Title

Overview of Existing Regulations for Ventilation Requirements of Enclosed Vehicular Parking Facilities

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ABSTRACT

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This paper provides an overview of the current standards and regulations regarding the ventilation in enclosed parking facilities in the U.S. and other countries. First, the paper discusses the emission rates of motor vehicle pollutants and their health effects. In particular, typical emission rates for different vehicle and fuel types are presented to highlight the effect of various parameters on the ventilation rate requirements for parking garages. In addition, the paper provides a brief description of some of the common ventilation problems reported in the literature for enclosed parking garages.

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INTRODUCTION

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Automobile parking garages can be partially open or fully enclosed. Partially open garages are typically above grade with open sides and generally do not need mechanical ventilation. However, fully enclosed parking garages are usually underground and require mechanical ventilation. Indeed, in the absence of ventilation, enclosed parking facilities present several indoor air quality problems. The most serious is the emission of high levels of carbon monoxide by cars within the parking garages.

In this paper, the standards and codes for the ventilation of enclosed vehicular parking facilities are discussed. First, combustion pollutants are described with an emphasis on their health effects on humans. Then, common ventilation problems specific to enclosed parking garages found in published case studies are described. Finally, a compilation of existing standards and codes is presented.

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AUTOMOTIVE AIR POLLUTANTS

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The most common problem in enclosed parking garages is the buildup of combustion pollutants generated from internal combustion engine (ICE) vehicles powered by conventional fuels (mainly

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gasoline). Five primary pollutants and a secondary pollutant emitted by conventional ICE vehicles are identified to have hazardous health effects on humans. The primary pollutants are carbon monoxide, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate lead, and particulate matter less than 10 microns. The secondary pollutant is ozone, a product of two primary pollutants, nitrogen oxides and volatile organic compounds.

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Health Effects of Emission Pollutants

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For the vehicle fleet currently available in the United States, only three combustion pollutants are generated in a significant amount to possibly cause health problems to humans: carbon monoxide, nitrogen oxides, and volatile organic compounds. The generation of sulfur dioxide and particulate matter from vehicle exhausts is negligible due to the high degree of fuel desulfurization and relatively good condition of the vehicle fleet. Similarly, the ambient lead concentrations have been reduced to well below the standards since the unleading of gasoline (Cooper and Alley 1994). The three remaining primary pollutants can cause considerable health effects if inhaled by humans, as discussed briefly below:

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1. Carbon monoxide (CO) is a tasteless, odorless, and colorless gas that can be adsorbed easily by hemoglobin (Hb) to form carboxyhemoglobin (HbCO) if it is breathed in by humans. Therefore, CO can inhibit oxygen delivery to the body (normally performed by the hemoglobin) and can cause significant health effects ranging from slight headaches to death. Typically, symptoms of CO intoxication begin when the HbCO saturation in the blood reaches 20%, and unconsciousness occurs at 60% saturation. The most serious effects are felt by individuals susceptible to oxygen deficiencies, including people with anemia, chronic lung or heart disease, and people living at high altitudes.

2. Excess concentration of nitrogen oxides (NOx) in the atmosphere is usually indicated by a brownish color, contributes to smog, and reduces visibility. The health effects of NOx on humans include nose and eye irritation, pulmonary edema, and bronchitis. Long-term exposure to NOx can cause pneumonia pulmonary fibrosis and emphysema.

3. Volatile organic compounds (VOCs) comprise all organic compounds with appreciable vapor pressures and include organic acids, hydrocarbons, aldehydes, and ketones. Some VOCs are

carcinogenic and have a significant human threat. For instance, benzene is a mutagen that changes the molecular structure of a cell and could lead to cancer.

B Heads → **Emission Rates**

Vehicles powered by conventional fuels (i.e., gasoline and diesel) emit pollutants through two fundamentally different processes: exhaust emissions and evaporative emissions as briefly described below:

Exhaust Emissions. They are commonly referred to as "tail-pipe" emissions and are the results of the combustion of fuels within the vehicle's engine. The rate of exhaust emissions depends significantly on the operation mode of the vehicle. For light duty vehicles, three operating modes are typically considered: cold start, hot start, and hot stabilized. The start mode includes the first few minutes of starting the vehicle's engine. The length of time between the shutoff and the restart of the engine differentiates the cold from the hot start. The hot stabilized mode occurs when the engine is running after the start mode periods. In general, emission rates for CO, NOx, and VOCs are less during hot starts than cold starts and are lowest for hot stabilized operation mode.

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Evaporative Emissions. These emissions consist of hydrocarbons escaping from the fuel storage and delivery system. The evaporative emissions occur through several mechanisms including hot-soak emissions (from carburetor or fuel injector when the engine is idle), diurnal emissions (due to temperature fluctuations over one day), running losses, resting losses, refueling losses, and crankcase emissions.

Several parameters affect motor vehicle emission rates of CO, NOx, and VOCs. These parameters can be classified into four categories:

- Vehicle characteristics, such vehicle class (i.e., engine size, weight, etc.), model year, accrued vehicle mileage, fuel delivery system, emission control system, and inspection and maintenance history.

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- Vehicle operating conditions, including cold vs. hot start mode, average vehicle speed, load (i.e., heavy loads or towing), and influence of driver behavior.
- Fuel properties, such as fuel type, oxygen content, fuel volatility, benzene content, and lead and metals content.

- Vehicle operating environment, including altitude, humidity, ambient temperature, diurnal temperature sweep, and road grade.

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However, to conduct a regional mobile source emission analysis, it is customary to rely on emission factor models since it is unrealistic to perform direct measurement on each individual vehicle in the fleet. In the U.S., the Environmental Protection Agency (EPA) allows the use of only two emission factor models:

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- MOBILE, an emission factor model that was developed and is maintained by EPA (1993). This model has to be used in every state except California.

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- EMFAC, a model developed and maintained by the California Air Resources Board (CARB). The model can only be used in California (CARB 1992).

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A detailed description of the various motor vehicle emission modeling approaches and their limitations is provided by Guensler (1994) and Cadle et al. (1998). However, even with their shortcomings, the mobile source emission models provide valuable tools to (1) conduct long-term planning of emission control, (2) perform compliance analysis with air quality standards, and (3) assess the effects of various parameters (such as vehicle characteristics and operating conditions) on emission rates.

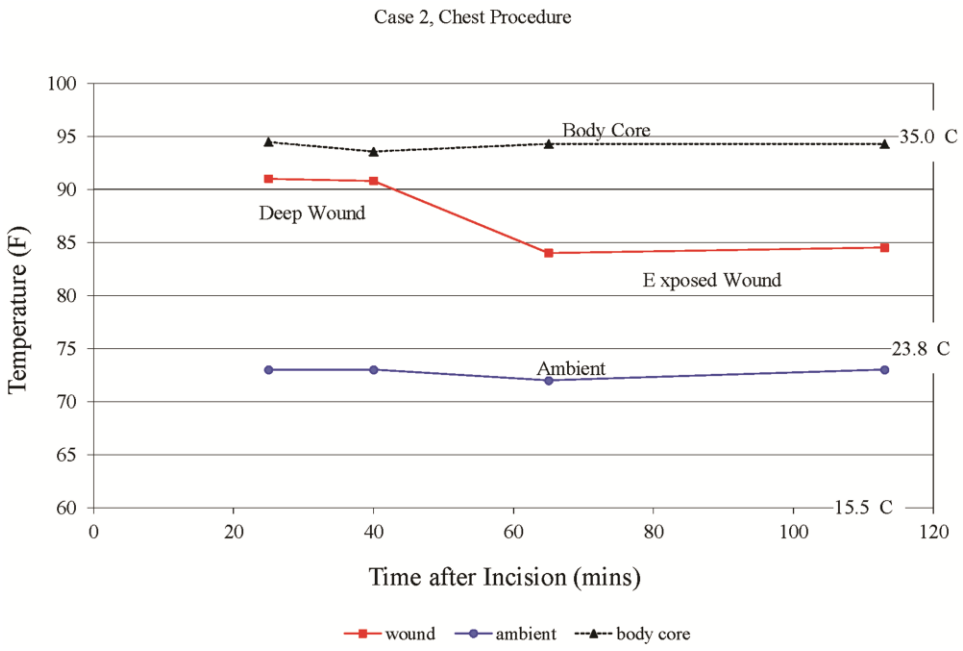

Figure #s

Figure 1. Case 2 data.

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Figure 1 presents the results of direct measurements of motor vehicle emissions. It is clear from the data presented in Figure 1 that the emission rates for the three combustion pollutants (CO, NOx, and

VOCs) are lower for the newer car models in both Colorado and Arizona, especially for the vehicles that passed the emission test. As expected, the CO emissions in Colorado are higher than those in Arizona due most likely to the higher altitude. The CO emission rates are significantly higher, especially in Colorado, for the vehicles that failed the emission test. Typically, the failure rate increases with the age of the vehicle. For the 1994-1997 car models, the failure rate is very low, less than 1% in Colorado (CDPHE 1997).

Table 1 presents the U.S. national average emission rates by vehicle and fuel type during 1997 as predicted by the Mobile5b model (BTS 1998). It is clear that the emission rate for all pollutants increases with the horsepower of the vehicle. Moreover, Table 1 indicates that the CO emission rates are significantly lower for vehicles powered by diesel compared to those powered by gasoline. However, the NOx emission rates are only slightly higher for vehicles powered by diesel fuel. It should be mentioned that the U.S. standards for motor emissions of CO, NOx, and VOCs are, respectively, 3.40, 0.40, and 0.41 grams/mile for light duty vehicles manufactured in 1994 and later. Thus, the 1997 U.S. average emission rates are significantly higher than the emission standards.

Table 1. 1997 U.S. National Average Vehicle Emission Rates (grams/mile) by Vehicle Type and Fuel Type (Source: BTS 1998)

Fuel Type	Vehicle Type	CO	NOx	VOCs
Gasoline	Light duty vehicle	19.86	1.51	2.36
	Light duty truck	26.38	1.92	3.14
	Heavy duty truck	69.13	5.25	6.70
	Motorcycle	20.47	0.84	4.29
Diesel	Light duty vehicle	1.71	1.55	0.74
	Light duty truck	1.95	1.78	1.05
	Heavy duty truck	11.93	13.33	2.36

Table 2 shows the emission rates predicted by the Mobile program for typical vehicle operating conditions within parking garages (for instance, the vehicle speed is assumed to be 5 mph). The emissions rates are provided for winter and summer conditions as well as for hot and cold operating modes. When, the vehicle is operating in cold start (to leave the parking), its engine is at full choke and operates with a rich mixture. As a consequence, the CO emission rates for cold start mode are significantly higher than those during hot stabilized mode, especially during winter conditions. Therefore, vehicle operating mode can be a crucial factor in determining the emission load within parking garages. The highest emission load is most likely to occur during winter afternoons when vehicles exit the parking garages (at least for parking facilities attached to office buildings).

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Table 2. Predicted CO Emissions within Parking Garages (ASHRAE 1995)				
	Hot Emissions (Stabilized), grams/min		Cold Emissions, grams/min	
Season	1991	1996	1991	1996
Summer (90°F)	2.54	1.89	4.27	3.66
Winter (32°F)	3.61	3.38	20.74	18.96

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Recently, alternative fuels have been proposed and used mainly to reduce combustion emissions. The alternative fuels include natural gas, hydrogen, and electricity. Table 3 summarizes typical emission rates of CO, NOx, and VOCs for vehicles using conventional and alternative fuels (Cooper and Alley 1994). The proportion of vehicles powered with alternative fuels, including electric cars or zero-emission vehicles (ZEVs), is still insignificant for the total U.S. fleet. However, in 1990 CARB passed a mandate to force car manufacturers in California to provide increasing proportions of lower exhaust emitting cars in their total volume of light duty vehicle sales (CARB 1996). For ZEVs, these proportions are respectively 2% in 1998 and 10% in 2003.

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COMMON PROBLEMS WITH PARKING FACILITIES

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Ventilation Problems within the Parking Facilities

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Poor ventilation system design is another reason for a buildup of combustion pollutants in enclosed parking garages. The problems associated with inadequate ventilation system design include the following:

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a) Short-circuiting of the ventilation airflow, due in most cases to the placement of the exhaust vents in the proximity of the supply vents (Koskela et al. 1991).

b) Reliance on air infiltration (i.e., nonmechanical ventilation) to supply fresh air to a large section of the parking garages (typically near ramps) as reported by Stankunas et al. (1989) for a parking facility in Los Angeles, California.

c) Obstruction of free airflow within the garage due to the existence of structural elements or parked vehicles as reported by Stankunas et al. (1989) for a two-level parking garage in Hartford, Connecticut.

d) Placement of outdoor air intake near pollutant source such as traffic fumes, restaurant exhausts, or exhaust vents of the parking garage itself. Sterling et al. (1987) found that the fresh air intake for the

parking area of a Canadian public library is located at the street level on a busy downtown area. This fresh air intake location lead to high CO concentrations in both the garage and the library.

Finnish Regulations. The Finnish hygienic regulations limit CO exposure to 30 ppm for an eight-hour average and 75 ppm for a 15-minute average. In addition, the Finnish building code require a ventilation rate of 0.53 cfm/ft2 (i.e., 2.7 L/sÞm2) for garages of office buildings (Koskela et al., 1991).

Swedish Regulations. The Swedish construction code requires ventilation of at least 0.18 cfm/ft2 (i.e., 0.9 L/sÞm2) for large detached garages even if they are used sporadically (Ancker 1992).

French Standards. The French standard states that for enclosed garages with a floor area larger than 215,000 ft2 (20,000 m2), the ventilation flow should provide an air change of 350 cfm (167 L/s) per car (FA 1995). In some cases, these ventilation flow rates may not be sufficient. In these cases, a simple calculation procedure needs to be performed to determine the CO level within the garage. The CO concentration in the garage should not exceed 200 ppm instantaneously, 100 ppm for a 20-minute period, and 50 ppm for an eight-hour period.

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German Standards. For enclosed parking facilities, the mean value of CO concentration should not exceed 100 ppm for a duration of one-half hour. This value is measured over 5 ft (1.5 m) of the ground. For small and large garages, the ventilation should be supplied at a rate of respectively 0.33 cfm/ft2 and 0.66 cfm/ft2 (i.e., 1.67 L/sÞm2 and 3.35 L/sÞm2).

Japanese and South Korean Standards. The ventilation requirements in Japan and South Korea are similar (KICTSC 1997). In particular, in both countries, the ventilation rates recommended for parking garages vary between 1.25 and 1.50 cfm/ft2 (6.9 and 8.3 L/sÞm2) depending on the size of the garage and the type of vehicles.

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SUMMARY AND DISCUSSION

The ventilation rate requirements recommended by ASHRAE and other codes are independent of the characteristics of the parking garage and do not consider the various parameters that may affect the indoor air quality, such as the emission generation rate and the acceptable pollutant level. A new design method is needed to determine the ventilation rate required for a wide range of enclosed parking garages. This design method should be flexible to accommodate not only the various CO exposure limits defined by the

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standards but also the changing emission inventory from motor vehicles. As discussed in this paper, motor emission rates have generally decreased over the years due to stricter emission standards for vehicles. In the future, this trend will most likely continue if low or zero emission vehicles become more popular.

It should be noted, however, that all the regulations reviewed in this paper are based on single chemicals and do not take into account the effects of exposure to mixtures such fuel fumes. On the other hand, the CO exposure depends on CO concentration in the breathing zone. As discussed earlier in the paper, the level of CO within a parking garage depends on several factors, such as vehicle type, ambient temperature, and engine operation mode, and is, therefore, difficult to estimate. However, well-controlled vehicular flow and well-planned pedestrian routing can reduce the breathing zone CO exposure to levels below those prevailing in other areas of the parking garages.

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