HVAC Design
Industrial Ventilation

by

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Introduction

This course is intended for mechanical engineers who want to learn more about Industrial Ventilation. This course qualifies for one (1) hour Professional Engineering CEU credit. Topics include refrigeration machine room ventilation, battery room ventilation, and warehouse ventilation & heating. Included free with this course are industrial ventilation Excel spreadsheets which are yours to keep and use. Upon completion of this course, you should have a thorough understanding of the design concepts involved in industrial ventilation.

Machine Rooms

Machine rooms, as they are referred to in the building code, are rooms which contain refrigeration equipment such as water chillers, ammonia compressors, or other mechanical refrigeration equipment. The ventilation requirements for machine rooms are governed by building codes such as the International Mechanical Code, the California Mechanical Code, and the Florida Mechanical Code. Insurance provider FM (Factory Mutual) and standards organizations such as ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) and IIAR (International Institute of Ammonia Refrigeration) also publish requirements for machine room ventilation.

Machine room ventilation serves two purposes. The primary purpose is to ensure that the concentration of any leaked refrigerant does not rise above dangerous levels. Secondly, machine room ventilation serves to keep the temperature in the room within set design parameters. Machine room ventilation typically consists of the following components: a) Two or more rooftop exhaust fans (or a single, two-speed exhaust fan); b) A method of supplying air such as wall louvers, gravity ventilators, or supply fans, and, c) Depending on the project locale, some method of heating the make-up air such as a unit heater or a make-up air unit. Another key ingredient in machine room ventilation is the refrigerant monitor. The refrigerant monitor serves to continuously monitor the concentration of refrigerant gas inside the machine room in order to trigger appropriate alarm and control action in the event of a potentially dangerous situation.

The building code prescribes the required continuous ventilation rate and emergency ventilation rate for a machine room. The emergency ventilation rate prescribed by the building code is as follows:

**CODE-REQUIRED EMERGENCY VENTILATION RATE**

\[ Q = 100 \sqrt{G} \]

Where:

- \( Q \) = Emergency Ventilation Rate, CFM
- \( G \) = Pounds of Refrigerant in the largest System
The minimum continuous ventilation rate prescribed by the building code is as follows:

**CODE-REQUIRED MINIMUM VENTILATION RATE**

\[ Q = 0.5 \text{ CFM/Sq. Ft.} \]

FM projects must meet a higher standard for the emergency and continuous ventilation rates. The ventilation rates prescribed by FM are as follows:

**FM-REQUIRED EMERGENCY VENTILATION RATE**

\[ Q = 10 \text{ CFM/Sq. Ft.} \]

**FM-REQUIRED MINIMUM VENTILATION RATE**

\[ Q = 1 \text{ CFM/Sq. Ft.} \]

IIAR has still more requirements related to the emergency ventilation rate:

**IIAR-REQUIRED EMERGENCY VENTILATION RATE**

\[ Q = 30 \text{ Air-changes per hour} \]

In addition, IIAR requires that if more than one fan is used to achieve the emergency ventilation rate, the fans must be selected such that the failure of any one single fan will not result in an overall ventilation rate of less than 20 air-changes per hour. In determining the required ventilation rates, all applicable requirements must be evaluated and the worst case (method resulting in the highest CFM) must be used.

Next is the summer or cooling ventilation rate. In order to calculate the required summer ventilation rate, the maximum allowable machine room temperature must be determined. Most codes allow the temperature in the machine room to peak at 18°F above the 1% ASHRAE summer outdoor design temperature. However, in cases where that value exceeds 104°F, the mechanical engineer should alert the electrical engineer to de-rate the power wiring in the room as required by NEC Article 310 (National Electric Code), or, just use 104°F as the maximum allowable temperature. The California Mechanical Code does not have the 18°F rule and instead simply limits the maximum machine room indoor temperature to 104°F. The California Code also requires that at all times the machine room must be kept at a 0.05” w.c. negative pressure.

The machine room summer ventilation rate is based on the design room temperature, the total horsepower in the room, the 1% ASHRAE summer outdoor design temperature, and the room solar load. Roof and wall solar loads can be calculated using standard ASHRAE methods as
outlined in the ASHRAE Fundamentals Handbook. The amount of motor heat is calculated by converting 10% of the rated motor HP to BTU/HR using the equation in Appendix A of IIAR Bulletin 111:

MACHINE ROOM MOTOR HEAT

MOTOR HEAT = HP x (1 – Motor Efficiency) x 2545  BTU/HR

IIAR has a requirement related to the summer ventilation rate:

IIAR-REQUIRED SUMMER VENTILATION RATE

Q = 20 Air-changes per hour

Again, the method resulting in the highest CFM must be used. Oftentimes the calculated emergency ventilation rate and the summer ventilation rate are similar in terms of airflow quantity. When the summer ventilation rate exceeds the emergency ventilation rate, good design practice is to use the summer ventilation rate as a combined summer/emergency ventilation rate. The required emergency ventilation rate is a minimum, therefore it can be exceeded. When the emergency ventilation rate exceeds the summer ventilation rate, again the greater value can be used as a combined summer/emergency ventilation rate unless the values differ significantly. If the summer ventilation rate is significantly less than the emergency ventilation rate, then the energy savings associated with running the fans at the lower rate during the summer should be weighed against the equipment cost required to provide two different rates for the summer and emergency ventilation.

Because a machine room requires continuous ventilation, heating will likely be required depending on the project locale. The first decision to make is the winter indoor design temperature. NFPA 13 requires a minimum of 40º F in any building area with fire protection sprinklers. Comfort conditions for operating staff may dictate a warmer winter indoor design temperature. The owner may be able to provide some guidance, or a value such as 50º F can be used. It is important to determine the amount of heat required without taking any credit for the heat generated by the machine room equipment. This is due to the fact that during a wintertime maintenance shutdown the machine room equipment will be de-energized thereby providing no heat.

The machine room winter heating requirement is based on the design winter room temperature, the minimum ventilation rate, the ASHRAE 99% winter outdoor design temperature, and the room envelope heat loss. Roof, wall and floor heat loss can be calculated using standard ASHRAE methods as outlined in the ASHRAE Fundamentals Handbook.
To mechanical engineers, it may come as a surprise that most building owners consider the machine room to be something less than the most glamorous part of their facility. Most owners just want the least-costly design for the machine room and its ventilation; i.e., something that provides the code-required minimums without straining the budget. A machine room ventilation design template that is both effective and cost-efficient would include the following: Two rooftop exhaust fans, two wall louvers, one unit heater, and a refrigerant monitor (see Diagram 1). One of the two exhaust fans is for continuous ventilation. Continuous means continuous, therefore this exhaust fan will run 24/7, 365 days a year. A good application for the continuous exhaust fan is an aluminum centrifugal unit. These fans provide quiet operation and excellent longevity in a continuous application. The second of the two exhaust fans is for the summer/emergency ventilation. A good application for this fan is a galvanized steel upblast propeller fan. These fans have a relatively low first cost for the high CFM delivered.

One of the two wall louvers in the design template is for continuous ventilation supply air. This wall louver does not need to be provided with a damper because by design the louver will always be open. The other wall louver is for the summer/emergency ventilation supply air. This louver will be much larger and will typically be fitted with a motor-operated damper to close the louver during the cold winter months. The unit heater serves to maintain the machine room space temperature in the wintertime under normal operating conditions (i.e., with the emergency ventilation de-energized). In this design template, the unit heater would be installed near the continuously-open wall louver so that it can provide heat to the incoming outside air as it enters the room. The unit heater is not intended to maintain the room above freezing in the event of an emergency (i.e., with the emergency ventilation energized).

Diagram 1 – Typical Machine Room Ventilation Design
Warmer climates allow a slight variation to the design template. In a warmer climate where the winter outdoor temperature never falls below the machine room indoor winter design temperature, some of the equipment outlined above can be eliminated (see Diagram 2). This would include the smaller (continuous) wall louver, the motor-operated dampers on the larger (summer/emergency) wall louver, and the unit heater. The smaller (continuous) wall louver is not needed because in a warm climate all of the air can come in through the larger wall louver. There is no need to restrict the amount of air coming in so the large wall louver can serve as both the continuous wall louver and the summer/emergency ventilation wall louver. Since it is continuous, no damper is needed on the large wall louver. Similarly, no unit heater is needed.

![Diagram 2 – Machine Room Ventilation - Warm Climate](image)

The final product as depicted in these diagrams might not look very complicated to the untrained eye, but obviously there is a lot to consider when designing machine room ventilation. The Excel spreadsheet entitled *Industrial Ventilation – Machine Room.xlsx* which accompanies this course serves to provide a quick and easy method to design machine room ventilation based on the design template. The spreadsheet input consists of the machine room dimensional data, the construction materials, building insulating values, the summer and winter indoor and outdoor design temperatures, the governing codes, the type and quantity of refrigerant, the machine room motor horsepower, and the machine room motor efficiency. The spreadsheet calculates the required CFM for the continuous and summer/emergency ventilation rates, wall louver sizes, and the required heating capacity.

The codes and standards have other HVAC-related requirements and should be read in their entirety before attempting a design. Some of the highlights would include:
- Limiting the unit heater coil temperature to 800°F
- Corrosion-resistant insect screens on all air intakes
- Motor-operated dampers that are power close, fail open
- All exhaust fans must discharge vertically with an air velocity of not less than 2,500 FPM
- All exhaust fans must have non-sparking blades
- All exhaust fan motors located inside the building or in the airstream must be TEFC (totally enclosed, fan-cooled)

Battery Rooms

Many industrial projects have designated areas for recharging battery-powered equipment such as forklifts and pallet jacks. Battery charge rooms require special consideration with regard to ventilation. Battery room ventilation is governed by section 502 of the International Mechanical Code and the Florida Mechanical Code, and section 608 of the California Fire Code. The battery room ventilation requirements are identical in all three codes. The code prescribes a continuous ventilation rate of 1 CFM per Sq. Ft. Alternately, the code allows the battery room ventilation system to be designed such that the room hydrogen concentration is limited to no more than 1%. This latter option typically results in a lower overall ventilation rate when compared to the 1 CFM per Sq. Ft. method. Using the 1% method provides the opportunity to lower the ventilation rate even further when the hydrogen concentration rate is below the 1% threshold. Lower ventilation rates result in energy savings and equipment cost savings.

The volume of hydrogen produced in a battery room during charging can be calculated as follows:

\[ H = \frac{(N \times C \times O \times G \times A)}{T} \]

Where:

- \( H \) = Hydrogen production rate, \( \text{FT}^3/\text{HR} \)
- \( N \) = Number of batteries
- \( C \) = Cells, number per battery
- \( O \) = Overcharge assumption
- \( G \) = Generated volume of hydrogen produced by 1 amp-hour of charge, \( \text{FT}^3/\text{cell} \)
- \( A \) = Amp-hour rating per battery
- \( T \) = Time period assumed during which hydrogen gas is released

Once the total hydrogen production rate has been determined, the air-change rate required to limit the hydrogen concentration in the room to 1% can be calculated as follows:

\[ R = \left( \frac{V \times HC}{H} \right) \times 60 \text{ Minutes per hour} \]
Where:

\[ R = \text{Rate of air-change} \]
\[ V = \text{Volume of battery room, FT}^3 \]
\[ HC = \text{Hydrogen percent concentration allowed} \]
\[ H = \text{Hydrogen production rate, FT}^3/\text{HR} \]

Finally, the rate of air-change \( R \) can be converted to the required exhaust rate CFM:

\[ Q = \frac{V}{R} \]

Where:

\[ Q = \text{Required battery room exhaust rate, CFM} \]
\[ V = \text{Volume of battery room, FT}^3 \]
\[ R = \text{Rate of air-change} \]

According to battery manufacturers’ published literature, the typical lead acid motive battery generates approximately 0.01474 FT\(^3\) of hydrogen per cell at standard temperature and pressure. The following example calculates the exhaust CFM required to limit the hydrogen concentration to the code-required 1%. The example is for a 1,000 Sq. Ft. battery room measuring 30 Ft high with 15 batteries charging, each battery has an 850 amp-hour rating and 36 cells, assuming 20% overcharge and a hydrogen release period of the last 4 hours of an 8-hour charge:

\[ H = (15 \times 36 \times 0.2 \times 0.01474 \times 850)/4 = 338.3 \text{ FT}^3/\text{HR} \text{ Total Hydrogen Produced} \]

\[ R = ((1,000 \times 30 \times 0.01)/338.3) \times 60 = \text{one air change every 53.2 minutes} \]

\[ Q = (1,000 \times 30)/53.2 = 564 \text{ CFM Required Battery Room Exhaust Rate} \]

The Excel spreadsheet entitled *Industrial Ventilation – Battery Room.xlsx* which accompanies this course serves to provide a straightforward tool to design battery room ventilation based on the equations outlined above. The spreadsheet input consists of the battery room dimensional data, the number of batteries, the amp-hour rating per battery, the number of cells per battery, the maximum hydrogen concentration allowed, the generated volume of hydrogen produced by 1 amp-hour of charge, the assumed charging hydrogen release time period, and the assumed overcharge. The spreadsheet shows default values for many of these parameters if unknown. The spreadsheet calculates the exhaust CFM required to limit the hydrogen concentration in the battery room to the code-required 1%.

Since many battery charge rooms are ventilated (i.e., not air-conditioned or refrigerated), the spreadsheet includes a provision for documenting the air-changes per hour provided for summer
ventilation. That is, the cooling ventilation provided in the summer which is unrelated to battery charging. If the battery charging room is air-conditioned or refrigerated, that part of the calculation should be disregarded.

Once the calculations have been performed, the battery room HVAC can be designed. There are a number of considerations to keep in mind. Battery charging rooms should be negatively pressurized. Typically a battery charging room is designed to be 10% negative with respect to adjacent areas.

Where possible, the exhaust fan for continuous ventilation should be a centrifugal, direct drive unit due to the fact that it operates all the time. A good application for the exhaust fan used for summer ventilation is a hooded propeller unit controlled by a thermostat. Upblast propeller fans should be avoided due to the possibility of water intrusion into the heavily-electrified space.

In cool climates, the make-up air for continuous ventilation should be provided with thermostatically-controlled heat for winter operation. A wall louver/unit heater arrangement should be avoided due to the lack of supply air distribution and the possibility of water intrusion. Instead, a 100% outside air (non-recirculating) gas-fired make-up air unit (MAU) should be used for the continuous ventilation make-up air.

A good application for the summertime ventilation supply air is a hooded propeller filtered supply fan. Filters and insect screens are often required because battery charge rooms typically communicate directly with (have open doors to) process and/or product storage space.

The continuous ventilation exhaust ductwork should be designed to exhaust the room at points both high and low. This is due to the fact that hydrogen is lighter than air and acid fumes are heavier than air. 75% of the total exhaust flow should be taken from within 12 inches of the top of the space, and the remaining 25% should come from within 12 inches of the floor. The exhaust for the summertime ventilation fan does not need to be ducted.

The supply air duct from the continuous ventilation MAU should extend out laterally over the charging area. The supply air duct should be provided with supply air diffusers directed down towards the floor to provide good air mixing. The supply duct should be located above the highest battery rack but not so high that it short-circuits with the exhaust. The make-up air supply fan for the summertime ventilation does not need to be ducted.

To conserve heating energy in the wintertime, consider using a hydrogen sensor to cut the winter ventilation rate in half whenever the hydrogen concentration is below 1%. Because hydrogen is lighter than air, the hydrogen sensor should be placed at the highest point in the space. The sensor should not have any effect on the heat removal fans.

**Warehouse Ventilation & Heating**
Warehouse ventilation is perhaps the least technically-challenging of the three industrial ventilation topics covered in this course. However, in other ways it may prove to be the most challenging. Mechanical engineers today are increasingly finding themselves in a design/build environment, where the construction team has a great deal of influence over the design process. Because warehouse ventilation is a relatively simple and intuitive endeavor, as Jimmy Durante used to say, “Everybody wants to get into the act!” In other words, designing warehouse ventilation can be a challenge because it looks so simple that everyone has an opinion on how it should be done. Those working in a design/build environment would be wise to seek input from the construction team before ever putting pen to paper. Those who don’t might find themselves designing the warehouse ventilation over and over again.

There are a number of ways to ventilate a warehouse space. Below is a list of some of the possible combinations of commonly-used warehouse ventilation equipment:

- Rooftop supply fans and rooftop exhaust fans.
- Sidewall supply fans and rooftop exhaust fans.
- Rooftop supply fans and sidewall exhaust fans.
- Sidewall supply fans and sidewall exhaust fans.
- Rooftop gravity vents and rooftop exhaust fans.
- Rooftop gravity vents and sidewall exhaust fans.
- Wall louvers and rooftop exhaust fans.
- Wall louvers and sidewall exhaust fans.

In addition, there are various permeations which provide plenty of options from which to choose. Some examples would include putting all of the exhaust on one side of the warehouse and all of the supply on the other side in order to create a cross-flow effect. Another would be to place all of the exhaust on the roof along the center with the supply split between two opposing walls creating a converging airflow pattern. The following plan-view diagrams depict a few commonly-used warehouse ventilation schemes:
Diagram 3 – Supply and Exhaust Fans on Roof

Diagram 4 – Wall Louvers and Sidewall Exhaust Fans
Once the basic layout is established, the next step is to determine the summer ventilation airflow quantity. It should be noted that the primary purpose of the summer warehouse ventilation is to provide a tenable environment for the workers inside the warehouse during the warm summer months, not to meet the code-required minimum ventilation rate. The code-required minimum ventilation rate is considerably less than the summer ventilation airflow quantity. The code-required minimum ventilation rate will be 0.05 – 0.06 CFM/Sq. Ft. (depending on the governing code), and it is a consideration only during the winter months.

Warehouse summer ventilation rates typically range from 2 – 4 air-changes per hour. The ventilation rate is calculated taking into consideration the estimated volume of air displaced by the warehouse product. As mentioned, the winter ventilation rate will be considerably less; it will be the greater of the code-required minimum and the ventilation air needed for propane forklifts (where applicable). The *Industrial Ventilation Manual* recommends 5,000 CFM of outside air per propane forklift.

The Excel spreadsheet entitled *Industrial Ventilation – Warehouse.xlsx* which accompanies this course calculates the required amount of summer and winter ventilation. The spreadsheet input consists of the warehouse dimensional data, the product displacement volume expressed as a percent of the warehouse volume, the design air-changes per hour, the design positive pressurization, the code-required minimum ventilation, and the number of propane forklifts (if any). The spreadsheet calculates the summer ventilation rate supply and exhaust CFM, as well as the winter (minimum) ventilation rate.

The heating capacity required for a warehouse depends on the type of heating system used. There are two fundamental methods used to heat warehouses: 1) Pressurized Heating, and 2) Recirculating Heating. Pressurized heating works by bringing all of the air used for heating in
from the outside, with no exhaust. This serves to pressurize the building which in turn prevents infiltration from entering the warehouse through the dock doors and other building areas. The heating system for a pressurized warehouse typically consists of several direct gas-fired make-up air units (MAUs) which heat 100% outside air. The required heating capacity is calculated by determining the building envelope losses and adding to that value the heat required to heat the outside air. Because the calculations for a pressurized warehouse are dependent on the amount of air being brought in, equipment sizing is best handled by working directly with the manufacturers. That way standard unit sizes can be specified which keeps the mechanical equipment costs low. Companies that specialize in pressurized warehouse heating can be found by doing a web search on “direct gas fired ventilation energy efficient warehouse.”

A recirculating heating system draws air used for heating from inside the warehouse and heats the air before discharging it back into the warehouse. Examples of a recirculating heating system would include air rotation units (ARUs) and unit heaters. Since a recirculating system does not pressurize the warehouse, infiltration must be taken into account when determining the required heating capacity. The required heating capacity for a warehouse with a recirculating heating system is calculated by determining the building losses and adding to that value the heat required to offset the estimated infiltration. Oftentimes the infiltration air quantity is more than enough to satisfy the required minimum ventilation rate, however this must be checked. In cases where the required minimum ventilation rate exceeds the estimated infiltration rate, tempered make-up air must be included in the design.

The Excel spreadsheet entitled *Industrial Ventilation – Warehouse Heating.xlsx* which accompanies this course calculates the heat required for a recirculating warehouse heating system. The spreadsheet input consists of the warehouse dimensional data, the design temperatures, the number of dock doors, dock door dimensions, building materials and insulating values. The spreadsheet calculates the total heating load including the estimated infiltration air.

**Conclusion**

We hope that you have found this course in industrial ventilation to be helpful. The success of industrial projects depends on the mechanical engineer getting the industrial ventilation right. Please navigate to the test page in order to receive credit for taking this course.

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