Ventilation Design for 1000 Car Parking Garage

Establishing a rational basis for safe, economical ventilation.

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THE Main Place Complex in Buffalo, New York is typical of the large scale urban redevelopment projects that are transforming the cores of American cities. Sited on a superblock 885 ft long by 233 ft wide, with a net ground cover of approximately 179,000 sq ft, it rises from what was a desolate zone of moribund commercial properties. It gives to central Buffalo a large parking garage for 1000 cars, a completely air conditioned shopping center with a commodious central mall, commercial space for a New York Telephone Company regional office, and a tower office building whose base is occupied by the Erie County Savings Bank.

This article will deal with the ventilation of the 400,000 sq ft parking garage, which occupies the subbasement, basement, and one street level of the shopping center.

It was decided at the outset that the garage should not be heated. This decision was based on the judgment that revenues from parking could not possibly justify the investment in heating plant and energy costs for the enormous ventilation load required to control air purity. Calculations showed that a 2 in. rigid board insulation layer pinned to the underside of the shopping center slab, in conjunction with shopping center air systems using low return air inlets and low set finned tube hot water convectors, would result in reasonably comfortable surface temperatures of the floor above—that is, a minimum of 62.5 F.

A Look at the Codes

The design criteria for garage ventilation were then carefully analyzed in light of modern views on air pollution. Existing codes for parking garage ventilation are contradictory and at least in some measure unrelated to rational environmental requirements.

Local Buffalo codes, it was found, did not give explicit direction to the design. The National Building Code extant at the time of construction required "a mechanical ventilating system with positive means of at least one cubic foot of air per minute per square foot of floor area."

The New York City Building Code requires the provision of at least four air changes per hour by mechanical exhaust with provision for a corresponding inflow of air from an uncontaminated source. Two of the four air changes are required to be taken from near the floor. The New York State Building Code, on the other hand, recommends six air changes per hour, with high mechanical supply and low mechanical exhaust.

The Chicago Ventilation Code requires 1 cfm of exhaust plus 0.75 cfm of supply per sq ft, or 1 cfm of exhaust per sq ft with adequate relief openings.

In vehicular tunnel ventilation, where a rational basis for controlling air contamination is essential, mechanical supply requirements of 2800 to 5600 cfm per vehicle are stipulated in various sources. At the same time, it was found that vehicular tunnels with very dense traffic were operating at 10 to 15 air changes per hour.

What Level of CO Control?

These high ventilation rates are understandable if the quantities of carbon monoxide emitted by typical passenger vehicles, given in Table 1, are considered. Carbon monoxide is the most hazardous component of internal combustion engine exhaust. It gives no warning of its presence. When it is inhaled, it is absorbed by the hemoglobin of the blood and destroys the blood's ability to transport oxygen to body cells. Even dilute concentrations of carbon dioxide in air make for headache, nausea, and vertigo. In cases where many cars have been forced to idle on exit ramps, motorists have become ill. But even before the sickening effects of carbon monoxide take hold, the rank odor of accompanying half burned carbon compounds can make an underground garage unbearable, or so unpleasant as to limit its utility.

The threshold limit value for carbon monoxide is given as 100 ppm or 0.01 percent by the American Conference of Government and Industrial Hygienists. This is a maximum allowable concentration based on exposure for eight hours per day, five or six days a week. It is a level that must be used as a limit, not as an average, since variations from the average could result in deadly local conditions. It was therefore decided that the garage ventilation system should be designed for:

- Long term max permissible CO concentration 100 ppm
- Long term average permissible CO concentration 50 ppm
- Peak CO concentration for one hour 200 ppm

With the design average set at 50 ppm, there would be a safety factor of 2 to safeguard against stratification, pocketing, and local concentrations due to normal packing. For jams at exit ramps for periods not exceeding one hour, it was agreed that a peak concentration of 200 ppm could be accepted.

The floor density of vehicles was calculated as 400 sq ft per car. With the CO emission per car set at 30 cu ft per hr, or 0.5 cfm (the very minimum for a small engine idling), the required clean air flow for dilution, Q_d, can be calculated as follows:

$$50/1{,}000{,}000 = 0.5/(0.5 + Q_d)$$
$$Q_d = 10{,}000 \text{ cfm}$$

Thus, the volume of air required on this minimal basis is 10,000 cfm for 400 sq ft, or 25 cfm per sq ft, an impossibly high ventilation rate. This theoretical rate for one small car idling was compared to ventilation requirements stipulated by the codes and authorities previously mentioned. The results are summarized in Table 2, which is based on an assumed floor height of 9 ft and 400 sq ft of floor area per car, or 3600 cu ft of garage volume per car.

The range of these requirements is so wide that it appeared that reference would have to be made to the performance of existing garages. It was obvious that vehicular tunnels, while acrid, constituted no obvious health hazard with 600 to 900 cfm ventilation rates and engines running at half throttle. Similarly, there are millions of square feet of commercial garage space operating at 240 cfm per parking stall with few reported complaints.

It should be emphasized that the requirements of various codes, Items *a* through *e* in Table 2, take into account diversity. That is, it is assumed that not all cars are operating simultaneously and/or not all parking stalls are occupied simultanously. The remaining items assume that every auto in the garage is operating. The requirement in Item *f* is based on 150 ppm of CO and CO production of 25 to 50 cfm per car.

A check of the literature indicated the design data in Table 3 for three large parking garages. The Newark design is based on maintaining a maximum CO concentration of 100 ppm. The Chicago design is based on control of CO levels with 10 percent of the autos idling.

Study Car Operating Time

The problem was resolved by reference to measurements made at the Grand Circus Garage in Detroit by George M. Hama, William G. Frederick, and Harry G. Monteith under the auspices of the Detroit Bureau of Industrial Hygiene in 1960.* Precise measurements were made of carbon monoxide concentrations as a function of the actual number of cars running per hour. A correlation was found, and as expected, peak carbon monoxide concentrations corresponded to peak hours of parking activity. By timing car operation accurately by means of two-way radio communication between parking attendants and a central control, the investigators determined that the average running time per car was 1.8 ± 0.2 minutes, within a range of 0.5 to 5.5 minutes. With the total number of cars operating per hour known, it was possible to determine the average number running. In Detroit, it ranged from 1.23 percent of parking capacity as a mean to 3.5 percent of capacity as a peak. From these data, extrapolation could be made to Buffalo, where physical similarities between garages were remarkable, as indicated in Table 4.

For Buffalo, therefore, the total air flow to maintain CO at 50 ppm, based on the 24,000 cfm per car requirement in Table 2 (Item *h*) and 1000 cars, was calculated as:

For average conditions—

$24{,}000 \times 100 \times 1.23/100 =$ 295,200 cfm total

or 295 cfm per car

For peak conditions—

$24{,}000 \times 1000 \times 3.5/100 =$ 840,000 cfm total

or 840 cfm per car

For design purposes, therefore, the median between average and peak conditions was used, scaled from 450 cfm per car on the first

*Hama, George M., Frederick, William G., and Monteith, Harry G., *How To Design Ventilation Systems for Underground Garages*, Air Engineering, April 1962.

TABLE 1—CARBON MONOXIDE EMISSIONS of typical passenger cars.*

	CO emission, cu ft per hr					
	Mean of light and full loads			Full load only		
Type of vehicle	Min	Max	Avg	Min	Max	Avg
Five passenger car	29	77	52	—	—	—
Seven passenger car	42	144	89	39	164	67
Average	36	111	72	—	—	—

**Ventilation of Vehicular Road Tunnels*, Journal of the Institution of Heating and Ventilating Engineers, Great Britain, September 1962.

TABLE 2—VENTILATION REQUIREMENTS from various codes and other sources.

Source	Requirement	Ventilation,[1] cfm per car
a) New York City Code	4 air changes per hr	240
b) New York State Code	6 air changes per hr	360
c) National Building Code	1 cfm per sq ft	400
d) Chicago Ventilation Code	1 cfm per sq ft	400
e) New York City Vehicular tunnels	10-15 air changes per hr	600-900
f) Fan Engineering[2]	—	2800-5600
g) Air to dilute 0.5 cfm CO emission from small car	—	10,000
h) Air to dilute 1.2 cfm CO emission for average car	—	24,000

[1]400 sq ft or 3600 cu ft per car.
[2]Buffalo Forge Co.

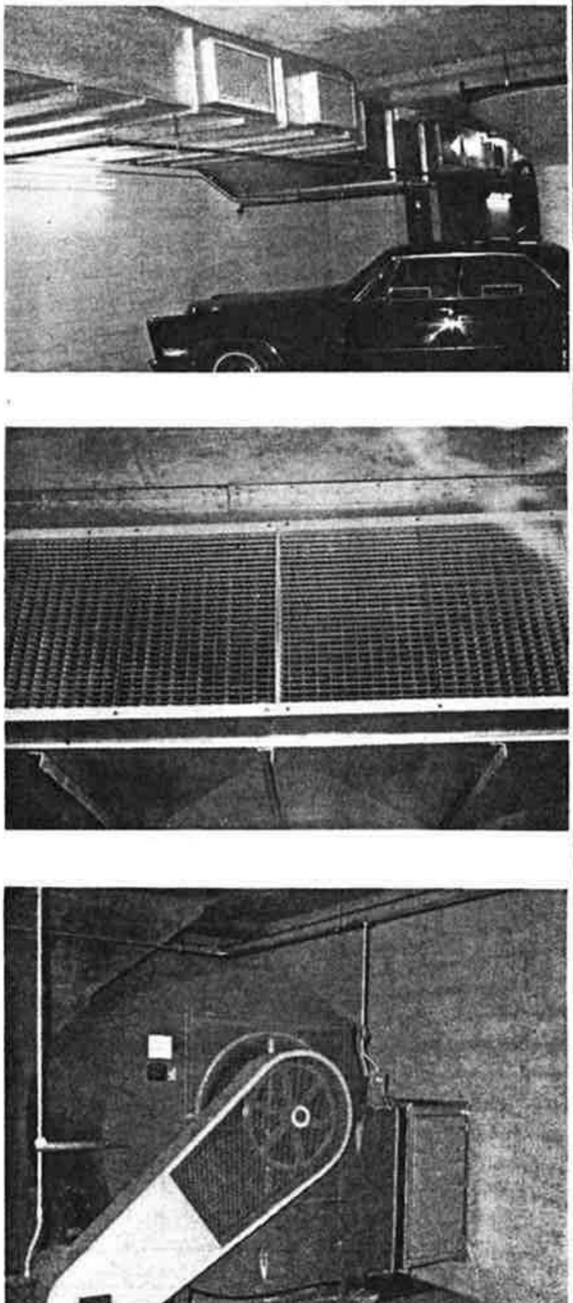
TABLE 3—DESIGN DATA for three large parking garages.

City and year	Capacity, cars	Design basis	Total ventilation air, cfm
Los Angeles, 1952[1]	5000	10 air changes per hr	640,000 (exhaust)
Chicago, 1955[2]	2300	15 air changes per hr	1,766,400 (exhaust) (880,000 sq ft)
Newark, 1960[3]	1031	1.15 cfm per sq ft	360,000 (supply) 400,000 (exhaust)

[1]*Los Angeles Builds World's Largest Underground Garage*, Heating, Piping & Air Conditioning, Vol. 24, No. 4, p. 101 (April 1952).
[2]Burke, Ralph, H., *World's Biggest Underground Garage*, Heating, Piping & Air Conditioning, Vol. 27, No. 3, pp. 105-108 (March 1955).
[3]*How Newark's Underground Garage Is Ventilated*, Heating, Piping & Air Conditioning, Vol. 32, No. 7, pp. 100-101 (July 1960).

TABLE 4—COMPARISON of Buffalo Main Place garage with Grand Circus Garage in Detroit.

Item	Grand Circus Garage, Detroit (1960)	Buffalo Main Place Garage (1968)
Number of levels	2-3	3
Number of cars	1100	1000
Total cfm per car	490	470
Total cfm	540,000	470,000
Total area, sq ft	360,000	400,000
cfm per sq ft	1.5	1.26



VIEWS of ductwork, grille, and fan.

level where operating time is short to 550 cfm per car on the subbasement level where operating time is necessarily longer.

Installing the System

To save in first cost, the main intake and exhaust shafts were constructed of reinforced concrete or masonry block. Specifications were drawn to secure reasonable air tightness, with air passageways plastered and all joints carefully caulked with a silicone sealant.

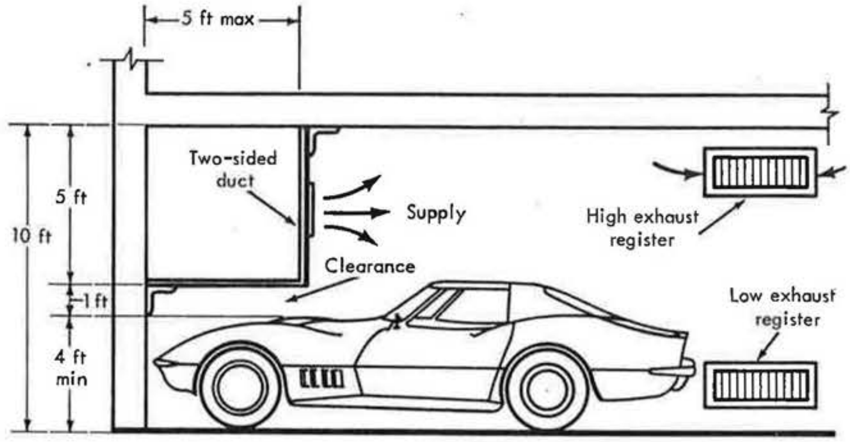
To save headroom and sheet metal costs, main air supplies are fed from two-sided sheet metal ducts that are flanged and bolted to the overhead slab and sidewall as shown in Fig. 1. No parking space was lost since the ducts were proportioned to fit over the hoods of standard American cars.

To conserve power for night, weekend, and off-peak operation, consideration was given to sensing CO concentrations by means of a gas analyzer. Fans were to be cycled automatically, with pairs of supply and exhaust fans called in to hold CO to acceptable levels. When the cost of maintaining gas analyzers in calibration was added to the first cost of a gas analyzing system, however, it was decided to operate fans manually, stepping them in pairs. Since fans are ganged in groups of two or three, automatic electric shutoff dampers were provided to prevent reverse rotation or, worse, the loss of capacity through bypass via an off fan.

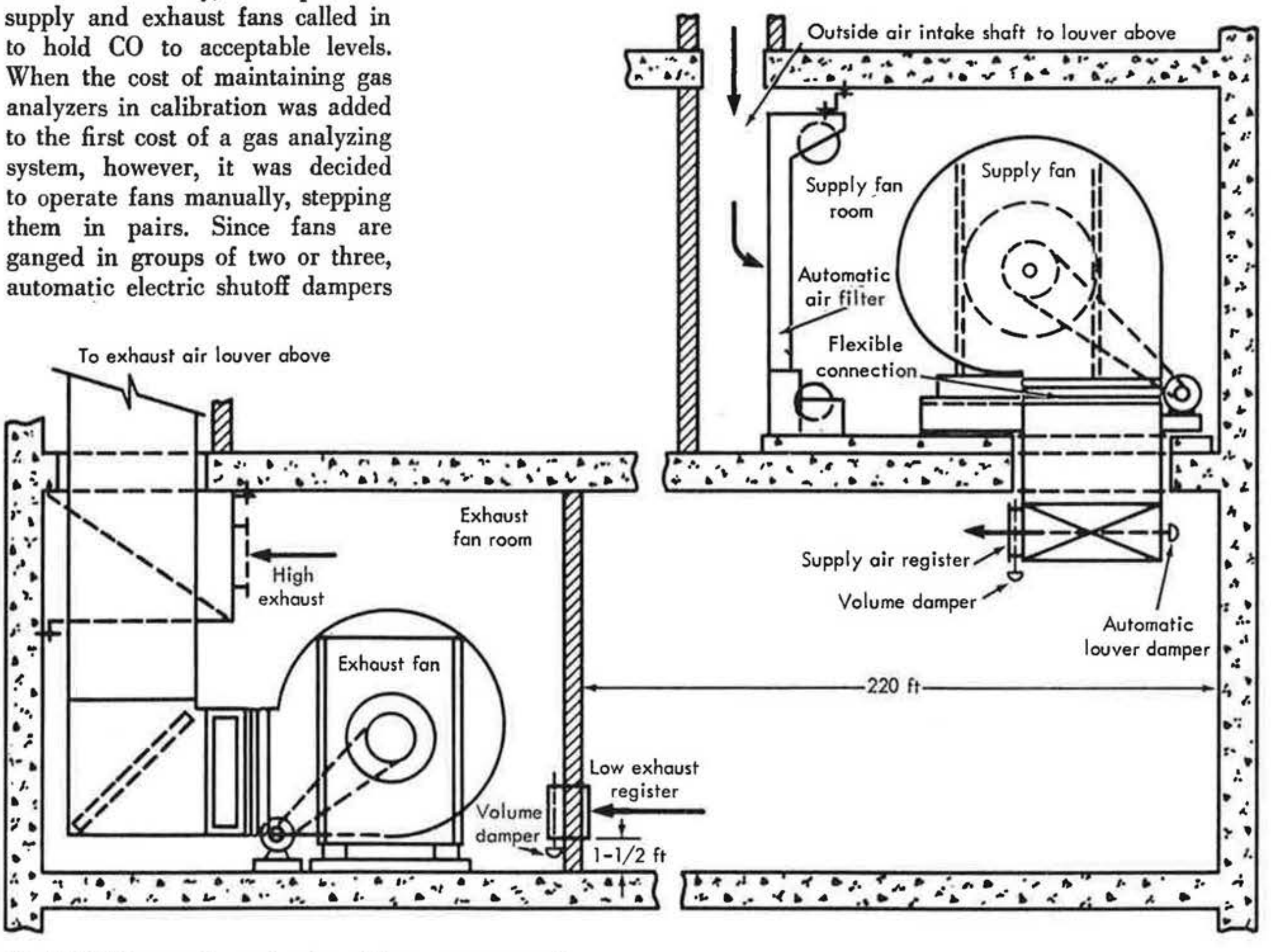
Automatic roll filters are employed, and intake louvers were elevated so that the lowest is approximately 7 ft above grade. By this means, the quality of the air supplied is at least as good as that delivered to commercial occupancies on the upper floors.

Typical fan room and air riser arrangements are shown in Fig. 2.

The contract cost for the garage ventilation was $350,000, which figures to $0.88 per sq ft or $0.74 per cfm. Buffalo Main Place was developed by Hammerson, Fusco, and Amatrudo; consulting engineers were Slocum and Fuller. ≠



1 TYPICAL CAR nosed in below two-sided duct.



2 TYPICAL supply and exhaust fan arrangements.