ANALYSIS OF THE VENTILATION REQUIREMENTS IN PARKING GARAGES

A Ayari, M Krarti, Ph.D., P.E.

ABSTRACT

In this paper, analysis of the ventilation requirements of enclosed vehicular parking facilities is discussed. First, a compilation of existing U.S. and international standards and codes pertinent to the ventilation of enclosed parking facilities is presented. Then, the results of a field testing study are summarized to determine the actual ventilation rates and the contaminant levels in seven U.S. enclosed parking garages. Finally, this paper presents a new design method that provides the minimum ventilation rate requirements for enclosed parking facilities.

INTRODUCTION

Automobile parking garages can be partially open or fully enclosed. Partially open garages are typically above-grade with open sides and do not need generally mechanical ventilation. However, fully enclosed parking garages are usually underground and require mechanical ventilation. Indeed, in 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. Other concerns related to enclosed garages are the presence of oil and gasoline fumes, and other contaminants such as oxides of nitrogen and smoke haze from diesel engines.

To determine the adequate ventilation rate for garages, two factors are typically considered: the number of cars in operation and the emission quantities. The number of cars in operation depends on the type of the facility served by the parking garage and may vary from 3% (in shopping areas) up to 20% (in sports stadium) of the total vehicle capacity. The emission of carbon monoxide depends on individual cars including such factors as the age of the car, the engine power, and the level of car maintenance. For enclosed parking facilities, ASHRAE standard 62-1989 specifies fixed ventilation rate of below 7.62 L/s.m^2 of gross floor area [2]. Therefore, a ventilation flow of about 11.25 air changes per hour is required for garages with 2.5-m ceiling height. However, some of the model code authorities specify an air change rate of 4 to 6 air changes per hour. Some of the model code authorities allow ventilation rate to vary and be reduced to save fan energy if CO-demand controlled ventilation is performed, that is, a continuous monitoring of CO concentrations is conducted, with the monitoring system being interlocked with the mechanical exhaust equipment. The acceptable level of contaminant concentrations varies significantly form code to code. A consensus on acceptable contaminant levels for enclosed parking garages is needed. Unfortunately, ASHRAE standard 62-1989 does not address the issue of ventilation control through contaminant monitoring for enclosed garages.

VENTILATION REGULATION FOR PARKING GARAGES

Table 1 provides a summary of existing codes and standards for ventilating enclosed parking garages in the Unites States, and other selected countries. As shown in Table 1, the recommendations for the CO exposure limits are not consistent between various regulations within the US and other countries. However, the recommendations offer an indication of risks from exposure to CO in parking garages. A limit level of 25 ppm for long-term CO exposure would meet almost all the codes and standards listed in Table 1.

Table 1. Summary of U.S. and International Satndards for Ventilation Requirements of Enclosed Parking Garages.

	Time [hrs]	ppm	Ventilation
ASHRAE	8 1	9 35	7.6 L/s.m^2
ICBO	8 1	50 200	
NIOSH/ OSHA	8 ceiling	35 200	
NFPA			6 ACH
ACGIH	8	25	
Canada	8 1	11/13 * 25/30	
Finland	8 15 minutes	30 75	2.7 L/s.m^2
France	Ceiling 20 minutes	200 100	165 L/s.car
Germany			3.3 L/s.m^2
Japan/ S. Korea			6.35-7.62 L/s.m^2
Netherlands	0.5	200	
Sweden			0.91 L/s.m^2
U.K.	8 15 minutes	50 300	6-10 ACH

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 standards but also the changing emission inventory from motor vehicles.

FIELD TESTING RESULTS

The field measurements for the seven tested parking facilities are briefly summarized below. The air change rates are measured using the tracer gas technique. First, the tracer gas (SF6) was injected in the building directly or through the supply fans. Then, the concentration of the tracer gas was monitored using a field portable electron capture gas chromatograph. For more detailed description of the field measurements, refer to [4]. Table 2 summarizes some of the results obtained during the field testing for all the seven garages described in this paper. The ACH values present the range of the air changes per hour measured at various locations of the facility using the tracer gas technique, while the L/s.m^2 provide the total ventilation rate.

The maximum and the average CO concentrations measured during the day of testing are listed in Table 2 to characterize the indoor quality within the tested parking facility. As indicated in Table 2, the CO level within all the parking garages never exceeded 35 ppm even though the ventilation rates in all cases is well below 7.62 L/s.m^2 recommended by ASHRAE standard 62-1989. The only garage that has ventilation rate close to below 7.62 L/s.m^2 is Garage-E, which serves a large shopping mall with heavy usage throughout the day. It should be noted that all the garages are ventilated continuously except Garage-B where CO sensor was used to control the operation of the supply fans.

Table 2. Summary of the field testing results for five parking garages

Garage	Location	Capacity (# cars)	ACH (Tracer)	L/s.m^2 (Tracer)	Maximum CO (ppm)	Average CO (ppm)
Garage-A	Denver, CO.	1,700	2.2-4.2	1.78	16	7
Garage-B	Denver, CO.	250	5.0-7.0	4.57	20	4
Garage-C	W. Plains, NY.	1,000	0.0-2.6	1.11	40	15
Garage-D	W. Plains, NY.	138	3.6-4.5	3.00	19	12
Garage-E	W. Plains, NY.	258	5.8-8.8	5.68	25	14
Garage-F	Rochester, MN.	448	7.77	5.28	10	9
Garage-G	Mahtomedi, MN	81	0.90-1.02	2.43	12	10

From the field study, the following results are obtained:

(a) All the tested enclosed parking garages have contaminant levels that are significantly lower than those required by even the most stringent regulations (i..e, 25 ppm of 8-hr weighted average of CO concentration).
(b) The actual ventilation rates supplied to the tested garages are generally well below those recommended by ASHRAE standard 1989-62 (i.e., below 7.62 L/s.m^2).
(c) When it is used, demand controlled ventilation is able to maintain acceptable indoor air quality within the tested enclosed parking facilities.
(d) The location of the supply and exhaust vents, the traffic flow pattern, the number of moving cars, and the travel time are important factors that affect the effectiveness of the ventilation system in maintaining acceptable CO (or NOx) levels within enclosed parking garages. Any design guidelines should account for these factors to determine the ventilation requirements for enclosed parking facilities.

It is clear from the results of the field study that the current ventilation rate specified in the ASHRAE standard 1989-62 is out-dated for enclosed parking garages. New design guidelines are needed to provide the minimum ventilation rate required to maintain contaminant concentrations within parking facilities at the acceptable levels set by the relevant health authorities without large penalties in fan energy use. These design guidelines should account for variability in the parking garage traffic flow, car emissions, travel time, and number of moving cars.

DESIGN APPROACH

Based on the results of several parametric analyses [4], a simple design method is developed to determine the ventilation flow rate required to maintain acceptable CO level within enclosed parking facilities. Ventilation rates for enclosed parking garages can be expressed in terms of either flow rate per unit floor area (7.62 $L/s.m^2$) or air volume changes per unit time (ACH). The design ventilation rate required for an enclosed parking facility depends on four factors.

- Contaminant level acceptable within the parking facility
- Number of cars in operation during peak conditions
- Length of travel and operation time of cars in the parking garage
- Emission rate of a typical car under various conditions.

Data for the above listed factors should be available to determine accurately the design ventilation rate for enclosed parking garages. A simple design approach is presented in the following section to determine the required ventilation rate for both existing and newly constructed enclosed parking garages.

GENERAL PROCEDURE FOR THE DESIGN METHOD

To determine the required design flow rate to ventilate an enclosed parking garage, the following procedure can be followed:

Step 1. Collect the following data

- Number of car in operation during the hour of peak use, N (# of cars)
- Average CO emission rate for a typical car per hr, ER, (gr/hr)
- Average length of operation and travel time for a typical car, T (seconds)
- The level of CO concentration acceptable within the garage, CO_{max} (ppm)
- Total floor area of the parking area, A_f (m^2)

The CO emission rate for a car depends on several factors such as vehicle characteristics, fuel types, vehicle operation conditions, and environment conditions [4]. Data provided in the ASHRAE Handbook [1] and reproduced in Table 3 below can be used to estimate CO emission rates for a typical car.

Table 3. Typical CO emissions within parking garages (reproduced from [1])

	Hot Emissions (Stabilized), grams/min		Cold Emissions, grams/min	
Season	1991	1996	1991	1996
Summer (32°C)	2.54	1.89	4.27	3.66
Winter (0°C)	3.61	3.38	20.74	18.96

Step 2. (a) Determine the peak generation rate, GR ($gr/hr.m^2$), for the parking garage per unit floor area using equation (1):

$$GR = \frac{N * ER}{Af} \qquad (1)$$

(b) Normalize the value of generation rate using a reference value GR_o=26.8 gr/hr.m^2. This reference value was obtained using the worst emission conditions (cold emissions in winter season) for an actual enclosed parking facility [4]:

$$f = \frac{GR}{GR_o} * 100 \qquad (2)$$

Step 3. Determine the required ventilate rate per unit floor area (L/s.m^2) the correlation presented by equation (3) depending on the maximum level of CO concentration CO_{max}:

$$L/s.m^2 = C.\ f.\ T \qquad (3)$$

Where, the correlation coefficient, C, is $= \begin{cases} 1.204 \times 10^{-3}\ L/m^2.s^2 \text{ for } CO_{max} = 15 \text{ ppm} \\ 0.692 \times 10^{-3}\ L/m^2.s^2 \text{ for } CO_{max} = 25 \text{ ppm} \\ 0.482 \times 10^{-3}\ L/m^2.s^2 \text{ for } CO_{max} = 35 \text{ ppm} \end{cases}$

and T is the average travel time of cars within the garage in seconds.

EXAMPLE

Consider 2 level enclosed parking garage with a total capacity of 450 cars, a total floor area of 8300 m^2, and an average height of 2.75 m. The total length of time for a typical car operation is 2 minutes (120 s). Determine the required ventilation rate for the enclosed parking garage in L/s.m^2 and in ACH so that the CO levels never exceeds 25 ppm. Assume that the number of cars in operation is 40% of the total vehicle capacity.

Step 1. Garage data: N = 450* 0.4 = 180 cars, ER = 11.66 gr/min (average emission rate for a winter day using the data from Table 3), T = 120 s, CO_{max} = 25 ppm.

Step 2. Calculate CO generation rate:

$$\text{(a)} \quad GR = \frac{180*11.66 gr/min*60 min/hr}{8300 m^2} = 15.17 gr/hr.m^2$$

$$\text{(b)} \quad f = \frac{15.17}{26.8} * 100 = 56.6$$

Step 3. Determine the ventilation requirement:

Using Chart to Figure 2 or the correlation of eq (3) for CO_{max} = 25 ppm L/s.m^2

$$L/s.m^2 = 0.692 \times 10^{-3} * 56.6 * 120\ s = 4.7$$

Or in terms of air change per hour:

$$ACH = \frac{4.7\ L/m.s^2 \times 10^{-3}\ L/m^3 \times 3600 s/hr}{2.75 m} = 6.1$$

Note: If emission rate was based on ER = 6.6 gr/min (which corresponds to 80 % hot emissions and 20% cold emissions based on data provided in Table 3), the required minimum ventilation rate will be 3.5 ACH (i.e., 2.67 L/s.m^2).

SUMMARY AND CONCLUSIONS

In this paper, a new design method is presented to determine the minimum ventilation rate for enclosed parking garages. The new design procedure is flexible and can account for several factors including the maximum acceptable CO level, the number of moving cars, the average vehicular CO emission rate, and the average travel time within the parking garage. The design tool is also simple to use and is suitable for inclusion in the ASHRAE Handbook.

A field testing study in various US locations has showed that the actual ventilation rates used in enclosed parking garages are significantly lower than the rates recommended by ASHRAE standard 62-1989 (i.e., 7.62 $L/s.m^2$). A more detailed description of the results for this field study is provided in [3]. With the continual decrease in average vehicular contaminant emission rate, it is expected that the ventilation rate requirements for enclosed parking garages will be reduced. Therefore, the initial cost for the mechanical ventilation system can be reduced. Moreover, the use of contaminant-based ventilation controls will achieve significant savings in operating cost of the ventilation system in parking garages.

However, further research is needed to determine the maximum acceptable contaminant levels within parking garages due to both car emissions, gasoline fumes, and oil vapors. In addition, more field testing and simulation analysis are required to evaluate the effects of poor mixing conditions (due for instance to poor system design) in determining the minimum required ventilation rates.

ACKNOWLEDGEMENTS

This paper is part of the work performed for the ASHRAE project 945-RP. The authors would like to thank ASHRAE support.

REFERENCES

1. ASHRAE, 1995, *ASHRAE Handbook for HVAC Applications, Chapter 12,* American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc., Atlanta, GA.

2. ASHRAE, 1989, *ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality,* American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc., Atlanta, GA.

3. Ayari, A., Grot, R.A., Krarti, M., 1999. "Field Evaluation of Ventilation System Performance in Enclosed Parking Garages", submitted to *ASHRAE Transactions.*

4. Krarti, M., Ayari, A., and Grot, R.A., 1998, "Evaluation of Fixed and Variable Rate Ventilation System Requirements for Enclosed Parking Facilities", Final report for ASHRAE project 945-RP.