise level produced by the machine.

In general, the price of the enclosure is directly related to the sound attenuation required. So, the greater the level of sound attenuation required, the greater the cost of the enclosure. It is not uncommon for enclosure costs to approach the cost of the generator set that it protects.

It should also be recognized that there may be a price in terms of generator set performance by use of high levels of sound attenuation. Carefully test sound attenuated machines for proper ventilation system and load–carrying performance.

NOTE: Be cautious when comparing cooling system ratings that the rating is based on ambient temperature not air–on–radiator. An air–on–radiator rating restricts the temperature of the air flowing into the radiator and does not allow for air temperature increase due to the radiated heat energy of the engine and alternator. Ambient rated system accounts for this increase in temperature in their cooling capability.

Exhaust Silencer Performance

Generator sets are almost always provided with an exhaust silencer (muffler) to limit exhaust noise from the machine. Exhaust silencers come in a wide variety of types, physical arrangements, and materials.

Silencers are generally grouped into either chamber–type silencers, or spiral type devices. The chamber type devices can be designed to be more effective, but the spiral types are often physically smaller, and may have suitable performance for the application.

Silencers may be constructed of cold–rolled steel or stainless steel. Cold–rolled steel silencers are less expensive, but more susceptible to corrosion than stainless steel silencers. For applications where the silencer is mounted indoors, and protected with insulation (lagging) to limit heat rejection, there is little advantage for the stainless variety.

Silencers can be provided in the following physical configurations:

- End in/end out; probably the most common configuration.
- Side in/end out; often used to help to limit ceiling height requirements for a generator set.
- Dual side inlet/end out; used on “V” engines to eliminate need for an exhaust header, and minimize ceiling height requirements.

Silencers are available in several different noise attenuation “grades”; commonly called: “industrial”, “residential”, and “critical”. Note that the exhaust noise from a generator set may not be the most objectionable noise source on the machine. If the mechanical noise is significantly greater than the exhaust noise, selection of a higher performance silencer may not improve the noise level present at the site.

In general, the more effective a silencer is at reducing exhaust noise, the greater the level of restriction on the engine exhaust. For long exhaust systems, the piping itself will provide some level of attenuation.

Typical Silencer Attenuation
Industrial Silencers: 12–18 dBA
Residential Silencers: 18–25 dBA
Critical Silencers: 25–35 dBA

Fire Protection

The design, selection and installation of fire protection systems is beyond the scope of this manual due to of the wide range of factors to consider, such as building occupancy, codes, and the efficacy of various fire protection systems. Consider the following, however:

- The fire protection system must comply with the requirements of the authority having jurisdiction, such as the building inspector, fire marshal or insurance carrier.
- Generator sets that are used for emergency and standby power should be protected from fire by location or by the use of fire–resistant construction in the generator set room. In some locations, generator room construction for installations that are considered to be necessary for life safety must have a two–hour fire resistance rating[27],[28]. Some locations will also require feeder fire protection. Consider use of automatic fire doors or dampers for the generator set room.

The generator set room must be ventilated adequately to prevent buildup of engine exhaust gases or flammable fuel supply gas.

- The generator room should not be used for storage purposes.
- Generator rooms should not be classified as hazardous locations (as defined by the NEC) solely by reason of the engine fuel.
- The authority having jurisdiction will usually classify the generator set as a low heat appliance when use is only for brief, infrequent periods, even though exhaust gas temperature may exceed 1000° F (538° C). Where exhaust gas temperature may exceed 1000° F (538° C), some diesels and most gas engines may be classified as high heat appliances and may require exhaust systems rated for 1400° F (760° C) operation. Consult the engine manufacturer for information on exhaust temperatures.
- The authority having jurisdiction may specify the quantity, type, and sizes of approved portable fire extinguishers required for the generator room.
- A manual emergency stop station outside the generator room or remote from a generator set in an outside enclosure would facilitate shutting down the generator set in the event of a fire or other type of emergency.

27 **CODE NOTE:** In the US, NFPA110 requires that generator sets used in Level 1 emergency systems be installed in a room with a 2–hour fire resistance rating. Other emergency systems are required to have 1–hour fire resistance ratings.

28 **CODE NOTE:** In Canada, CSA282–2000 requires that a room with 1–hour fire resistance rating protect emergency power systems that are installed in buildings.

- Typical liquid fuel systems are limited to 660 gallons (2498 liters) inside of a building. However, the authority having jurisdiction may enforce much more stringent restrictions on the amount of fuel that can be stored inside a building. Also, exceptions may be made to allow use of larger amounts of fuel in a generator set room, especially if the generator set room has properly designed fire protection systems.
- Fuel tanks located inside buildings and above the lowest story or basement should be diked in accordance with NFPA standards and environmental regulations.
- The generator set should be exercised periodically as recommended under at least 30 percent load until it reaches stable operating temperatures. It should also be run under nearly full load at least once a year to prevent fuel from accumulating in the exhaust system.

Equipment Room Design

General Considerations

Generator sets should be installed according to instructions provided by the generator set manufacturer, and in compliance with applicable codes and standards.

General guidelines for room design:

- Most generator sets will require access for service to both sides of the engine as well as the control/alternator end of the machine. Local electrical codes may require specific working space for electrical equipment, but in general, allow for working space equal to the width of the genset on both sides and rear.
- Location of fuel system, or electrical distribution system components may require additional working space. See fuel supply requirements elsewhere in this section for more information on that subject.
- There should be access to the generator set room (or outdoor enclosure) that allows the largest component in the equipment to be removed (almost always the engine). Access may be through wide doorways, or via removable inlet or exhaust air louvers. An ideal design will allow moving the generator set as a package into the equipment room.

Roof–top Installations

With more pressure on building cost, it is becoming more common to locate generator sets on roof–tops. These installations can be successfully accomplished if the building structure can support the weight of the generator set and associated componentry. General advantages and disadvantages of these installations:

Advantages

- Unlimited ventilation air for system.
- No (or little) need for ventilation duct work.
- Short exhaust runs
- Fewer Noise issues (may still require sound attenuated enclosure).
- Fewer space limitations
- Generator set is isolated from normal service, for better system reliability.

Disadvantages

- Roof structure may need to be strengthened to support generator set.
- Moving equipment to roof may be expensive. (crane or disassembly)
- Code restrictions

- Longer cable runs
- Limited fuel storage at generator set; fuel supply (and possibly return) must run through building.
- More difficult to service generator set

Note: Even though the generator set is mounted on the roof, care must still be taken with engine exhaust, to avoid contamination of air inlet ducts into the building or adjacent properties. See Ventilation General Guidelines earlier in this section for more information.

It is recommended that generator sets that have limitations in their service access be provided with a load bank connection within the building distribution system. This will allow load banks to be temporarily connected in a convenient location. Otherwise, the difficulty of connecting a load bank may hinder or even prevent proper testing of the generator set.