## 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.

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 buildup 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[8]. See **Figure 6–14** 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.
- 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 6–15**) 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.

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

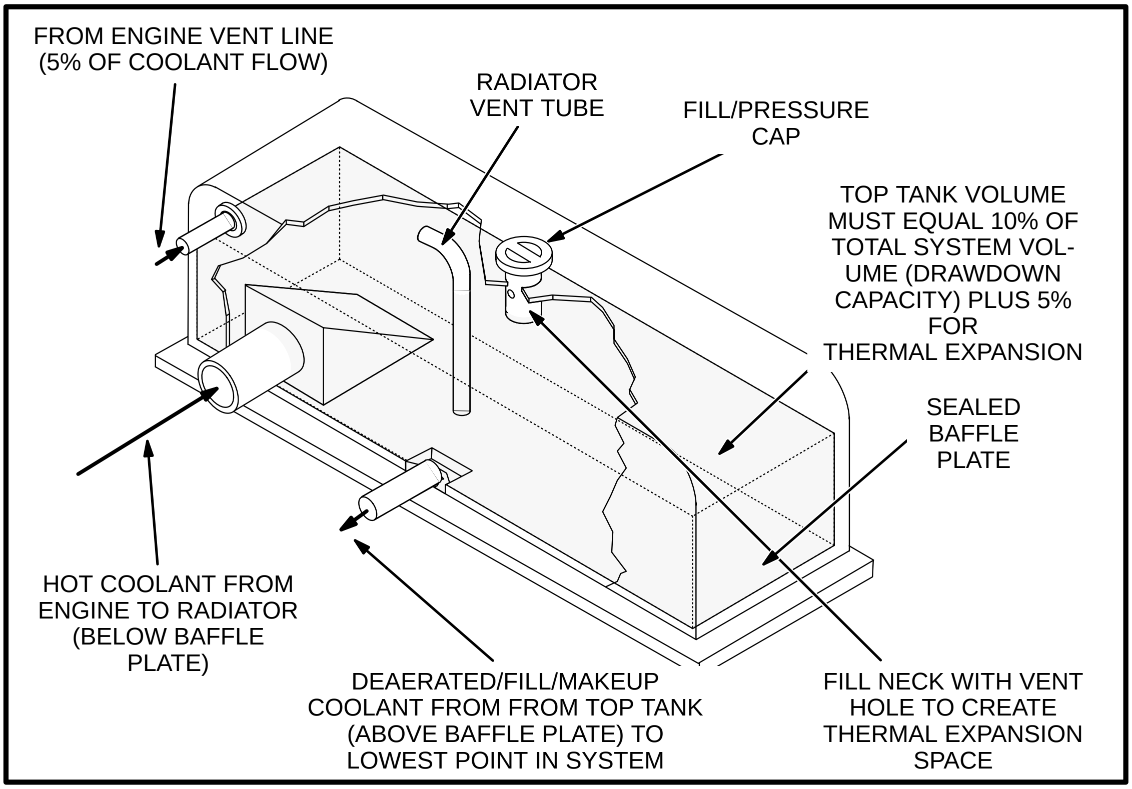



**Figure 6–14.** Deaeration Type of Radiator Top Tank

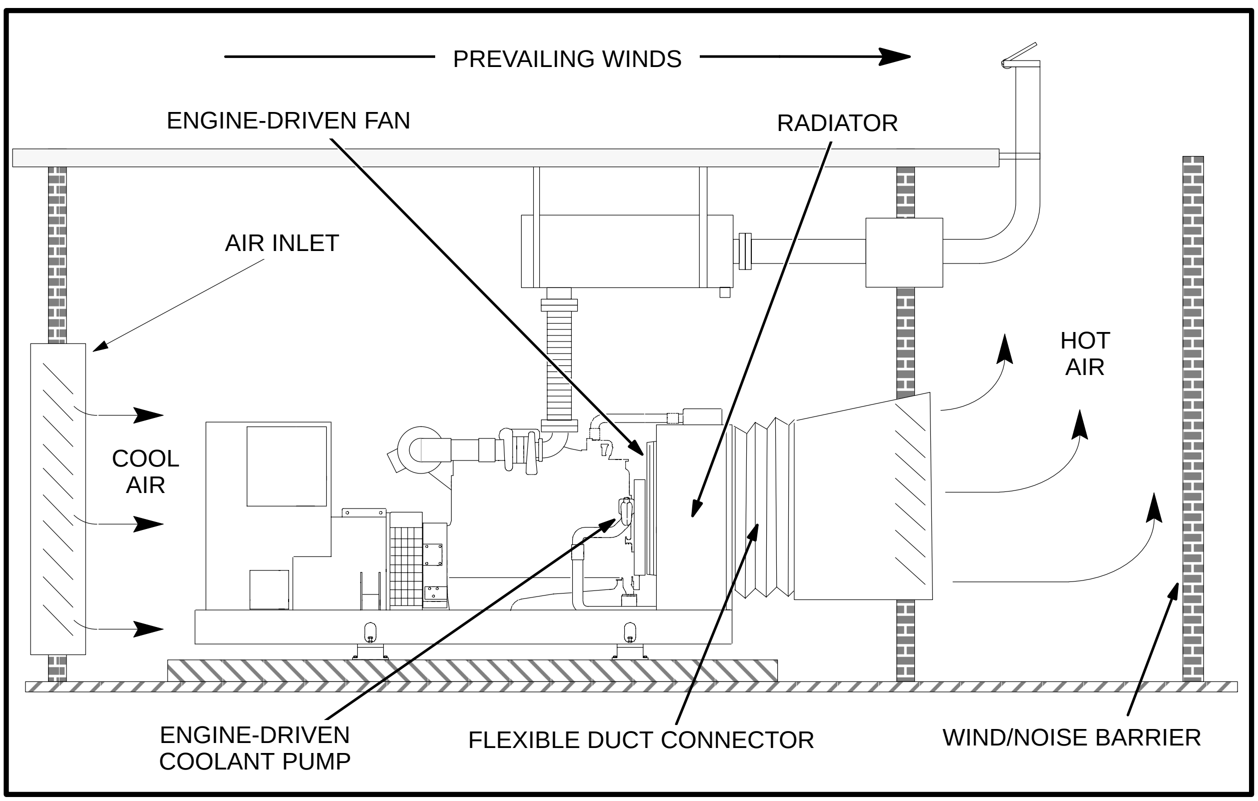



**Figure 6–15.** Factory-Mounted Radiator Cooling

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 6–16.**

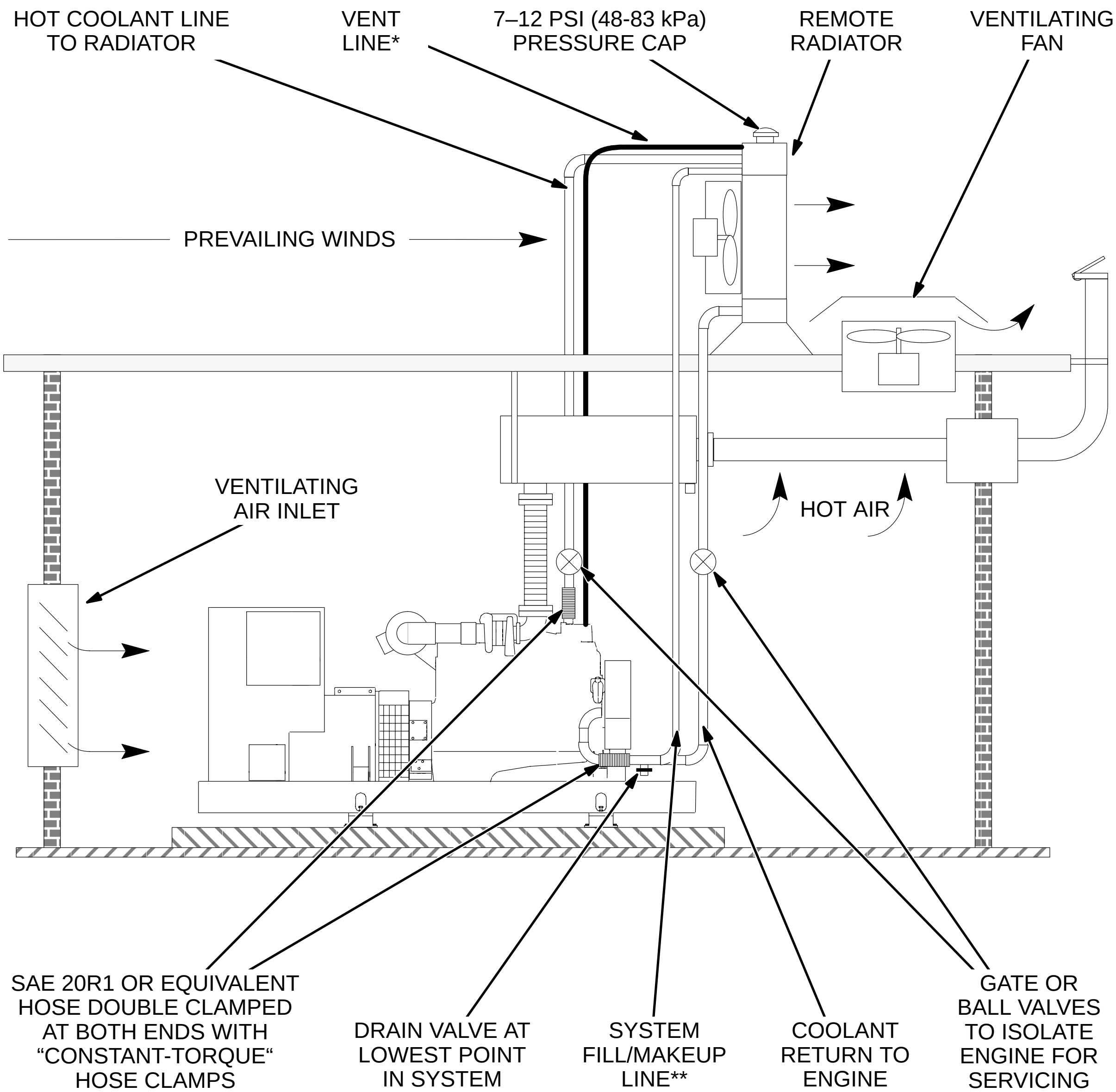
If the friction head is exceeded, but static head is not, a remote radiator system with auxiliary coolant pump can be used. See **Figure 6–14** and Remote Radiator With Auxiliary Coolant Pump, in this section.

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 200º F (93º 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[9].
- 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 6–14.**

9 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 6–16.** Remote Radiator Cooling (Deaeration Type System, See **Figure 6–14**)

- 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[10]. 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.

10 Data for Cummins engines is in the Power Suite.

### 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).

### Remote Radiator with Auxiliary Coolant Pump

A remote radiator with an auxiliary coolant pump (**Figure 6–17**) 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:

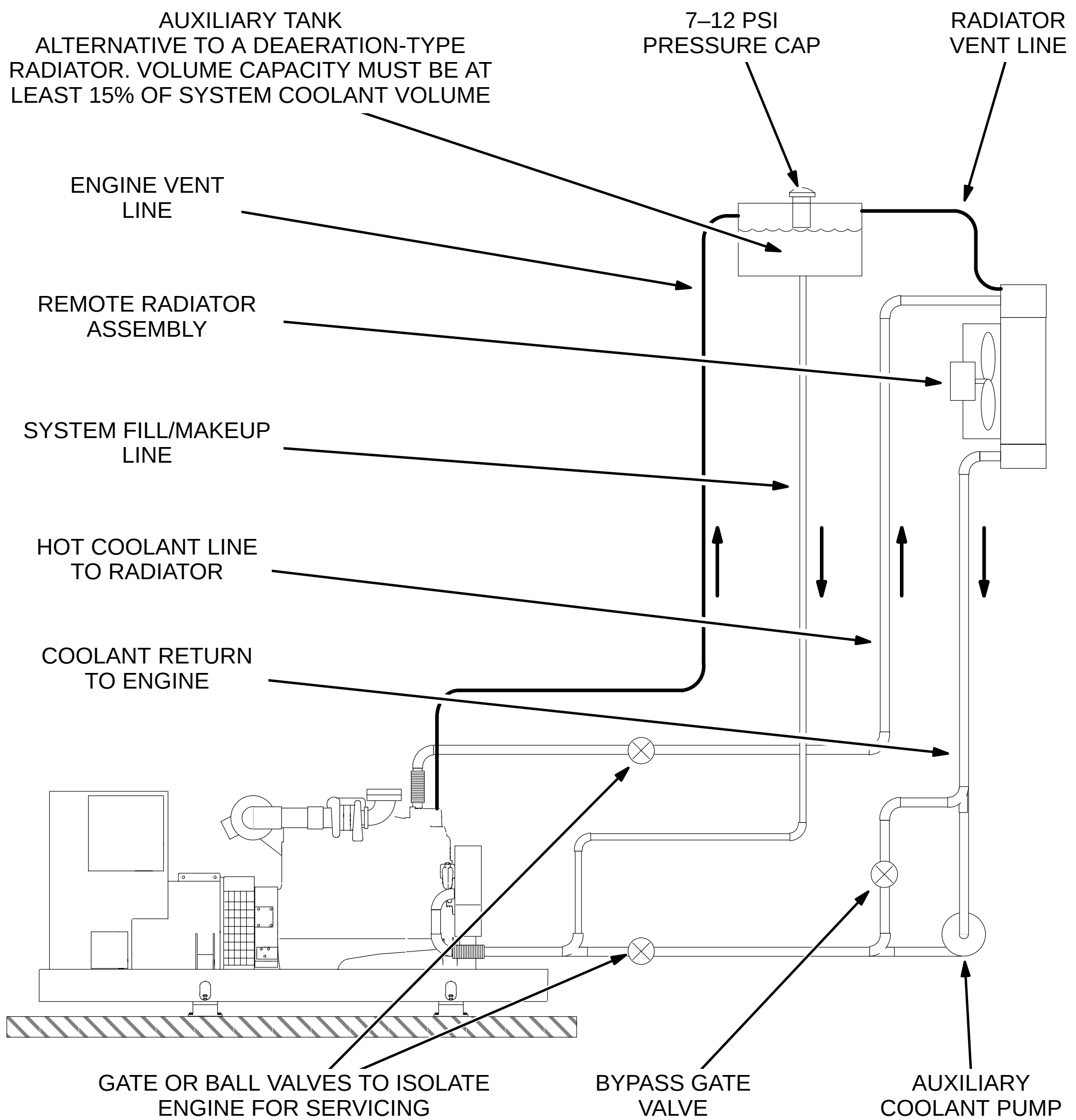



**Figure 6–17.** Remote Radiator With Auxiliary Coolant Pump and Auxiliary Tank

- 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 6–18)** 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.

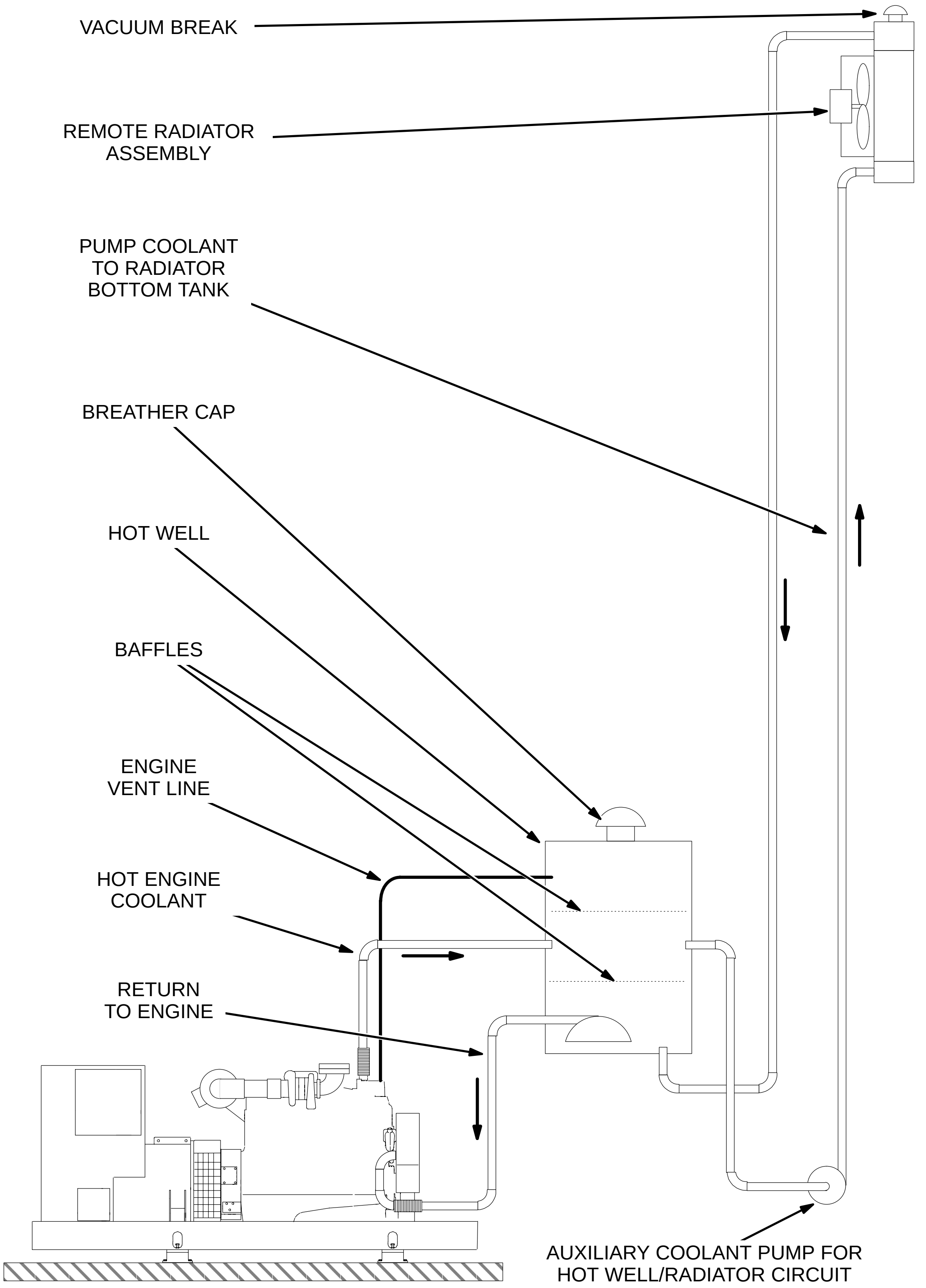



**Figure 6–18.** Remote Radiator With Hot Well and Auxiliary Coolant Pump

- 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 6–19**.

*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.

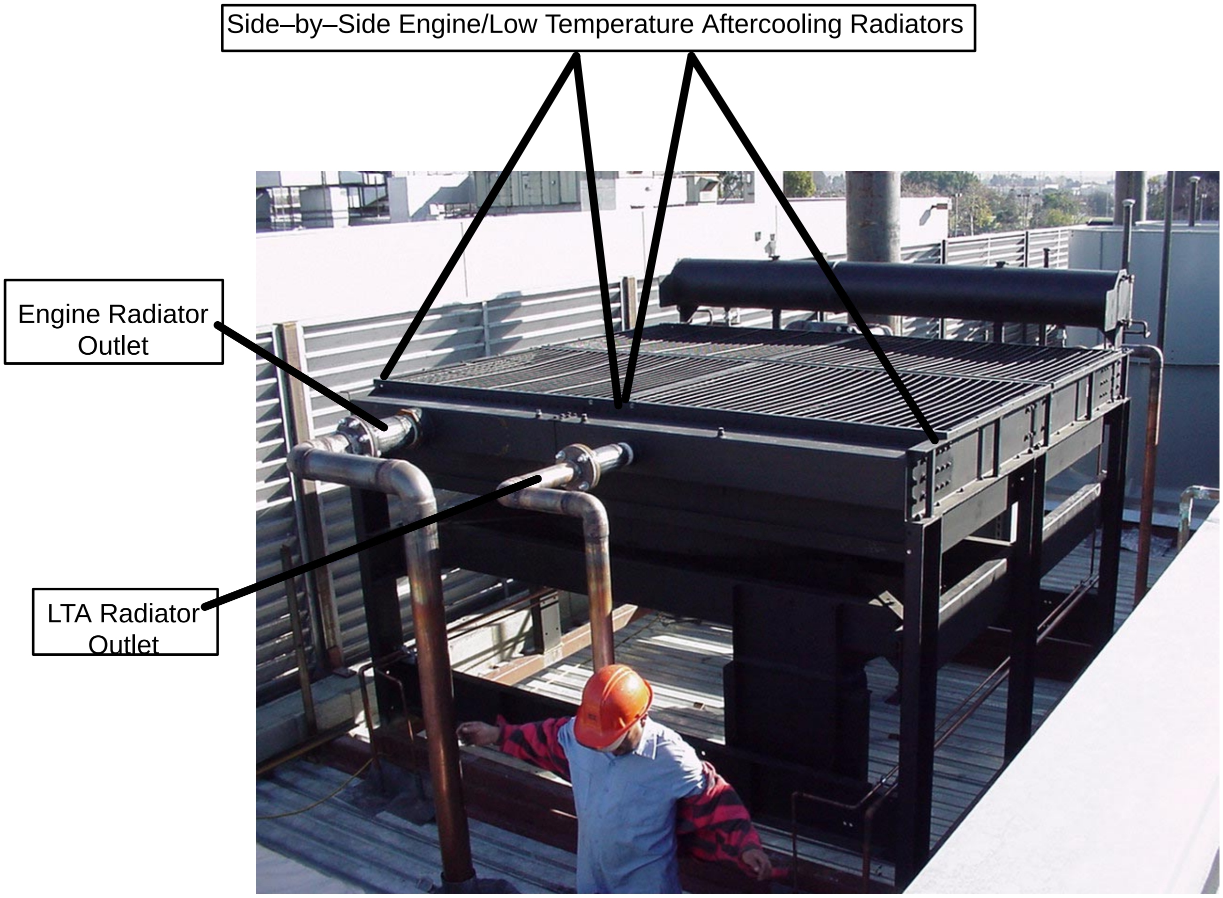



**Figure 6–19.** A Horizontal Remote Radiator and Aftercooler Radiator

Radiators may be either horizontal type (radiator core is parallel to mounting surface) or vertical type (radiator core is perpendicular to mounting surface) (**Figure 6–19**). 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 6–20**). 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

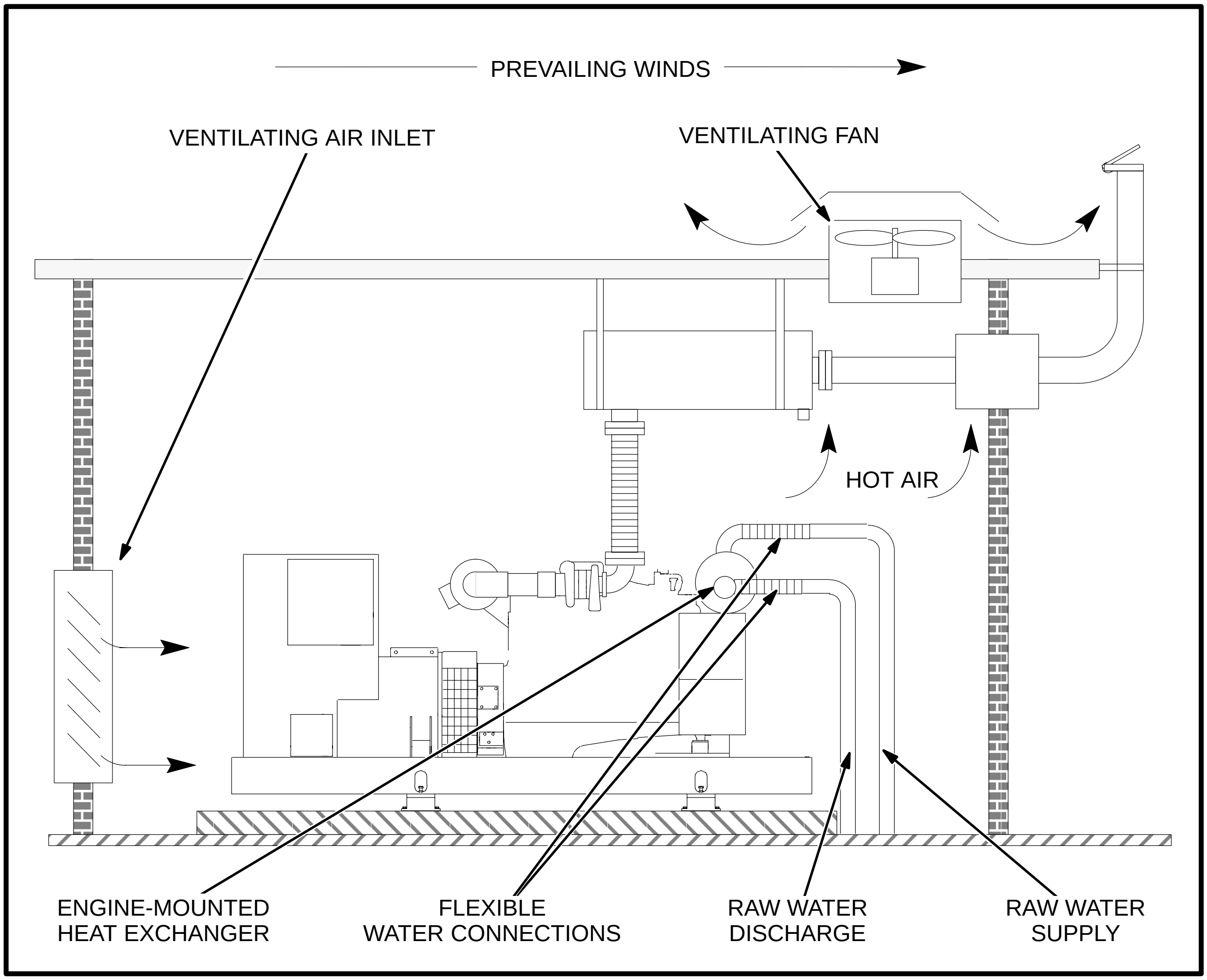



**Figure 6–20**. Factory-Mounted Heat Exchanger Cooling

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.

- 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[11].
- The heat exchanger and water piping must be protected from freezing if the ambient temperature can fall below 32 F (0 C).
- 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:

11 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.

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

Where:
$\Delta$ 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 6–21**) 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

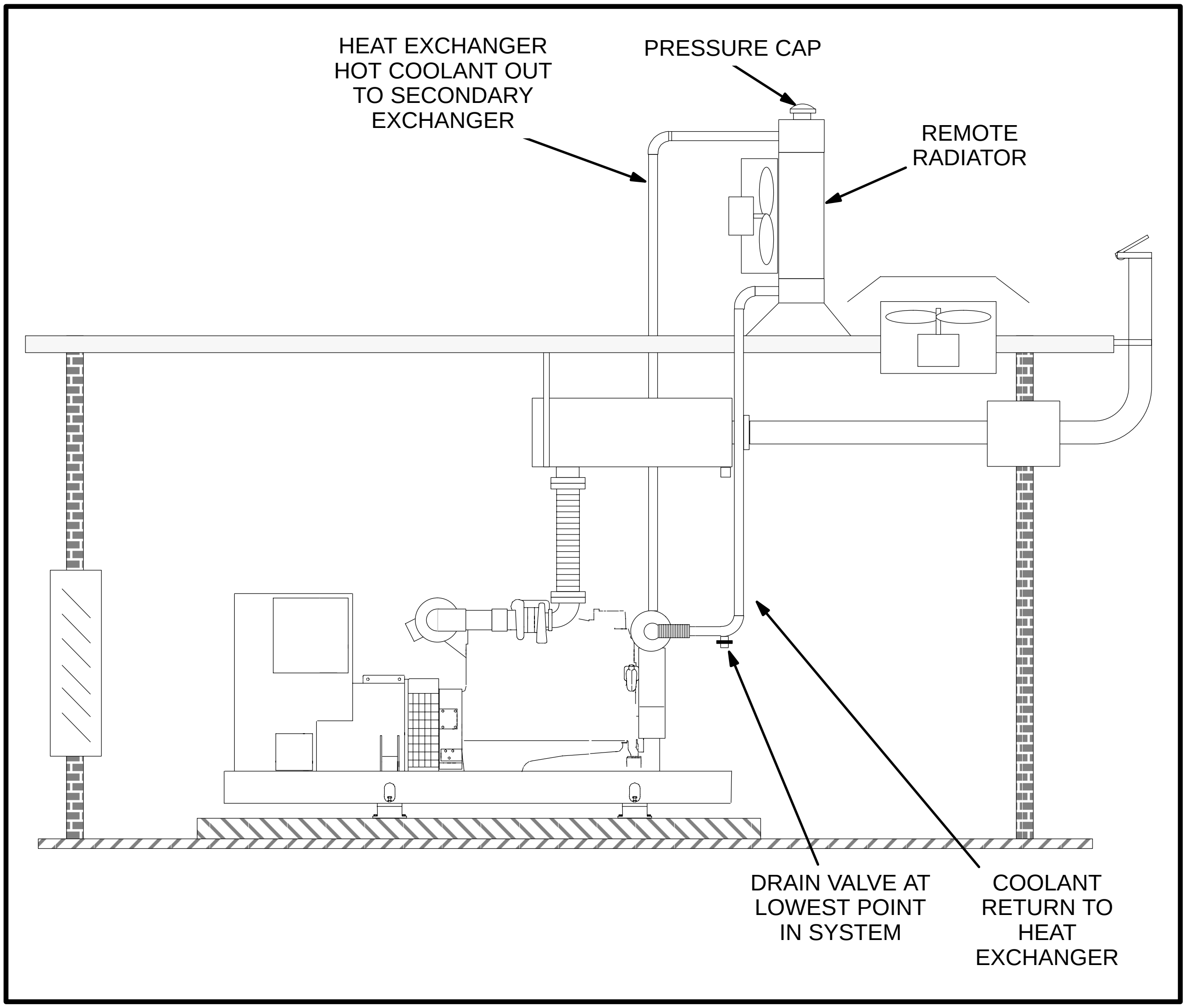



**Figure 6–21.** Dual Heat Exchanger System (With Secondary Liquid–to–Air Cooler)

specific application, considering the requirements of the engine, liquid to liquid heat exchanger, and remote heat exchanger device[12].

*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 6–22.**

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.

12 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.

### 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.

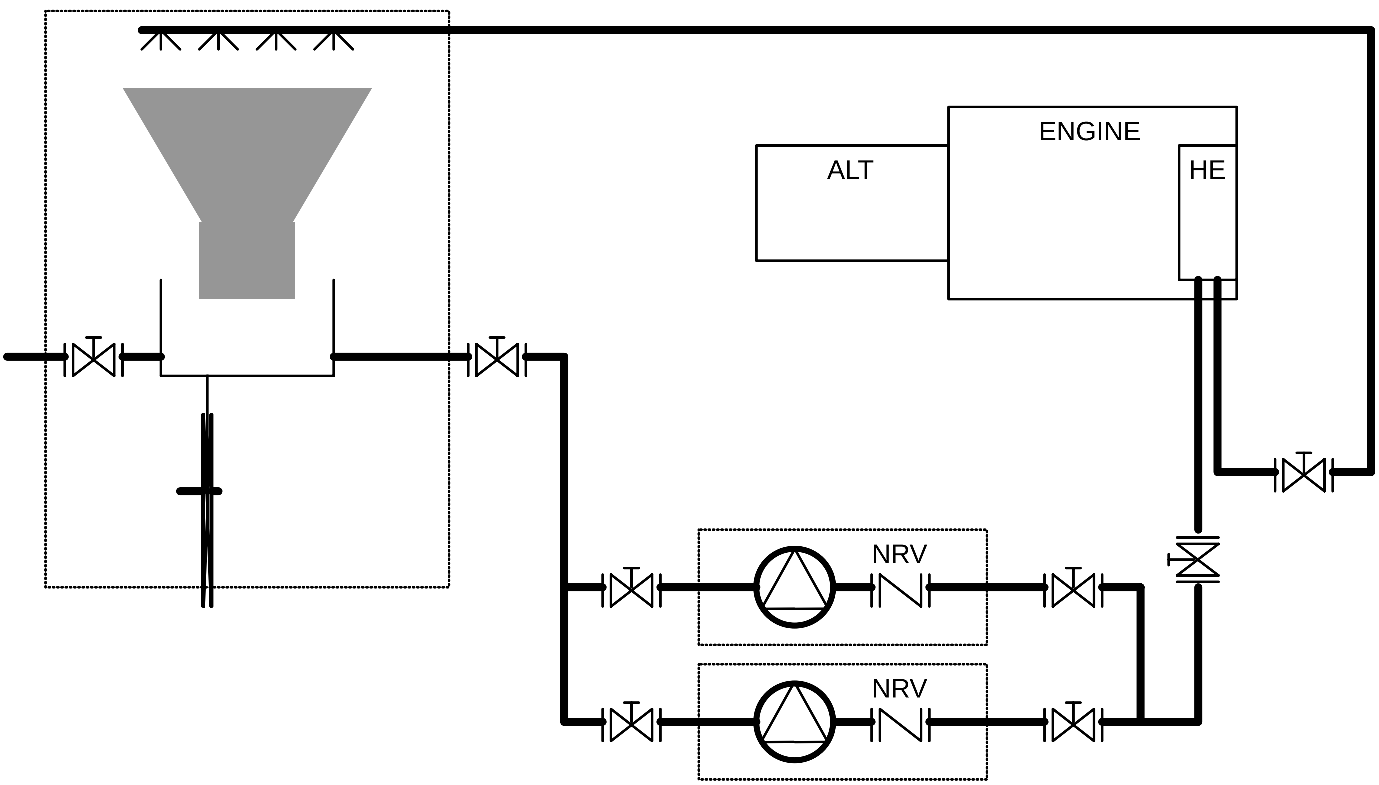



**Figure 6–22.** Diagram of Representative Cooling Tower Application

## Cooling Pipe Sizing Calculations

The preliminary layout of piping for a remote radiator cooling system shown in **Figure 6–16** 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 6–3** 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 6–23**, 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

| 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 1/2** | 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° 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° 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 6–3**. Equivalent Lengths of Pipe Fittings and Valves in Feet (Meters)

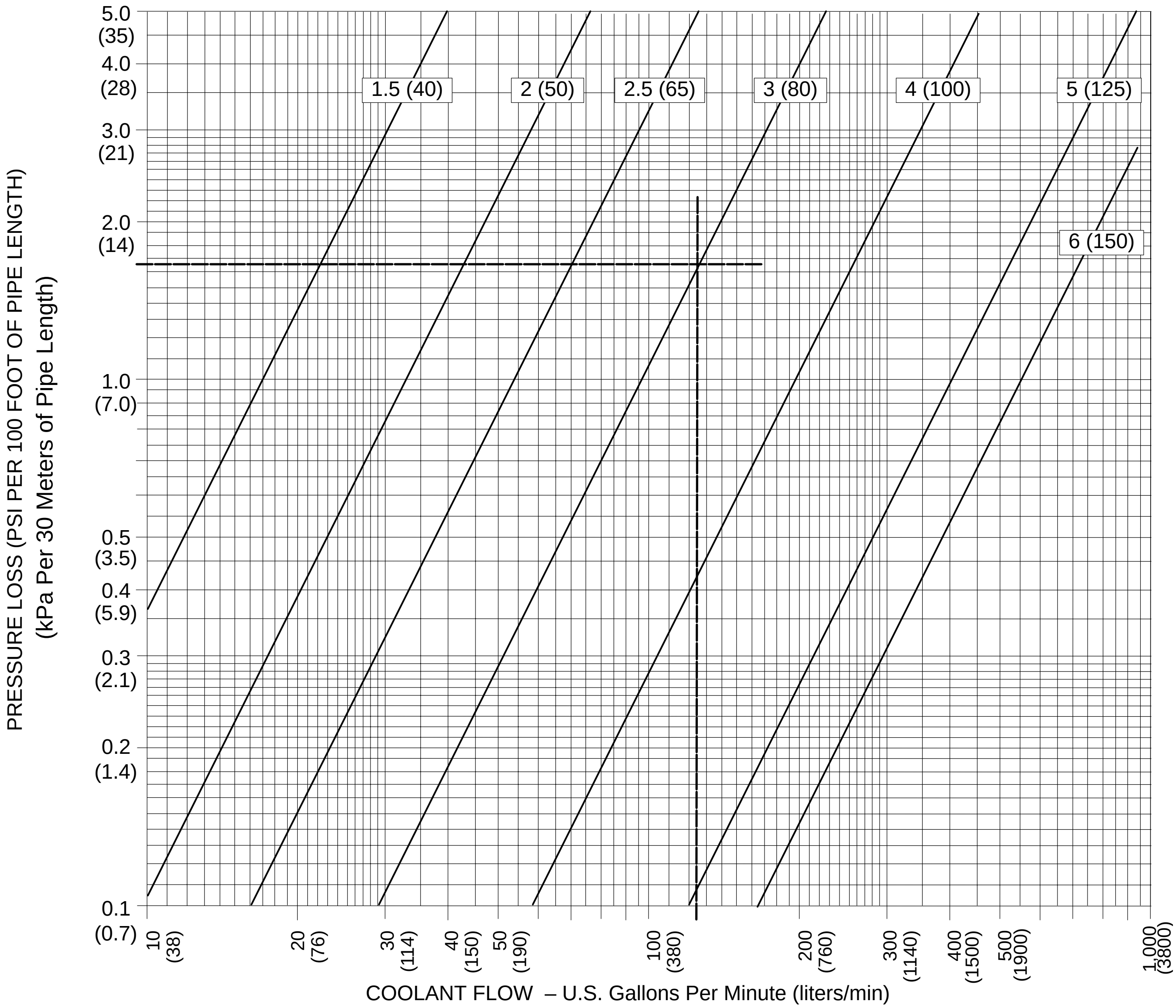



**Figure 6–23.** Frictional Pressure Losses for Inch (mm) Diameter Pipes

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.

*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 6–4** 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

### 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 6–24**). 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 6–4.** Freezing and Boiling Points vs. Concentration of Antifreeze

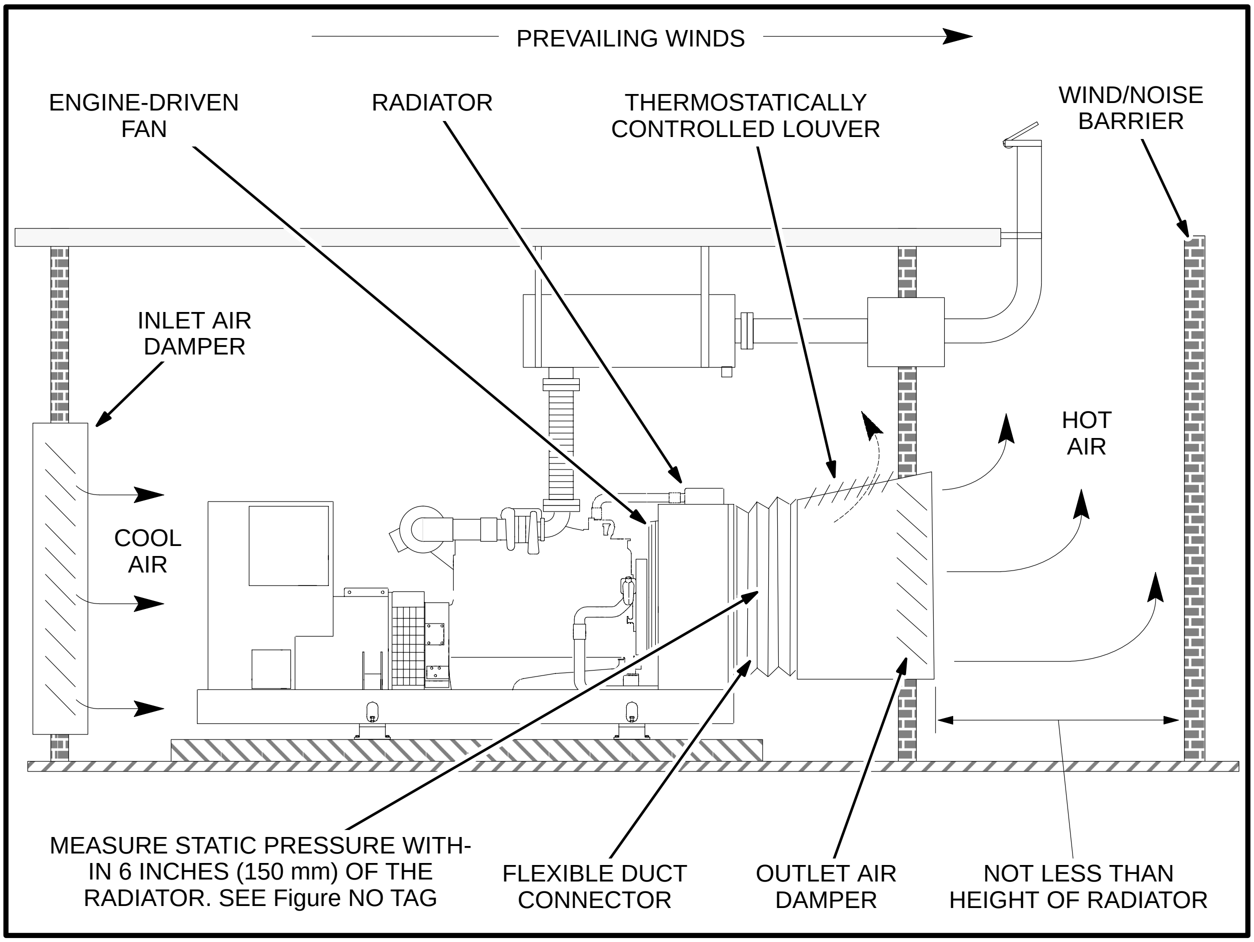



**Figure 6–24**. Factory-Mounted Radiator Cooling

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 6–25**. 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[13]. 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.

13 .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.

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.

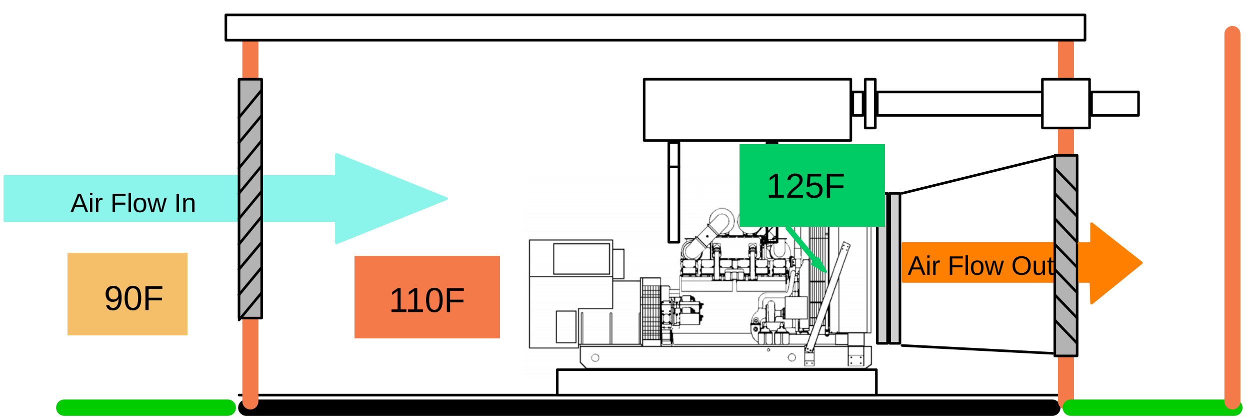



**Figure 6–25.** Typical Air Temperature Surrounding an Operating Genset

## 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 ($1.01 \times 10^{-3}$ MJ/kg–° C).
$\Delta T$ = 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[14].

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.

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.

14 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.

## 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 6–24**), 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 6–24, 6–26, and 6–27**, 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 6–27**). 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 6–27**, 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.

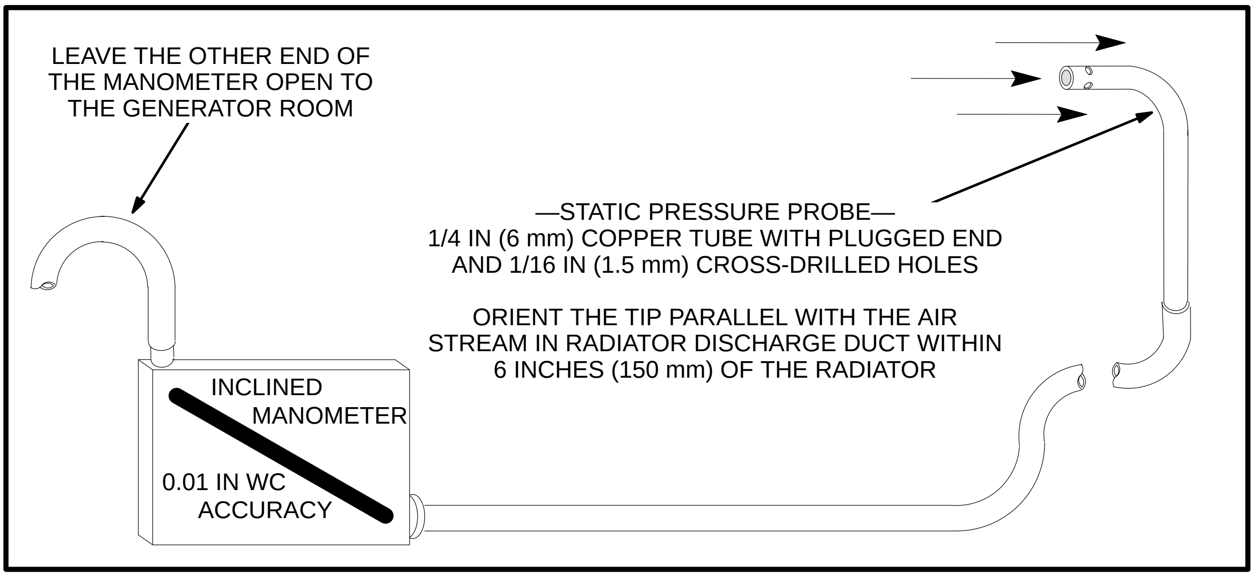



**Figure 6–26.** Recommended Instrumentation for Measuring Air Flow Restriction

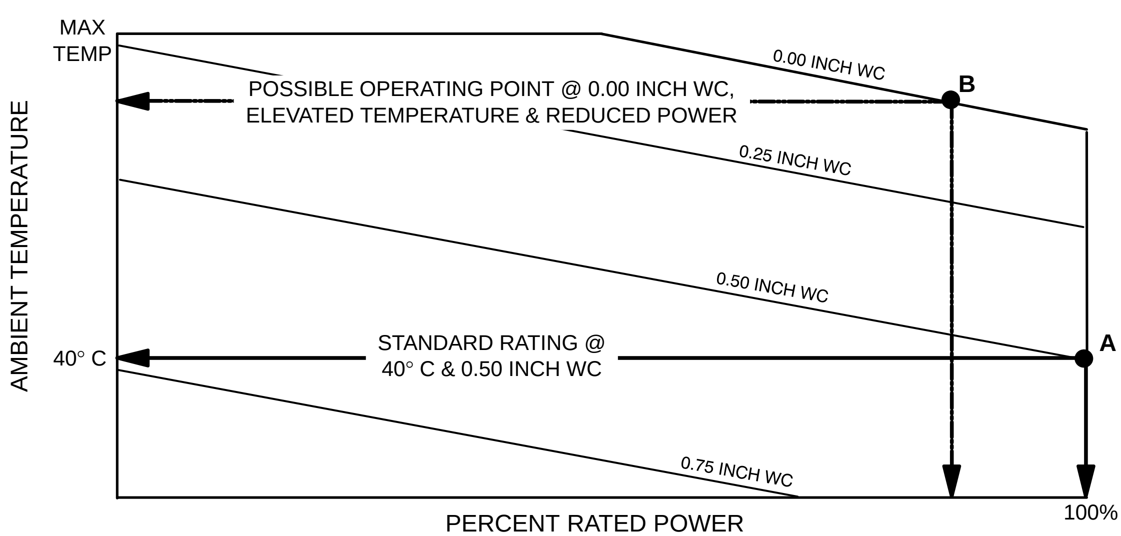



**Figure 6–27.** Figure Cooling Capability in Elevated Ambients

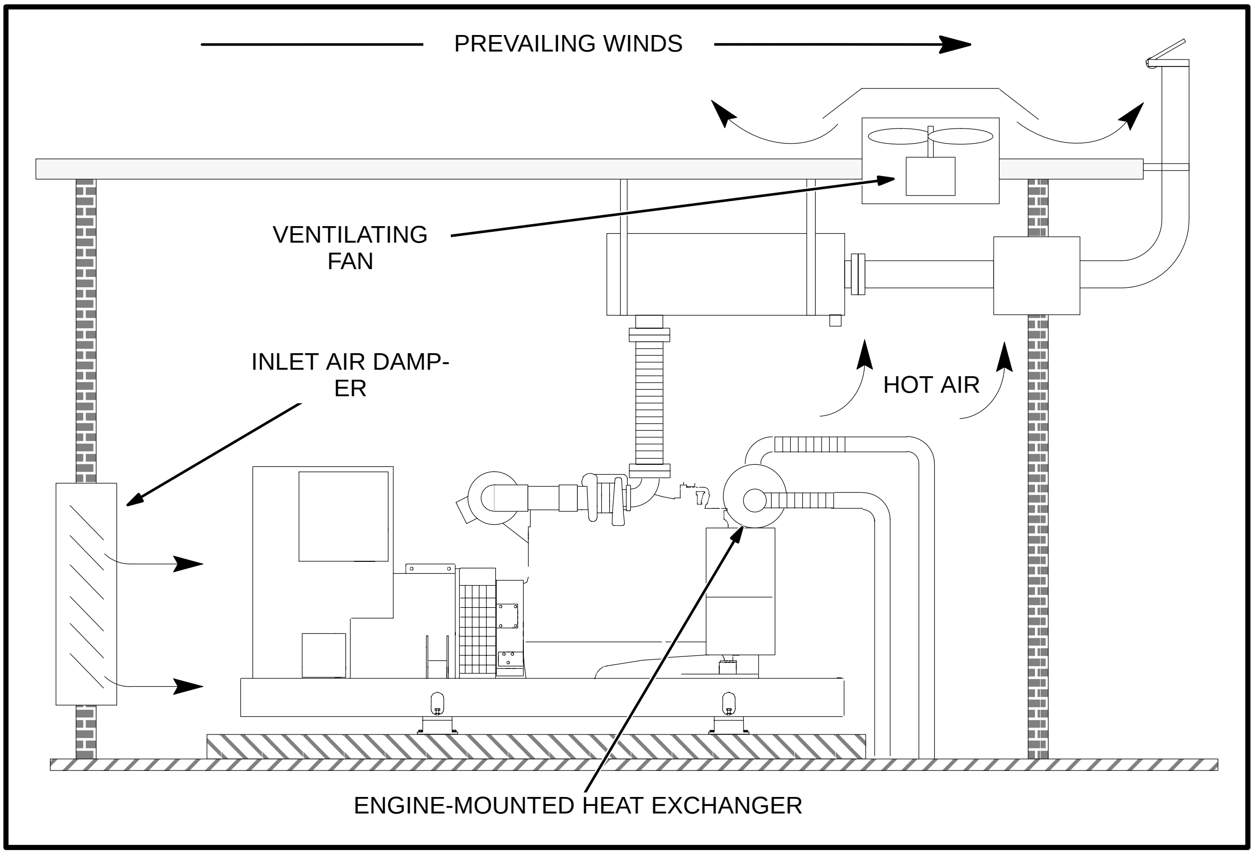



**Figure 6–28.** Ventilation for a Heat Exchanger Cooling System

### Ventilating Heat Exchanger or Remote Radiator Applications

A heat exchanger (**Figure 6–28)**, 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 6–5** 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 |

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):

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