Ventilation of 19 South Florida Fire Stations

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Abstract

Combustion gases from diesel engines of trucks accumulate in the apparatus rooms of fire stations when fire trucks and emergency vehicles leave for or return from an emergency run. The situation is most extreme when fire trucks leave for an emergency run. All doors are closed for security reasons and combustion gases become trapped in closed apparatus rooms. These gases can migrate to the living quarters located next to the apparatus rooms, causing discomfort or potential health problems for personnel returning to the building. This paper discusses a study and investigation of the methods available to minimize these combustion gases and the subsequent installation of apparatus room ventilation systems in nineteen City of Tampa Fire Stations.

Keywords

- Ventilation
- Air Quality
- Garage Ventilation
- Indoor Air Quality
- Truck

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Abstract

Combustion gases from diesel engines of trucks accumulate in the apparatus rooms of fire stations when fire trucks and emergency vehicles leave for or return from an emergency run. The situation is most extreme when fire trucks leave for an emergency run. All doors are closed for security reasons and combustion gases become trapped in closed apparatus rooms. These gases can migrate to the living quarters located next to the apparatus rooms, causing discomfort or potential health problems for personnel returning to the building. This paper discusses a study and investigation of the methods available to minimize these combustion gases and the subsequent installation of apparatus room ventilation systems in nineteen City of Tampa Fire Stations.

Ventilation Challenge Description

When receiving an emergency or fire alarm call, fire station and emergency personnel immediately start the diesel engines of their fire trucks and emergency vehicles. If the weather is pleasant, the fire station apparatus room garage doors are immediately opened. In cases of extremely hot, cold or otherwise inclement weather, the garage doors are not opened until emergency and fire personnel board the trucks and are ready to leave the fire station. After leaving the fire station, the building, in most cases, is empty of all personnel and all fire station doors are then closed for security reasons. This enables the combustion gases produced by several minutes of an operating diesel engine to remain in the enclosed apparatus room space. These gases can then migrate to adjacent kitchen, bedroom, living room and other living areas near the fire station apparatus room. Upon return to the fire station, vehicles are backed into the apparatus room, contributing additional combustion gases. If the weather is pleasant, the apparatus room doors are left open to allow the combustion gases to escape completely and outdoor air to enter the apparatus room. If it is extremely cold or hot that day, the doors are left open a minimal amount of time, disbursing only a majority of the combustion gases with outdoor air and then the doors are closed. Again, with combustion gases trapped in the apparatus room, chances of migration to the living spaces exist.

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The City of Tampa Fire Department recognized that these conditions could cause discomfort, unpleasant working conditions and potential health problems for its fire department and emergency personnel. The City of Tampa architectural and engineering department commissioned a study to determine the most effective method of minimizing the effect of the combustion gases in the fire station living spaces and apparatus rooms. Based upon the results of this study, the City of Tampa installed ventilation systems in all nineteen active fire stations.

The Study

Four methods of minimizing combustion gases in the apparatus rooms and living spaces of the fire stations were studied:

System #1. **"On vehicle" exhaust pipe filter.**

System #2. **Direct connection of flexible piping to vehicle exhaust pipe and connected combustion gas exhaust removal system.**

System #3. **General ventilation of apparatus room with manual start control.**

System #4. **General ventilation of apparatus room with combustion gas monitoring and automatic control.**

Evaluation

The study evaluates the advantages and disadvantages, the projected implementation, the costs and use of each system in relation to the expected results of each system.

Table 1 lists the criteria used to evaluate systems for minimizing combustion gases in the apparatus rooms of nineteen City of Tampa Fire Stations. The following criteria are weighed as to its importance (as shown in the rated score factor in Table 1) with the total weighted score determined for each system:

1. *System installation costs*: The system installation costs were calculated to ensure that all systems would be within budget and placed in relative order in the evaluation.
2. *Operational costs:* Operational costs include electrical, maintenance and replacement costs. These were also placed in relative order in the evaluation.
3. *Ease of use*: Ease of use was an important consideration in the evaluation. A system that is totally automatic or requires little or no human intervention operates and provides service more reliably than a system which requires manual operation or intervention.
4. *Continuous use potential:* Although some of the systems are mechanically simple, there are maintenance or replacement factors which diminish the possibility of continuous use. It is very important to ensure removal of carbon dioxide and carbon monoxide gases on a continuing basis, making this an important evaluation factor.
5. *CO and CO_2 monitoring*: Monitoring of these gases was deemed extremely important for health considerations and litigation potential.
6. *Fume/Gas Removal*: A relative rating of the ability of each system to remove fumes and gases was included in the evaluation.
7. *Soot Removal*: Although not a serious health or litigation problem, soot removal was included in the evaluation.
8. *Noise:* Each system's relative noise contribution to the apparatus room was another minor evaluation criteria.
9. *Negative pressure in the apparatus room:* Because the migration of gases into adjacent living spaces could pose a health and/or litigation problem, ability to provide negative pressure was extremely important in the evaluation.
10. *Door closure mishap:* Although only a minor potential problem for system operation, failure of an automatic garage door to close completely could pose security problems for unmanned fire stations during a call, making this an important consideration in the evaluation.

11. *Automatic control*: Automatic control was included for assurance of operation, whether through electronic control devices or because the operation of the system is intrinsically automatic.
12. *Maintenance:* Maintenance effort and its capacity to interfere with proper operation if not performed was considered in the evaluation.
13. *Breakdown potential*: The breakdown potential included in the evaluation is for loss of use of equipment, even for short periods of time.

Each of the above criteria was weighted with importance factors, evaluation comments and the total weighted score determined for each alternative as shown in Table 1.

System #1: "On Vehicle" Exhaust Pipe Filter System

This system employs a filter that is designed and sized to fit directly on a fire truck vehicle. It remains in place to trap soot and some combustion gases while the vehicle is in operation. The advantages of the system include the least first and least operational costs, it has a relatively high potential continuous use because the only time it is removed is for cleaning and/or replacement, it is always on the vehicle ready to use, and it has a relatively high (up to 80%) soot removal efficiency. Additionally, because it is located directly on the vehicle there is no possibility for it to interfere with the operation of the automatic garage doors or cause noise in the apparatus room during operation.

The disadvantages of this type of system include no CO or CO_2 monitoring, removal of very little of the products of combustion, no negative pressure in the apparatus room (thereby potentially allowing combustion gases to migrate to living quarters), relatively high possibility of breakdown if not cleaned, requires vigilant maintenance and must be removed and installed on the vehicle exhaust pipe for cleaning and maintenance.

System #2: Direct Connection Of Flexible Piping To Vehicle Exhaust Pipe And Connected Combustion Gas Exhaust Removal System

This system employs the use of a light weight hose that connects directly to the vehicle exhaust pipe (similar to a maintenance or repair garage exhaust system). The system is designed to start the exhaust fan upon sensing a back pressure signal caused by vehicle engine start. Exhaust gases are drawn directly from the exhaust pipe and exhausted from the building. The high negative pressure on these devices minimize the amount of gases allowed to escape. They are designed to "fall" off of the exhaust pipe after the vehicle exits the building. This system uses an overhead track for hose support and hose retraction which may be subject to damage and breakdown, and therefore requires maintenance. Operational costs include a relatively large horsepower motor, but run time is minimal, only when vehicles are operated, entering or leaving the building.

The advantage of this system is that the majority of combustion exhaust particles (soot) and exhaust gases are removed directly at their source and they are exhausted directly out of the building. Also, the cost is slightly less than an automatic general exhaust system, but greater than a vehicle filter or manually operated general ventilation system. Additionally, the system is 100% automatic as long as the hose is reattached to the vehicle exhaust pipe after each run. The automatic controls and the exhaust fan require minimal maintenance. Due to the minimal run time of the exhaust fan, noise is kept to a minimum in the apparatus room and is very low if the exhaust fan is located outdoors.

Disadvantages of the system require that a device be available for each truck or emergency vehicle in each apparatus room, the exhaust fan must be sized to capture the gases of the expected number of vehicles that may be operating at any one time and the effect of potential back pressure to the diesel engines is uncertain. Much of the combustion gases are produced upon acceleration when the vehicles leave the apparatus room and the capturing devices falls to the floor. This allows for the possibility of the gases to escape back into the apparatus room even if the fan operates for a few minutes through an "off" time delay. If the devices are not placed on the hot vehicle exhaust pipes until the vehicles are stopped upon returning to the fire station, fumes and soot are exhausted into the apparatus room when backing, in without the capture device attached. A disciplined procedure must be in place to ensure that the capture devices are placed on each and every vehicle exhaust pipe each and every time a vehicle is parked in order to ensure that the system is successful. Another disadvantage is no CO or CO_2 monitoring. Because the hose separates from the truck after it exits the building, there is a possibility that it would prevent an automatic garage door from closing thereby causing a security problem, and there is a possibility of causing injury when the hose "snaps back".

System 3: General Ventilation With Manual Start Control

This system consists of a series of intake louvers and corresponding exhaust fans located in the apparatus room to provide thorough, bottom to top displacement ventilation of the room when the fans are in operation. Operation of the fans are manual. The fan is manually started when the vehicles leave on an emergency run, and operates automatically for a pre-set time. The exhaust fans are again manually started when the vehicles return from the emergency run. With this system, when the fan is operating, there is negative pressure in the apparatus room and the system should remove the majority of the fumes, but at a slightly slower rate than through a direct connection exhaust pipe system, and only if it is operated at the proper time.

The advantages of this system include minimal maintenance, minor breakdown potential, no possibility of interference with automatic garage door closure, moderate initial and operational system costs and a system that is relatively easy to use as long as personnel remember to turn the exhaust fan on and off.

Disadvantages to this system include no CO or CO_2 monitoring, no automatic control, and no negative pressure in the apparatus room when CO and/or and high levels of CO_2 gases are present, unless the fans are manually operated. Other disadvantages include a minimal amount of soot removal and moderate amount of noise generation when the fan is running during the automatic off delay period.

System #4: General Ventilation With Combustion Gas Monitoring And Automatic Control

This system is identical to System #3: *General Ventilation With Manual Start Control System* except that it includes carbon monoxide (CO) and carbon dioxide (CO_2) monitoring in the apparatus room space and automatic sensing of the operation of the garage doors. The sequence of operation is as follows:

1. Upon the operation of any overhead door in the apparatus room, the exhaust fan sequence starts.
2. Operation of the overhead door switches indicate travel beyond 2 inches from an opened or closed position.
3. The exhaust fans operate on an adjustable off delay time sequence upon opening or closing the doors or when the carbon dioxide level and/or carbon monoxide levels exceed certain set points. Anytime the carbon monoxide and/or carbon dioxide levels are above these set points the exhaust fans will operate, even if the doors have not been opened or closed recently.
4. Once the gas levels drop below an off-set of the set points, the fans sequence a time-out and stop.
5. If for some reason the carbon dioxide level and/or carbon monoxide levels continue to rise above a set point, an audible and visual alarm actuates.
6. When the fans are operating and the garage doors are closed, the apparatus room operates at a negative pressure to minimize the chances of carbon dioxide and/or carbon monoxide fumes migrating to adjacent living quarters.

As an added feature for automatic controls, a timed override switch is available to operate the exhaust fans if there is a requirement for ventilation while using the apparatus room for training, operating vehicles for minor maintenance, or for general purpose ventilation.

The advantages of this system are that it provides for continuous carbon dioxide and carbon monoxide monitoring (with the potential for recording the CO and CO2 levels), it automatically removes the majority fumes, (although at a slightly slower rate than the direct pipe connection exhaust system), is totally automatic and very easy to use, and when properly maintained it is available for continuous use. When CO and/or CO2 gases are above set point levels and the exhaust fans are operating, it will always provide negative pressure in the apparatus room. There is no chance of mishap with the automatic garage doors closing. The system operates automatically and there is minimal potential for operational failure. The only equipment requiring maintenance are the exhaust fans and automatic controls.

The disadvantages include that it has the highest relative initial and operational costs of all systems studied, has minimum soot removal capability, and depending upon fan location, can generate moderate noise while operating in the apparatus room. Additionally, if used in apparatus rooms in a cold climate area, the initial and operational costs would be even higher due to the outdoor air pre-heat requirement.

Recommendation

Based upon the highest weighted score from the evaluation as listed in Table 1, the City's requirement that monitoring carbon monoxide and carbon dioxide levels was essential, and the OSHA requirement that the system be "used for so long as the contaminant is present", **SYSTEM #4, GENERAL VENTILATION WITH COMBUSTION GAS MONITORING AND AUTOMATIC CONTROL**, was recommended for the nineteen Fire Stations. Note that Tampa is located in a temperate climate, and below freezing temperatures are extremely rare - very few hours during the year are below 45°F (7.2°C) temperatures. Pre-heating of outdoor ventilation air was not considered in the evaluation. Although this was the best choice for the City of Tampa Fire Stations, it may not be the system for other municipalities. Depending upon the location (specifically cold climate) and the initial and operating costs, an automatically controlled general ventilation system may not be the most effective method of minimizing combustion gases in apparatus rooms of fire stations.

Investigation

Once it was determined that general ventilation with combustion gas monitoring and automatic control would be provided for each of the fire stations, site investigations were conducted. From the study it was determined that the dilution rate for removal of combustion gases from diesel engines is recommended at a ratio of 75 parts of outdoor air to 1 part of combustion gases emitted. For an idling diesel fire truck engine, this amounts to approximately 8,000 CFM (3,776 L/S)/Truck of outdoor air per minute. Because each fire station has a different layout and volume cubic area, and the number of trucks that can operate in each fire station is varied, the ventilation air requirements varied from 13 to 66 air changes per hour for the nineteen various Tampa Fire Stations.

To achieve complete dilution and total "flushing" of the spaces, the design approach was to introduce make-up air opposite from and at a different elevation than the exhaust air. In many cases ducting of makeup or exhaust air to/from a grille on an inside wall was required. This ducting had to be constructed to minimize space consumed (footprint) to still allow fire truck access and constructed (reinforced) to withstand accidental damage in an industrial garage atmosphere.

Additionally, because of the varied wall structure design, roof structure and location of living spaces relative to the apparatus room, each fire station required a unique solution to determine whether wall exhausters, roof exhausters, or inline exhaust fans should be provided. Site review also determined whether side wall louvers, roof ventilators and/or floor to ceiling transfer ducts should be provided. Because of building configuration and footprint, each fire station required a minimum of two carbon monoxide and two carbon dioxide sensors, with some of the fire stations requiring three of each type. Figures 1, 2 and 3 depict three of the most typical ventilation systems of the fire stations.

Other factors for consideration were for the number of garage doors, the location of garage door switches and the automatic control system. Finally, the site investigation considered interior and exterior obstructions and other mechanical devices located at the fire stations which might possibly interfere with the installation or operation of any components of the ventilation system.

System Installation

Creative design and close cooperation with the installation contractor and with the owner was required in order to minimize roof penetrations, determine wall penetrations for louvers, avoid exhaust air flows being entrained with existing outdoor air intakes near and around the roof, and routing ductwork to ensure ventilation cross flow for maximum fume removal of the apparatus space.

DDC Controls were provided for the system with the following benefits.

1. Display of actual CO and CO_2 values.
2. Display of CO and CO_2 set points.
3. Display of CO and CO_2 alarm points.
4. Allow for accessible and easy sequence changes.
5. Allow for testing of the system sequence.

Photo #1 shows Fire Station #18 with vertical louvers located outside. Photo #2 shows the DDC panels, the display control panel, the starter disconnects and the intake louvers located to the left of the panels. Photo #3 shows side wall exhaust fans on the apparatus room exterior wall, located above the living quarters roof.

System Testing and Checkout

System testing and checkout included a physical review of all exhaust fans, louvers, wall penetrations, roof penetrations, etc. The test and balance report was reviewed and air flows and cross air flow flushing of all apparatus rooms was verified. Checkout required certification of the calibration of the CO and CO_2 sensors. The sequence of operation was observed in each fire station to insure that the opening and closing of doors would actuate the exhaust fan. The fire trucks were operated with the doors closed to observe the buildup of the CO_2 and CO values in the apparatus room. For quick buildup of CO and CO_2 levels at each sensor, a gasoline leaf blower was used with the exhaust directed at each sensor to allow for rapid verification of operation of the exhaust fans, and to ensure the alarms initiated at their proper set points. Ambient carbon dioxide levels ranged from 320 PPM to 570 PPM depending on their proximity to outside traffic. Ambient carbon monoxide levels ranged from 0.0 to 4.0 PPM depending on the same circumstances. The system set points and alarms are as follows:

Carbon Monoxide (CO)	Carbon Dioxide (CO_2)
25 PPM-fan cut-in	750 PPM-fan cut-in
20 PPM-fan cut-out	700 PPM-fan cut-out
30 PPM-alarm	825 PPM-alarm

In stations where the fire trucks were allowed to operate with the doors closed until actuation of the exhaust fan, the carbon dioxide level built up to approximately 750 PPM with the carbon monoxide level at approximately 30 to 40 PPM. The truck engines were then stopped. With the doors then opened, the carbon monoxide and carbon dioxide readings dropped to normal levels within one to two minutes. With the doors left closed, the amounts dropped to normal levels within approximately eight to 10 minutes. Because the system was not designed to operate with the fire trucks continually operating with closed doors, systems were not checked under these conditions.

Conclusions and Future Recommendations

The project spanned two years from the beginning of the study to the final acceptance of the nineteen Fire Stations. Due to budget considerations, the system testing and checkout was not very sophisticated and included limited testing and checkout as outlined above. Recommendations for future testing include the following:

1. After one year of operation, verify the calibration of the carbon monoxide and carbon dioxide sensors.
2. Determine room air flows and cross air flow flushing with smoke/tracer gas test.
3. Determine CO and CO_2 level concentrations at matrix points throughout the apparatus room space and compare these to levels found at the sensor locations.
4. With carbon dioxide and carbon monoxide levels at their highest concentration, and with exhaust fans operating, measure the CO and CO_2 levels at doorways leading to the living and sleeping areas.

If municipal funds are available, these tests can be carried out in the future. Or, perhaps these systems can become the basis of an ASHRAE research funded test and report.

Each fire station now has a ventilation system that helps remove carbon dioxide and carbon monoxide gases from the apparatus rooms, minimizes the effect of fumes and gas migration into the living quarters and has the capability to record carbon dioxide and carbon monoxide levels in each of the fire stations. With proper maintenance and operation of the system, the City of Tampa Fire Fighters and Emergency Personnel have an improved work environment.

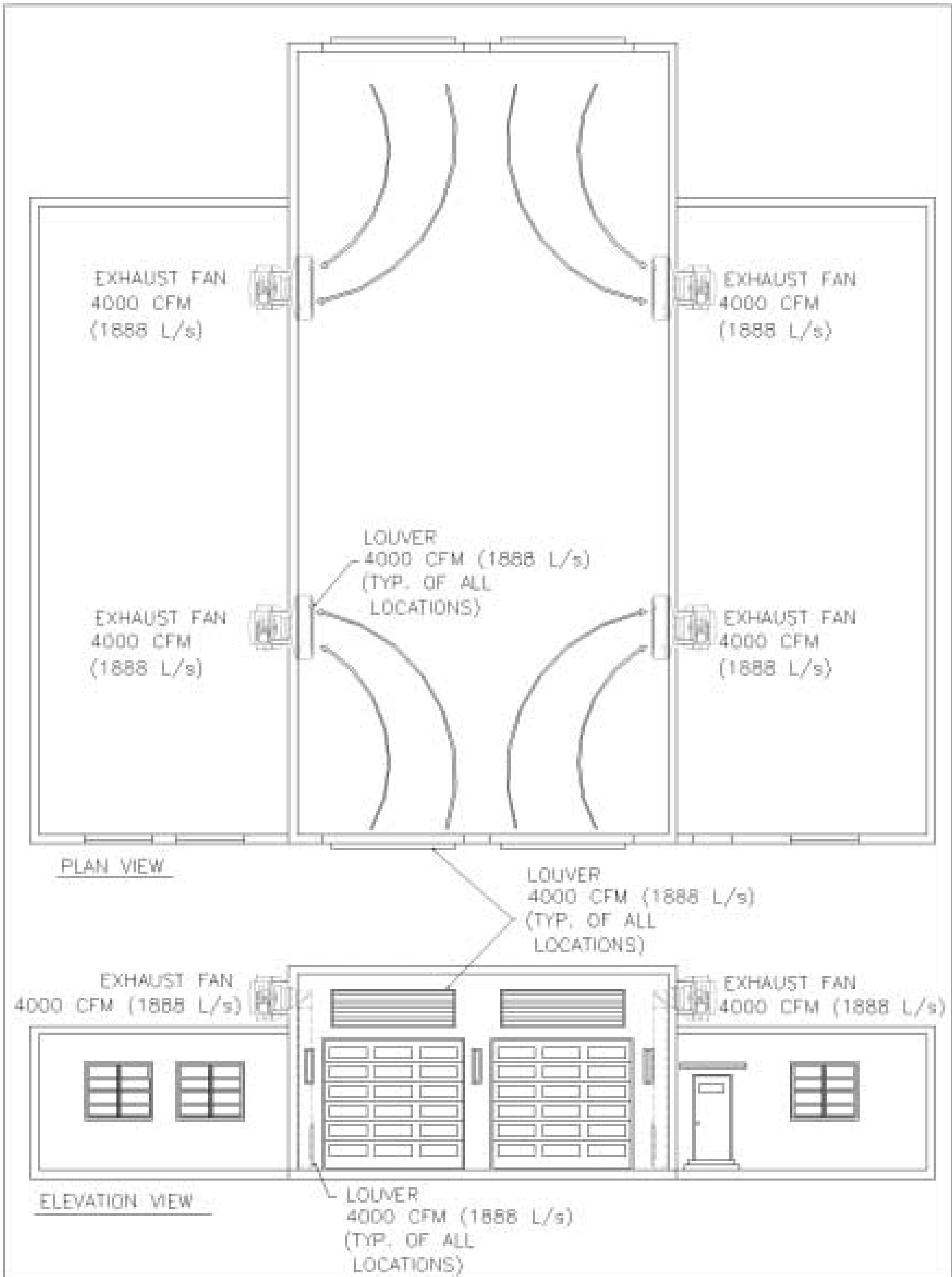

FIGURE 1
TYPICAL APPARATUS ROOM, DORMITORIES EACH SIDE, WITH DUCTS FROM FLOOR TO EXHAUST FANS AT HIGH WALL AREA ABOVE DORMITORY ROOFS AND OUTSIDE VENTILATION AIR ENTRANCE LOUVERS ABOVE GARAGE DOORS.

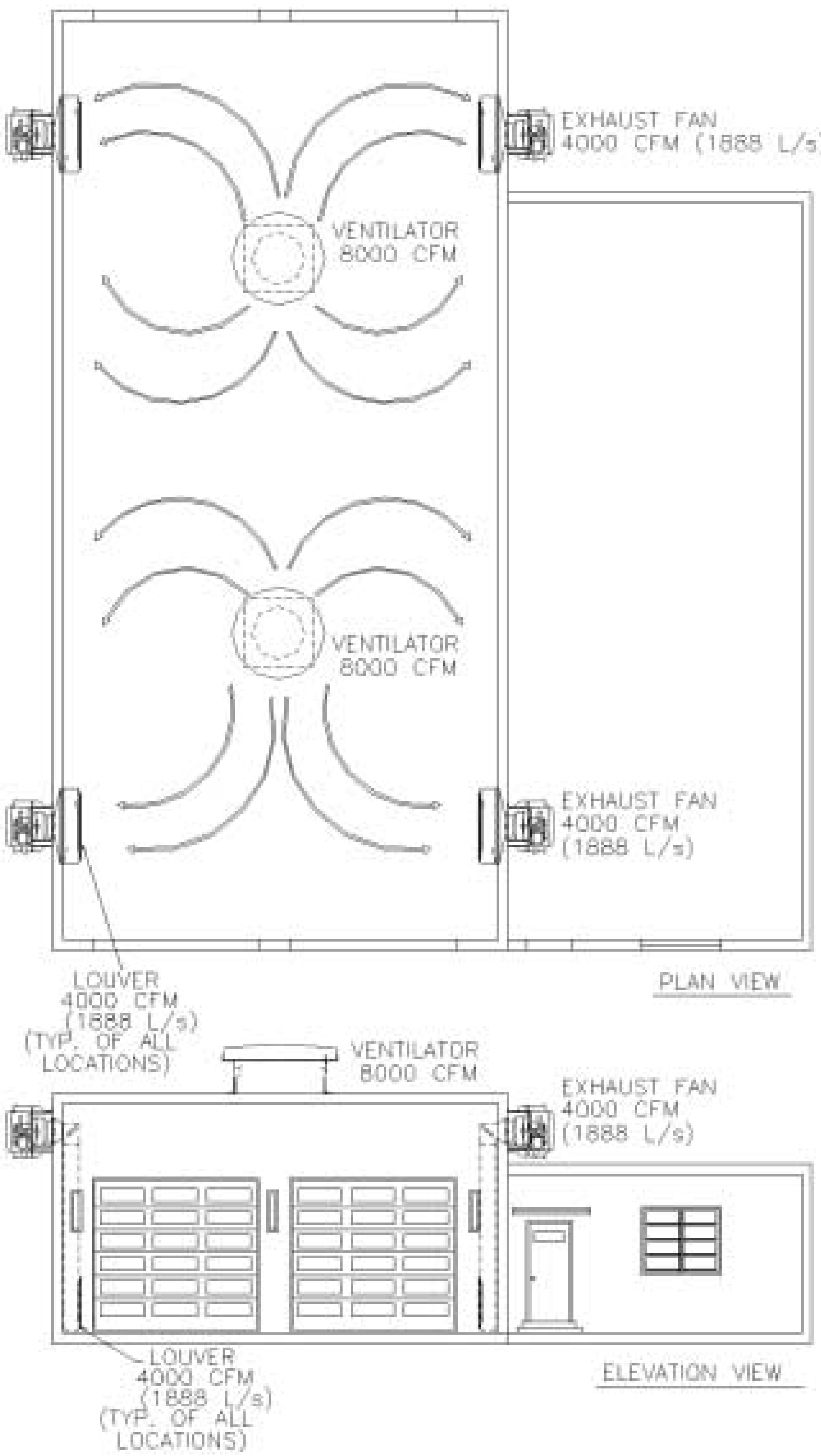

FIGURE 2
TYPICAL APPARATUS ROOM, DORMITORY ONE SIDE. VENTILATION AIR THROUGH ROOF VENTILATORS, EXHAUST FANS AT HIGH WALL AREA ABOVE DORMITORY ROOF.

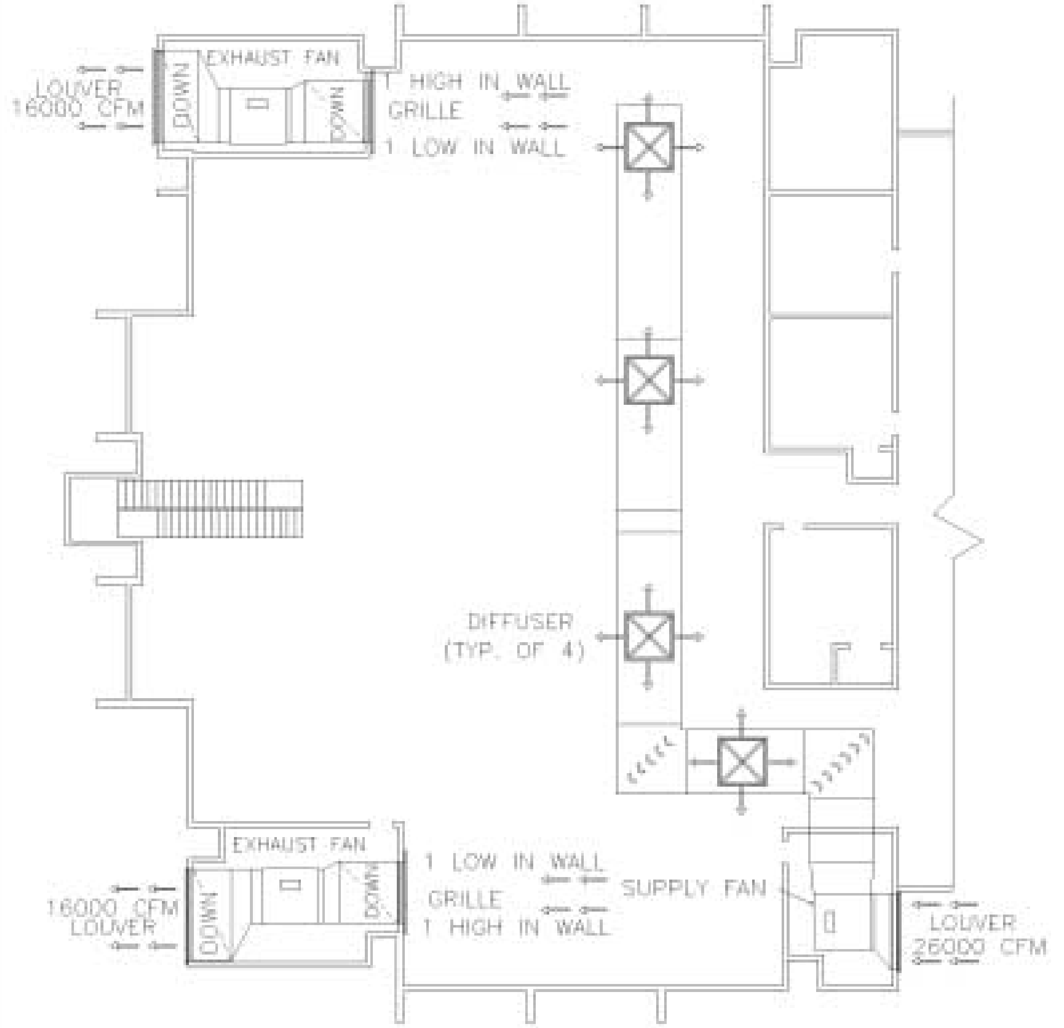

FIGURE 3
LARGE APPARATUS ROOM. SINGLE IN-LINE SUPPLY FAN WITH TWO IN-LINE EXHAUST FANS. SUPPLY AIR PROVIDED OVERHEAD. EXHAUST AIR PICKED UP AT FLOOR AND NEAR CEILING TO BE EXHAUSTED HIGH, ABOVE ENTRANCES.

ASHRAE info:
Photo #1
Fire Station #18 with vertical louvers located outside.

ASHRAE info:
Photo #2
DDC panels, display control panel, starter disconnects and intake louvers to the left of the panels.

ASHRAE info:
Photo #3
Side wall exhaust fans on apparatus room exterior wall, located above living quarters roof.