To determine the required design flow rate to ventilate an enclosed parking to achieve carbon monoxide level less than or equal to 15 ppm.

1.0 Carpark level considered: Basement-1

No. of cars = 80

Normally, the total number of car in operation can be assumed as 40 % of the total vehicle capacity but in this calculation, it was assumed that total no. of cars are in operation: 80.

Area of basement-1 = 4207 m²

Height of basement = 5 m

Emission rate shall be based on ER = 6.6 gr/min (which corresponds to 80 % hot emissions and 20 % cold emissions as per ASHRAE.

Average length of operation and travel time for a typical car as per ASHRAE, T = 120 sec

The level of concentration acceptable within basement floor = 15 ppm to 35 ppm

Therefore, the calculations shall be based on lowest CO generation level as 15 ppm

Determining the peak generation rate, GR for the basement per unit floor area = $f = \frac{GR}{GR_0} \times 100$

Normalize the value of generation rate using a reference value GR_0 = 26.8 gr/hr.m², this reference value was obtained using the worst emission conditions (cold emissions in winter season.

2.0 Calculate CO generation rate:

GR = $\frac{N \times ER}{A_F}$

GR $= \frac{80 \times 11.66 \frac{gr}{min} \times 60\ min/hr}{4207\ m^2}$ = 13.31 gr/h.m²

$$f = \frac{GR}{GR_0} \times 100$$

f = 13.31 / 26.8 x 100 = 50

3. Determining the ventilation requirement:

L/s.m² = c x f x T

Where correlation coefficient, C is given by $1.204 \times 10^{-3} \frac{L}{m^2}.s^2$ for 15 ppm

L/s.m² = $1.204 \times 10^{-3} \times 50 \times 120\ s = 7.23$

$$\text{ACH} = \frac{7.23\frac{L}{s}.m^2 \times \frac{10^{-3}}{m^3} \frac{L}{} \times 3600\ s/h}{5\ m} = 5.21$$

Therefore, at 5.21 ACH, we can achieve 15 ppm CO concentration in the basement carpark.

Ventilation for Enclosed Parking Garages

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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 (CO) 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 (NO_x) 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 stadiums) of the total vehicle capacity. The emission of carbon monoxide depends on individual cars including factors such as the age of the car, the engine power, and the level of car maintenance.

For enclosed parking facilities, ANSI/ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality* specifies a fixed ventilation rate of below 7.62 L/s·m^2 (1.5 cfm/ft^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 (8 ft) ceiling height.

However, some of the model code authorities specify an air change rate of four to six air changes per hour. In addition, some of the model code authorities allow the 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 from code to code. A consensus on acceptable contaminant levels for enclosed parking garages is needed.

Unfortunately, Standard 62-1989 does not address the issue of ventilation control through contaminant monitoring for enclosed garages. Thus, ASHRAE commissioned a research project (945-RP) to evaluate current ventilation standards and recommend rates appropriate to current vehicle emissions/usage.

Ventilation Regulation

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 United States and other countries. However, the recommendations offer an indication of risks from exposure to CO in parking garages. A limit of 25 ppm for long-term CO exposure would meet almost every code and standards listed in *Table 1*.

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 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

As part of an ASHRAE-sponsored project (945-RP), field measurements for the seven tested parking facilities were performed. The air change rates are measured using the tracer gas technique. First, the tracer gas (SF_6) 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 a more detailed description of the field measurements, see Reference 4.

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Table 2 summarizes some of the results obtained during the field testing for seven garages described in Ayari, et al. (2000). 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 $L/s{\cdot}m^2$ (cfm/ft^2) values 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 the 7.62 $L/s{\cdot}m^2$ (1.5 cfm/ft^2) recommended by Standard 62-1989. The only garage that has a ventilation rate close to 7.62 $L/s{\cdot}m^2$ (1.5 cfm/ft^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 sensors were used to control the operation of the supply fans.

From the field study, the following results were obtained:

1. All the tested enclosed parking garages had contaminant levels that are significantly lower than those required by even the most stringent regulations (i.e, 25 ppm of 8-hour weighted average of CO concentration).
2. The actual ventilation rates supplied to the tested garages were generally well below those recommended by Standard 62-1989 (i.e., below 7.62 $L/s{\cdot}m^2$ [1.5 cfm/ft^2]).
3. When it is used, demand controlled ventilation was able to maintain acceptable indoor air quality within the tested enclosed parking facilities.
4. The location of supply and exhaust vents, traffic flow pattern, the number of moving cars, and travel time were important factors that affect the effectiveness of the ventilation system in maintaining acceptable CO (or NO_x) 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 Standard 62-1989 is outdated 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. Guidelines should account for variability in the parking garage traffic flow, car emissions, travel time, and number of moving cars.

	Time (hrs)	PPM	Ventilation
ASHRAE	8 1	9 35	7.6 L/s · m^2 (1.5 cfm/ft^2)
ICBO	8 1	50 200	7.6 L/s · m^2 (1.5 cfm/ft^2)
NIOSH/ OSHA	8 Ceiling	35 200	—
BOCA	—	—	6 ACH
SBCCI	—	—	6–7 ACH
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 (0.53 cfm/ft^2)
France	Ceiling 20 minutes	200 100	165 L/s · car (350 cfm/car)
Germany	—	—	3.3 L/s · m^2 (0.66 cfm/ft^2)
Japan/South Korea	—	—	6.35–7.62 L/s · m^2 (1.25–1.5 cfm/ft^2)
Netherlands	0.5	200	—
Sweden	—	—	0.91 L/s · m^2 (0.18 cfm/ft^2)
U.K.	8 15 minutes	50 300	6–10 ACH

Table 1: Summary of U.S. and international standards for ventilation requirements of enclosed parking garages.

Design Approach

Based on the results of several parametric analyses,[4] a simple design method was 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 ($L/s{\cdot}m^2$ or cfm/ft^2) or air volume changes per unit time (ACH). The design ventilation rate required for an enclosed parking facility depends on four factors:

1. Contaminant level acceptable within the parking facility;
2. Number of cars in operation during peak conditions;
3. Length of travel and operation time

of cars in the parking garage; and,

4. Emission rate of a typical car under various conditions.

Data for these 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 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:

1. Number of cars operating during the hour of peak use, *N* (# of cars). The ITE Trip Generation Handbook[5] is a good source to estimate the value of *N*.

2. Average CO emission rate for a typical car per hr, ER, (gr/hr). 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* can be used to estimate CO emission rates for a typical car. Typically, hot starts are common in facilities where cars are parked for short periods such as shopping malls. Meanwhile, cold starts characterize facilities where cars park during long periods such as office buildings.

3. Average length of operation and travel time for a typical car, *T* (seconds). The ASHRAE Handbook gives average entrance/exit times for vehicles. Higher values may be used for worst case scenarios such as during rush hours or special events.

4. The level of CO concentration acceptable within the garage, CO_{max} (ppm).

5. Total floor area of the parking area, A_f (m²).

Step 2.

1. Determine the peak generation rate, GR (gr/hr·m² [gr/hr·ft²]), for the parking garage per unit floor area using *Equation 1:*

$$f = \frac{GR}{GR_o} \times 100 \qquad (1)$$

2. Normalize the value of generation rate using a reference value GR_o=26.8 gr/hr·m² (GR_o=2.48 gr/hr·ft²). This reference value was obtained using the worst emission conditions (cold emissions in winter season) for an actual enclosed parking facility:[4]

$$GR = \frac{N \times ER}{A_f} \qquad (2)$$

Step 3. Determine the required ventilation rate per unit floor area (L/s·m² or cfm·ft²) the correlation presented by Equation 3 depending on the maximum level of acceptable CO concentration CO_{max}:

$$L/s{\cdot}m^2 = C\,f\,T \qquad (3)$$

Where, the correlation coefficient, *C* is given below:

$$C = \begin{cases} 1.204\times10^{-3}\ L/m^2{\cdot}s^2\ (2.370\times10^{-4}\ cfm/ft^2{\cdot}s)\ \text{for}\ CO_{max}=15\ ppm \\ 0.692\times10^{-3}\ L/m^2{\cdot}s^2\ (1.363\times10^{-4}\ cfm/ft^2{\cdot}s)\ \text{for}\ CO_{max}=25\ ppm \\ 0.482\times10^{-3}\ L/m^2{\cdot}s^2\ (0.948\times10^{-4}\ cfm/ft^2{\cdot}s)\ \text{for}\ CO_{max}=35\ ppm \end{cases}$$

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

Example

Consider a two-level enclosed parking garage with a total capacity of 450 cars, a total floor area of 89,300 ft² (8300 m²), and an average height of 9 ft (2.75 m). The total length of time for a typical car operation is two minutes (120 s). Determine the required ventilation rate for the enclosed parking garage in L/s·m² 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 (a shopping mall facility).

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:

(a) $$GR = \frac{180 \times 11.66\ gr/min \times 60\ min/h}{8300\ m^2} = 15.17\ gr/h{\cdot}m^2$$

(b) $$f = \frac{15.17}{26.8} \times 100 = 56.6$$

Step 3. Determine the ventilation requirement:

Using the correlation of Equation 3 for CO_{max} = 25 ppm, the design ventilation rate in L/s·m² can be calculated:

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

Or in terms of air change per hour:

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

Garage	Location	Capacity (# cars)	ACH [Tracer]	L/s · m² [Tracer]	cfm/ft² [Tracer]	Maximum CO (ppm)	Average CO (ppm)
Garage A	Denver	1,700	2.2–4.2	1.78	0.35	16	7
Garage B	Denver	250	5.0–7.0	4.57	0.90	20	4
Garage C	West Plains, N.Y.	1,000	0.0–2.6	1.11	0.22	40	15
Garage D	West Plains, N.Y.	138	3.6–4.5	3.00	0.59	19	12
Garage E	West Plains, N.Y.	258	5.8–8.8	5.68	1.12	25	14
Garage F	Rochester, Minn.	448	7.77	5.28	1.04	10	9
Garage G	Mahtomedi, Minn.	81 (trucks)	0.90–1.02	2.43	0.48	12	1

Table 2: Summary of field testing results for seven U.S. parking garages.

	Hot Emissions (Stabilized), grams/min		Cold Emissions, grams/min	
Season	1991	1996	1991	1996
Summer (32°C [90°F])	2.54	1.89	4.27	3.66
Winter (0°C [32°F])	3.61	3.38	20.74	18.96

Table 3: Typical CO emissions within parking garages.[1]

Notes

- 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·m²).
- The assumed travel time is higher than any value provided by ASHRAE[1] and is used to represent a worst case scenario (Christmas evening or an unusual event). If a longer travel time of 3 minutes is used, the design ventilation rate will be 7.05 L/s·m² or 9.2 ACH (close to the current ventilation rate recommended by Standard 62-1989).

Summary and Conclusions

In this article, 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.

A field testing study in various U.S. locations has showed that the actual ventilation rates used in enclosed parking garages are significantly lower than the rates recommended by Standard 62-1989 (i.e., 7.62 L/s·m² 1.5 cfm/ft²). A more detailed description of the results for this field study is provided in the article in Reference 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.[1]

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.

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