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CONTROL MEASURES

For Diesel Engine Exhaust Emissions in the Work Place

Canada

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For Diesel Engine Exhaust Emissions in the Work Place

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This guideline has been developed by the Labour Program to assist federally regulated workplace parties understand how to manage and control exposure to diesel engine exhaust emissions (DEEEs) in the work place, and for identifying in which work places this hazard is commonly found. The Guideline will be particularly useful for industrial hygiene specialists and health and safety professionals who may be recommending or installing different control measures that are appropriate for federal jurisdiction legislative and meet regulatory requirements.

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1. Introduction

The lean-burning nature of diesel engines and the high temperatures and pressures of the combustion process result in significant production of nitrogen oxides (NO_x), and provide a unique challenge in reducing these compounds. Modern on-road diesel engines typically use selective non-catalytic reduction to meet emissions laws, as other methods such as exhaust gas recirculation cannot adequately reduce NO_x to meet newer standards in many jurisdictions. However, the fine particulate matter in the exhaust emissions (sometimes visible as opaque dark-coloured smoke) has traditionally been of greater concern, as it presents different health concerns and is rarely produced in significant quantities by spark-ignition engines. It was reported in 2012 that although total NO_x from petrol/gasoline cars have decreased by around 96% through adoption of exhaust catalyst, diesel cars still produce NO_x at a similar level to those bought a decade and a half ago under real world tests, resulting in diesel cars emit around 20 times more NO_x than petrol/gasoline cars.[1]

In addition to NO_x, diesel engines produce carbon (soot), sulphur oxides, e.g. sulphur dioxide (SO_2), aldehydes, ketones, alcohols, nitrogen, hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and water. Diesel engines produce very little carbon monoxide (CO) as they burn the fuel in excess air even at full load.

The quantity and composition of DEEEs vary depending on:

- the type of engine;
- the composition of the fuel;
- maintenance and tuning;
- the engine temperature; and
- the workload.

There are also three types of visible smoke that may be produced during the diesel fuel combustion process. White smoke (water droplets and unburnt fuel) is observed when the engine is started from cold. Blue smoke (oil and unburnt fuel) is associated with poorly serviced and tuned engines, and black smoke (soot, oil and unburnt fuel) indicates mechanical problems. The soot content varies from 60% to 80% depending on the fuel used and condition of engine.[2]

2. Occupational Exposure to DEEEs

Worker exposure to diesel exhaust mainly occurs by breathing in the gases and soot, which then enter the workers' lungs. Repeated exposure to diesel exhaust can lead to lung and bladder cancer and can also cause chronic bronchitis, chronic obstructive pulmonary disease and asthma. According to Carex Canada, 897,000 Canadian workers face exposure to diesel exhaust at work every year.[3]

The major sources of worker exposure to DEEEs are from heavy vehicles that use diesel fuel such as trucks, trains/locomotives, buses and fork-lift trucks. As a result, employees in the following types of work places are among the most affected in the federal jurisdiction:

- inter-provincial trucking, vehicle maintenance and repairs;
- railways, railway repairs and rail tunnels;[4]
- bus garages, vehicle maintenance and repairs;
- toll booths, warehouses and garages;
- airport ground service equipment and auxiliary, luggage transport service.

3. Federal Legislation Requirements

Part X *(Hazardous Substances)* of the *Canada Occupational Health and Safety Regulations* (COHSR)[5] issued under Part II of the *Canada Labour Code* requires that, if there is a likelihood that the health or safety of an employee in a work place is or may be endangered by exposure to hazardous substances (including DEEEs), a hazard investigation to assess the risks to health must be conducted. On completion of the investigation, it is further required that employee exposure to the hazardous substance be eliminated or reduced by the implementation of engineering controls and, if necessary, other control measures such as administrative controls and the use of respiratory protection devices. The adequate maintenance of the controls that have been implemented, as well as employee training, are also required.

4. Occupational Exposure Limit

The Regulations prescribe the occupational exposure limits for hazardous substances. Subsection 10.19(1 (a) states that an employee shall be free from exposure to a concentration of an airborne chemical agent in excess of the value for that chemical agent adopted by the American Conference of Governmental Industrial Hygienists (ACGIH®) in its publication entitled *Threshold Limit Values and Biological Exposure Indices*.[6]

However, due to disagreement among experts on what components of diesel exhaust should be measured to accurately assess exposure, the ACGIH® offers no specific TLV® for DEEEs.

In 2012, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), classified DEEEs as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer and limited evidence with an increased risk for bladder cancer.[7]

It is a general rule that exposures to carcinogens must be kept to a minimum. Employees who are or may be exposed to confirmed human carcinogens without a TLV® or OEL should be properly equipped to eliminate or, if not reasonably practicable, to reduce to the fullest extent possible all exposure to the carcinogen.

5. Control Measures

Measures to mitigate exposure to DEEEs include:

- modifying the engine;
- installing diesel particulate filters (DPF);
- implementing exhaust gas recirculation (EGR);
- selective non-catalytic reduction (SNCR);
- using other fuels, such as dimethyl ether or low sulfur diesel; and
- proper maintenance of the engine and exhaust system

An excellent source of information is the Health and Safety Executive (HSE) publication entitled *Control of diesel engine exhaust emissions in the workplace*.[2]

The publication identifies warehouses, depots, and bus garages as work places where DEEEs are common occupational exposures. Examples of good working practices for controlling the engine exhaust emissions from diesel powered vehicles such as fork-lift trucks, railway locomotives, buses and lorries, and where there is likely to be an accumulation of DEEEs such as in warehouses, locomotive depots, bus garages, vehicle testing sites, fire stations etc. are provided. Many methods also apply to emissions from petrol/gasoline engines.

Substituting diesel fuel with a safer fuel, e.g. dimethyl ether or low sulphur diesel fuel, or alternative technology, e.g. battery operated vehicles or equipment would be the most effective way to reduce exposure, however, in many instances, these solutions neither are reasonably practicable nor possible, and other options or a combination of options should apply.

The three most effective engineering controls to eliminate or reduce exposure to DEEEs are the use of:

- engine exhaust filters;
- local tailpipe exhaust ventilation; and
- dilution ventilation.

In addition, administrative controls[8] such as:

- modifying the methods of work, e.g. by limiting speeds and using one-way travel routes to minimize traffic congestion or prohibiting and/or restricting unnecessary idling or lugging of engines;
- modifying the operations, e.g. by restricting the amount of diesel-powered equipment and total engine horsepower operating in a given area and ensure that the number of vehicles operating in an area does not exceed the capacity of the ventilation system;
- modifying the layout of the work place, e.g. by designating areas that are off-limits for diesel engine operation and/or personnel travel; and
- leaving garage doors and windows open (weather permitting)

and, if necessary, the use of respiratory protection devices (RPDs), will help employers reduce the generation of DEEEs into the working atmosphere and the number of employees exposed.

Note: As there are special requirements for work in mines and offshore situations, this guideline does not apply to emissions from diesel powered vehicles or appliances in such situations. The guideline also does not apply to the control of engine exhaust emissions in confined spaces.

6. Respiratory Protection Equipment

Where there is a hazard to an airborne hazardous substance, the COHSR[9] require that the employer provide a respiratory protective device (RPD) that is listed in the *NIOSH Certified Equipment List* and a RPD be selected, fitted, cared for, used and maintained in accordance with the CSA Z94.4 *Selection, care and use of respirators* Standard requirements. However, the RPD should only be used as a last resort.

7. Monitoring and Verification of the Effectiveness of the Control Methods[10]

Since there is no scientific consensus on what components of diesel exhaust should be measured to accurately assess employee exposure and there is no established TLV®/OEL for DEEEs, it is essential that control measures used to eliminate or reduce exposure of employees to the carcinogen be effective to the fullest extent possible.

Although the quantity and composition of DEEEs vary depending on the type of engine, the composition of the fuel and many other factors, there are certain indicators that can be used to effectively evaluate the engineering and other control methods used to ensure full protection of employees.

As indicated in the Introduction, there are three types of visible smoke that may be produced during the diesel fuel combustion process: white smoke (water droplets and unburnt fuel), blue smoke (oil and unburnt fuel), and black smoke (soot, oil and unburnt fuel). In addition, the soot content varies depending on the fuel used and condition of engine.

In order to carry out a hazard investigation and assess the effectiveness of the control methods used, or develop a hazard prevention program in the work place, a qualified person should answer the following questions:

1. Are or may employees in the work place be endangered by exposure to DEEEs?
2. How many employees are potentially exposed to the DEEEs?
3. What are the sources of exposure and who is affected?
4. What is duration of possible exposure?
5. Have there been any complaints? If so, what are the health symptoms, if any?
6. Have there been any personal and/or area samples taken? Which airborne chemical agents, e.g. NO_x, elemental carbon, SO_2, have been sampled? What are the concentration levels? Do they exceed the established TLVs® and/or OELs?[10]
7. What is the concentration level of carbon dioxide (CO_2) in the work place? Does the level exceed 1000 ppm 8-hour time-weighted average (8-hour TWA)?
8. What has the employer done for the control of the diesel emissions to protect the employees from exposure?
9. Is a medical surveillance program for the benefit of employees established in the work place? What does the program include, e.g. pre-employment /periodic examination, clinical tests, action levels, health education?
10. Is the employee education program developed and implemented in the work place?
11. How many diesel-fueled equipment/vehicles are operating within a given area? Does or may total engine horsepower exceed the capacity of the ventilation system in place?
12. Are the engines running at full speed and/or left idling? Why? Can the speed be limited and/or unnecessary idling restricted?
13. Are there designated areas for diesel engine operation and/or personnel travel? Are the work place layout modifications feasible?
14. When possible, are the garage doors and windows kept open?
15. Is any visible white, blue or black smoke in the work place? Are the engines serviced and tuned on a regular basis? If black smoke is visible, have the engines been checked for mechanical problems?
16. Are any visible soot deposits in the work place? Where and how significant? What type of the fuel is being used? What is the condition of the engine?
17. Based on the findings, are the control measures in the work place adequate? If the controls are not adequate, what needs to be done on control strategy to eliminate or reduce exposure?

8. Engineering controls

Engine Exhaust Filters[11]

Engine exhaust filters are designed to remove particulates from the exhaust stream. The filters are installed in the exhaust system or at the tailpipe. One commercially available filter system consists of a porous ceramic filter, a diverter valve, and an electronic control module. The diverter valve is installed in the exhaust pipe and directs the exhaust through a ceramic filter when the engine is started. This filter "cleans" the exhaust of diesel exhaust particulates. After about 20 seconds to three minutes (enough time for the vehicle to exit the apparatus bay), the electronic control bypasses the filter and vents the exhaust directly into the exhaust pipe. When the vehicle is shifted into reverse to back into the garage, the electronic control again routes the exhaust emissions through the filter. The ceramic filter weighs between 20 and 30 pounds (9 and 14 kg) and collects about two pounds of particulates before requiring servicing (approximately every 30 operating hours). Ceramic filters have reduced diesel particulate concentrations by 90 percent in the mining industry.

Another version of the particulate filter is a filter trap, which reduces diesel particulate levels by at least 80%.

A third version of the particulate filter is a two-stage diesel emission control system designed to regulate emissions based on proximity, or *Smog Free Zones*.[12] Diesel exhaust capture occurs at the tailpipe before it can enter the breathable air. Radio signals automatically activate the filtration mode when the vehicle enters the Smog Free Zone and continues to filter emissions until the vehicle drives out of range. Filtration occurs any time the vehicle is within a 100-meter range of a radio frequency transponder (e.g. installed at a repair shop), not just on engine start up or when backing up, and is not limited to 100 seconds (or less). Filtration occurs when the vehicle is idling or in any forward or reverse gear for as long as needed. Within the proximity of radio frequency transponders, diesel exhaust is diverted downstream of the muffler into the filter, effectively reducing emissions by 99 percent. The muffler acts as both a silencer and a spark arrester. The filter is downstream of the muffler and is the final exhaust trap, which does not affect the engine's warranty.

Local Tailpipe Exhaust Ventilation

Local tailpipe exhaust ventilation works by attaching a hose to the tailpipe and connecting it to a fan [Figure 1] [Figure 2], which discharges the exhaust outside the worksite. The exhaust hoses can be purchased with several options. One is an automatic disconnect feature, which automatically disconnects the hose from the vehicle exhaust pipe as the vehicle pulls out of the garage. Installing an overhead rail to keep hoses off the floor is another option. The hoses are suspended from the rail by a balancer that automatically retracts the hose when it is not in use. Various hose diameters are available for different sizes of exhaust pipes.

An advantage of the local tailpipe exhaust hose and ventilation is that it removes not only the diesel particulates but also the gaseous emissions, such as nitrogen oxides and sulfur oxides. The tailpipe exhaust hose captures the exhaust emissions when the vehicle exits the garage but affords no control when the vehicle re-enters the garage unless the employee re-attaches the exhaust hose to the vehicle before re-entering the garage. A disadvantage is that the system requires employees to remember to attach the hose to the tailpipe.

For vehicles in service garages, the ACGIH® recommends either the overhead or under floor systems as shown in Figure VS-85-01 [Figure 3] of the *Industrial Ventilation. A Manual of recommended Practice for Design*.[13] Exhaust volumes depending on the type of engines are provided in Figure VS-85-02 [Figure 4].

Examples of engineering solutions to control DEEEs in the work place: Figures 1 – 4.

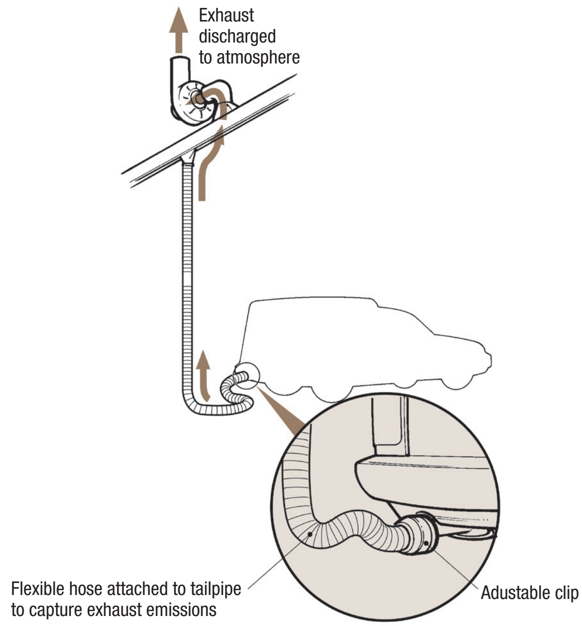

Figure 1 Fixed length flexible hose with tailpipe exhaust extraction system

HSE Books – Control of diesel engine exhaust emissions in the workplace – http://www.hse.gov.uk/pubns/priced/hsg187.pdf

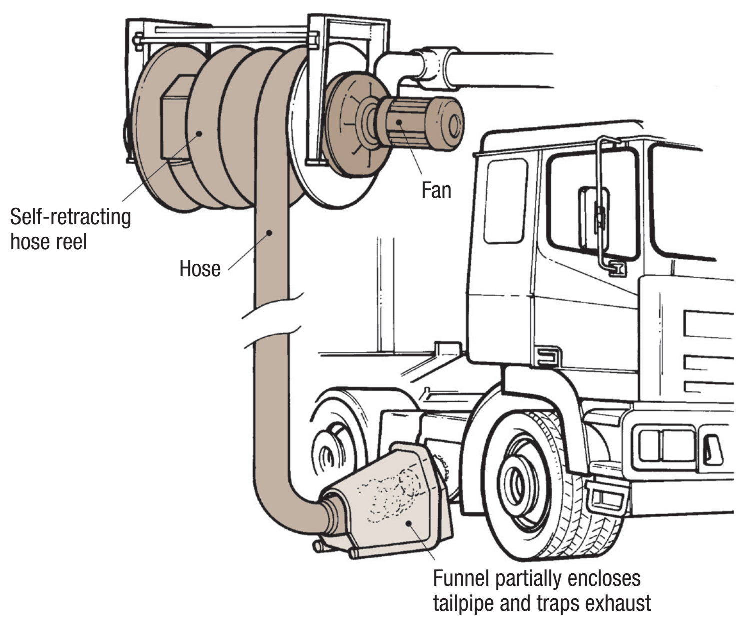

Figure 2 Fixed hose and funnel-type local exhaust extraction system

HSE Books – Control of diesel engine exhaust emissions in the workplace – http://www.hse.gov.uk/pubns/priced/hsg187.pdf

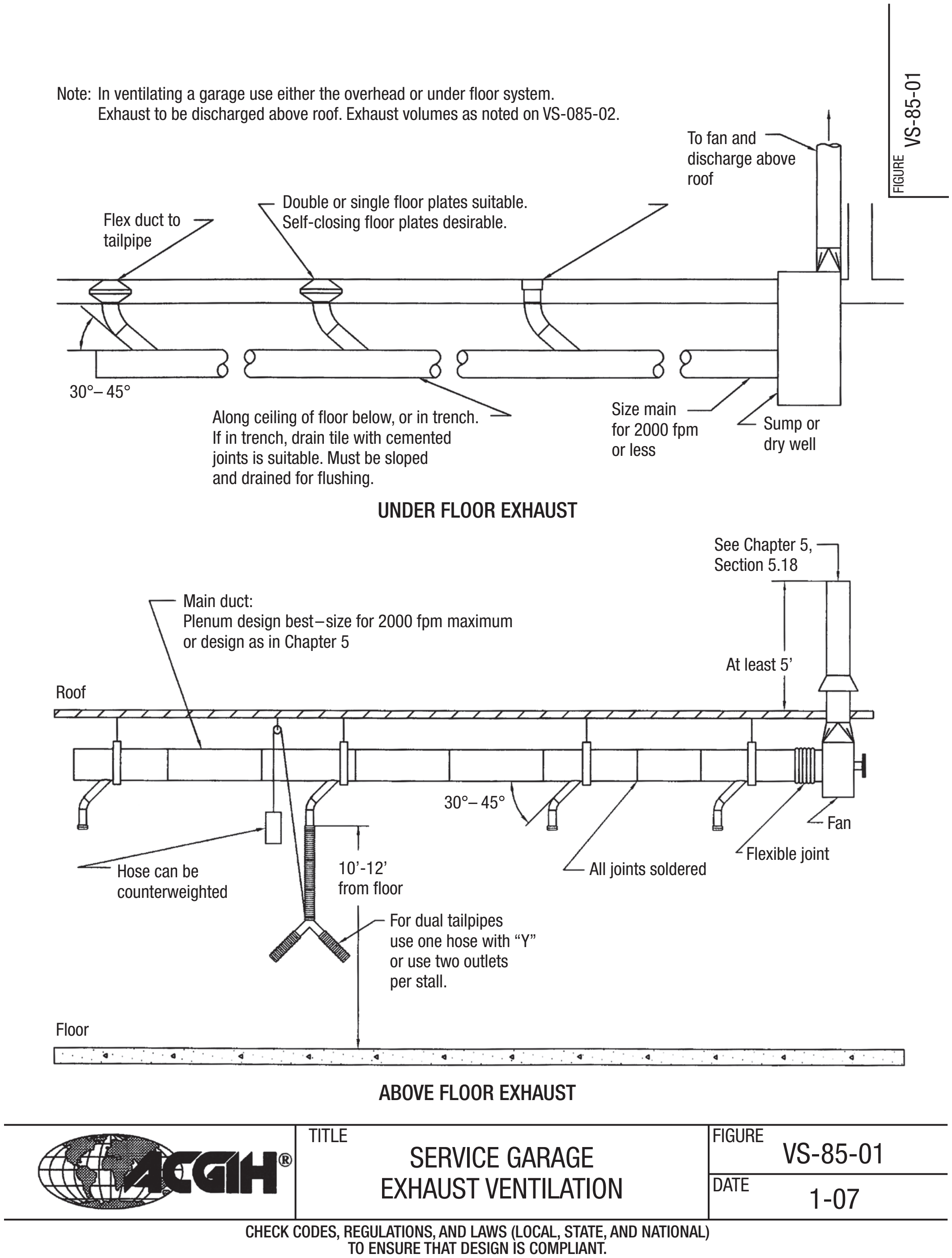

Figure 3 Local tailpipe exhaust ventilation, under and above floor systems

FIGURE VS-85-02

Exhaust ventilation volumes for operating engines connected directly to a tailpipe exhaust system are determined by the engine displacement, the engine RPM, and tailpipe exhaust temperature, plus a 20% safety factor. This is specified in actual cubic feet per minute (acfm).

$$Q_e = (1.2)(D_{eng} \times N)\left(\frac{460\,F + T_{eng}}{530\,F}\right)$$

where: Q_e = Exhaust Flow (acfm)
T_{eng} = Engine tailpipe temperature (F)
D_{eng} = Engine displacement (ft^3)
N = Engine revolutions per minute

For propane and gasoline engines, these temperatures vary from as low as 350 F to 800 F depending on the usage of the vehicle. Diesel engine exhaust gas temperatures are higher.

The phrase "under load" indicates that the engine is generating additional power and the temperature of the engine exhaust gases may be higher than when at idle. The exhaust gas temperatures will be in the range of 1,000 F to 1,400 F, as opposed to 350 F to 900 F.

As an example, a 15L engine at 1,000 rpm would displace 530 scfm. At an exhaust gas temperature of 1,300 F (under a heavy load), this would be 1,758 acfm. With the "safety factor" of 20%, this would be 2,110 acfm.

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$$Q_e = (1.2)\left(15L \times \frac{0.0353\,ft^3}{L} \times 1000\right)\left(\frac{460\,F + 1300}{530\,F}\right) = 2110 \text{ acfm}$$

Any engine can be calculated the same way, as long as the exhaust gas temperature is known.

ACGIH®	TITLE: TAILPIPE EXHAUST VENTILATION VOLUMES	FIGURE: VS-85-02 / DATE: 1-07
CHECK CODES, REGULATIONS, AND LAWS (LOCAL, STATE, AND NATIONAL) TO ENSURE THAT DESIGN IS COMPLIANT.		

Figure 4 Tailpipe exhaust ventilation volumes

ACGIH® – Industrial Ventilation. A Manual of Recommended Practice for Design. 26th Edition. 2007.
Reproduced with the permission of the ACGIH®.

Dilution Ventilation (Exhaust Fan)

With dilution ventilation [Figure 5], the air contaminated with DEEEs is exhausted to the outside while fresh outside makeup air flows into the garage through open doors or supply air openings. Air is exhausted using a roof or wall fan. The exhaust fan should be toward the rear of the garage opposite the garage doors so that outside air flows through the open garage doors, sweeping the entire length of the building before being exhausted. The exhaust fans should be high in the wall (or in the ceiling). If the garage doors cannot be kept open while the exhaust fan is running, a supply air fan can be installed at the opposite side of the building from the exhaust fan to bring fresh air into the garage.

The ACGIH® recommends a dilution ventilation rate of 100 cfm per horsepower for diesel engines.
The recommended dilution rate is based on average operating conditions.

The major disadvantage of using the dilution ventilation is that it doesn’t capture emissions at the source. Thus, employees may still be exposed to some DEEEs.

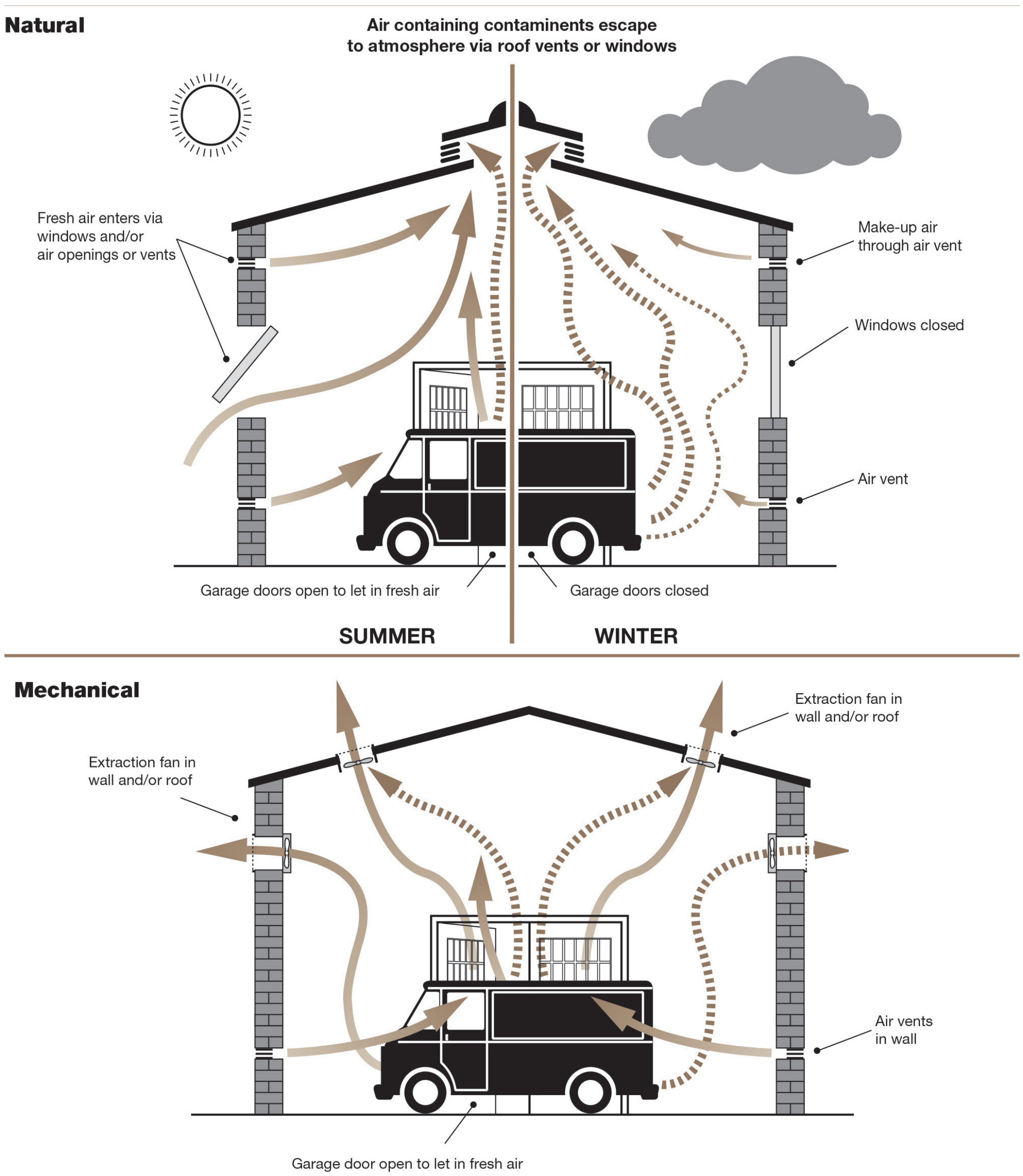

Figure 5 General ventilation in a garage, e.g. natural and mechanical

HSE Books – Control of diesel engine exhaust emissions in the workplace – http://www.hse.gov.uk/pubns/priced/hsg187.pdf

Other Local Exhaust Ventilation

In addition to the dilution and natural ventilation, local exhaust or extraction ventilation may be required at train stations with sheltered platforms, maintenance and repair shops to help remove generated DEEEs from the employees' breathing zone.

Exhaust Gas Recirculation (EGR)[1]

In internal combustion engines, exhaust gas recirculation (EGR) is a NO_x emissions reduction technique used in petrol/gasoline and diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. This dilutes oxygen in the incoming air stream and provides gases inert to combustion to act as absorbents of combustion heat to reduce peak in-cylinder temperatures. NO_x are produced in a narrow band of high cylinder temperatures and pressures.

In a diesel engine, the exhaust gas replaces some of the excess oxygen in the pre-combustion mixture. Because NO_x form primarily when a mixture of nitrogen and oxygen is subjected to high temperature, the lower combustion chamber temperatures caused by EGR reduces the amount of NO_x the combustion generates (though at some loss of engine efficiency). Gasses re-introduced from EGR systems will also contain near equilibrium concentrations of NO_x and CO; the small fraction initially within the combustion chamber inhibits the total net production of these and other pollutants when sampled on a time average. Most modern engines now require exhaust gas recirculation to meet emissions standards.

Catalytic Converters[1]

A catalytic converter is an emissions control device that converts toxic substances in engine exhaust emissions to less toxic substances by catalyzing a reduction/oxidation reaction. Catalytic converters are used with internal combustion engines fueled by either petrol/gasoline or diesel, including lean-burn engines. Since they combine oxygen with carbon monoxide and unburned hydrocarbons to produce carbon dioxide and water, as well as, they reduce oxides of nitrogen, the catalytic converters are applied to exhaust systems in forklifts, trucks, buses and locomotives.

Selective Non-catalytic Reduction (SNCR)[1]

SNCR is a method to lessen NO_x emissions. The reaction mechanism itself involves ammonia radicals that attach to NO_x and then decompose. The reaction requires a sufficient reaction time within a certain temperature range, typically 1,400 and 2,000 °F (760 and 1,090 °C), to be effective. If the temperatures are lower, the NO_x and the ammonia do not react. Further complications involve insufficient mixing of ammonia with NO_x for the chemical redox reaction. Consequently, even though in theory selective non-catalytic reduction can achieve the same efficiency of about 90% as selective catalytic reduction, these practical constraints of temperature, time, and mixing often lead to worse results in practice. However, selective non-catalytic reduction has an economical advantage over selective catalytic reduction, as the cost of the catalyst is not there.

Other Control Measures

Other controls such as:

- modifications of weather stripping on all doors leading from the garages to the adjacent offices to prevent infiltration of DEEEs; or
- keeping the offices or toll booths (if applicable) under positive pressure and providing with sufficient fresh air supplied from an uncontaminated source should also be considered to further reduce exposures.

9. Work practices

In addition to engineering controls, good work practices[11] may help reduce DEEEs and hence worker exposures. Examples include:

- always open the garage doors before starting vehicles;
- keep garage doors open (weather permitting) for at least 10 minutes following vehicle operation;
- perform regular engine maintenance on the vehicles to minimize DEEEs;
- consider a retrofit program to rebuild diesel engines to generate less diesel particulates when they require major overhauls;
- consider both mechanical performance and emissions data when selecting new engines.

10. Employee education and training

The *COHSR* require employers to develop and implement an employee education program with respect to hazard prevention and control at the work place. It is necessary that every employee who is or may be endangered by exposure to DEEEs, be given instruction and training on the health hazard and on the proper use of control measures.

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