SMOKE CONTROL AND NOXES IN CAR PARKS

PIETREANU COSTEL-MARIAN[1*], STRUGARIU ROBERT-DUMITRU[2], PANAITESCU VALERIU[3]

[1] and [2] Fire Security Bureau, General Inspectorate for Emergency Situations from Bucharest, Romania

[3]Energetic Faculty, Polytechnic University from Bucharest, Romania

Abstract: The main purpose of this article is to describe the principles of CO ventilation in car parks and to provide a brief description of smoke extraction and control system. It provides information on the possibilities provided by jet ventilation. In closed car park, in Romania, we use for CO and smoke extraction system fans and a lot of ducts. In many country of the Europe, they use for this jet ventilation system, without ducts, characterized by low installation and energy costs.

Key words: smoke control, car park, ventilation, jet fan

1. INTRODUCTION

Cars have become a natural part of everyday life. Parking facilities are therefore in great demand, particularly in cities and large towns. Conventional, open-air car parks take up far too much space, while people to an increasing degree prefer parks and open spaces in their cities and towns. In other situations, climate conditions or a desire to prevent parked cars from being vandalized necessitate closed parking facilities. To meet these requirements, more and more multi-storey car parks are being built, both below and above ground level. However, car exhaust contains several hazardous gases, carbon monoxide (CO) and benzene among others and these must be extracted from car parks for health reasons. Based on experience in the densely populated and the large cities where space is at a premium, the designers have developed car park ventilation systems for CO extraction and smoke control in case of fire. They require no ducts in the car park, like in Romania, and are thus extremely flexible [1]. The references include CO and smoke control systems installed in many country of the Europe. Ventilation is the transport of air.

To transport air a mass must be moved. At 20 °C, the density of air is approx. 1.2 kg/m³. Ventilating 10 m³ air therefore involves moving a mass of 12 kg. Air can be moved in three ways. The best known method is to transport it through ducting by means of a fan that either sucks or pushes the air through the duct. It is also well known that air moves vertically in response to thermal differentials. The other method is known as jet ventilation and utilizes the fact that a moving body changes velocity when it is subjected to a "pushing force". On the basis of continuous testing, the use of jet ventilation has been optimized and integrated into car park safety systems.

Basically, there are two types of car park, open or closed. Open car parks include uncovered car parks and those that are sufficiently open to ensure the necessary ventilation. Several requirements must be met before a car park is classified as being open. Each country has its own regulations, which may be more or less stringent.

[*] Corresponding author, email: pietreanuc@yahoo.com

Generally, requirements are more specific in countries with a longer tradition of building car parking facilities and thus more experience in their design.
Closed car parks are characterized by:

a) outside walls are closed;
b) only a single outside wall with ventilation openings;
c) ventilation openings, if any, that do not meet the requirements on open car parks;
d) underground car parks with no ventilation openings;
e) a standard distance to neighboring buildings;
f) partitioning walls that impede natural ventilation.

2. CONVENTIONAL VENTILATION METHODS IN CAR PARKS

Presently, four different ventilation methods are used in car parking facilities, depending on whether the car park is open or closed. Natural ventilation by means of wind and thermal conditions is used in open car parks (Figure 1).

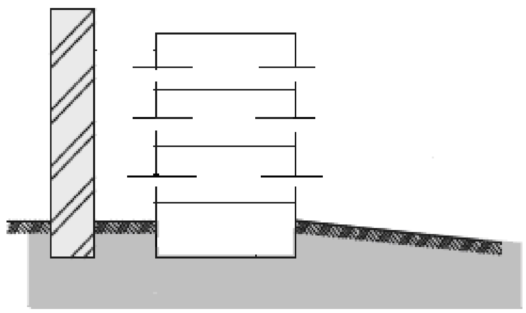


Fig. 1. Natural cross-ventilation.

Fan-assisted natural ventilation is similar to the above, but supplemented with a fresh-air fan or exhaust fan. Such systems may also include ducts (Figure 2) or jet fans.

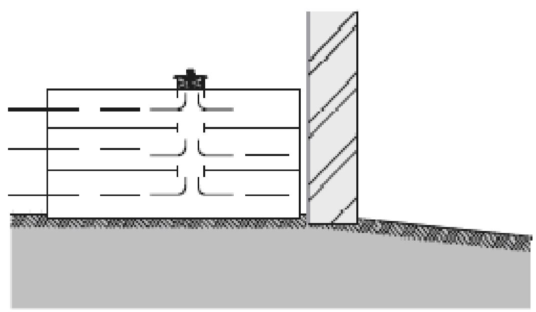


Fig. 2. Semi-natural ventilation.

Simple conventional ventilation is used in closed car parks. Such systems also consist of fresh-air fans and exhaust fans, but no ducts are used (Figure 3).

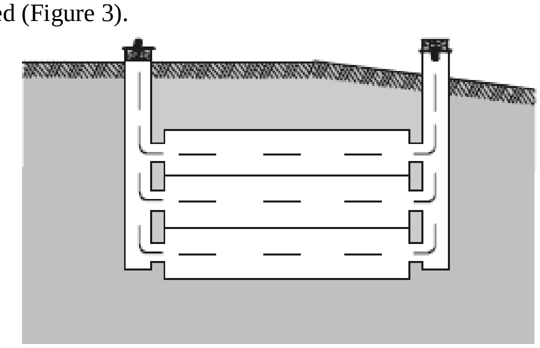
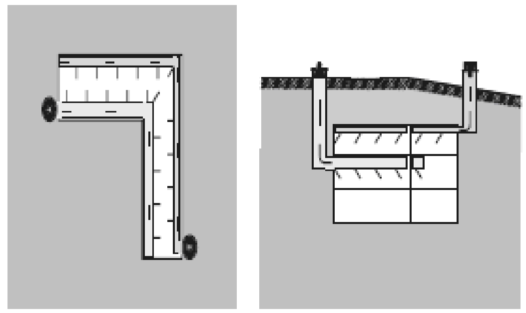


Fig. 3. Semi-mechanical ventilation.

Conventional ventilation is used in closed car parks. It consists of both fresh-air fans and exhaust fans in combination with ducts for transporting air (Figure 4).



Top view Side view

Fig. 4. Mechanical ventilation.

In practice, there are several problems with conventional ventilation systems. For example: there is no or insufficient room for inlet and/or exhaust ducts, there is no guarantee that the system will provide sufficient ventilation, so-called "dead" corners with little or no ventilation may result, there is no room for ducts, smoke control in case of fire is not considered during system design, the possibility of regulating the level of ventilation in response to variable requirements is not considered, fire protection installations such as fire doors and fire walls prevent an unobstructed view of the car park [2, 3 and 4].

Jet ventilation systems can be adapted to cover needs for both CO ventilation and, in special circumstances, smoke control in case of fire. Considerable energy savings are also possible if large facilities are sectioned into independent zones.

3. PRINCIPLE OF JET VENTILATION

In conventional ventilation systems, all air is drawn through fans and ducting. This applies to both the fresh air supplied and the spent air discharged. To prevent pressure drop, air velocity is kept as low as possible. However, this means that must be relatively wide, thus requiring considerable space. In jet ventilation, a different approach is taken. Here, a small quantity of air is sucked into a fan and then ejected at high velocity. When this air hits the air in front of the fan, it thrusts it forwards while at the same time drawing the surrounding air along with it. In this way, all the surrounding air is set in motion and transported over a distance of 20 - 40 meters without the use of ducts. The entire car park functions as a duct. The principle behind jet ventilation is the same as used in rockets, where a small quantity of air (combustion products) is forced from the burner at high velocity, thus thrusting the rocket upwards. As the fan is firmly secured, all energy is transferred from the ejected air to the surroundings in the form of a velocity. The fan stays in place while the air is driven forwards. As a result of entrainment, the quantity of air in motion will always be considerably greater than the quantity of air passing through the fan. The quantity of air in motion is the same in different cross-sections of the facility. Depending on system dimensioning, an average velocity of, for example, 1 m/s can be achieved. The necessary size and number of jet fans depend on the size and layout of the car park and on whether the system is primarily to be used for CO ventilation or also for smoke control. Thrust, the force generated by jet fans, is expressed in Newton [N] and is the product of the mass flow rate and the change in velocity. It is the unit of measurement for jet fans. Jet fans are typically installed beneath the ceiling. It is important that jet fans be positioned in the midst of the air they are to set in motion. In theory, assuming that the surrounding air has zero initial velocity, the thrust generated by a jet fan is equal to the volumetric flow rate times the density of air times the outlet velocity. For optimum efficiency, jet fans should be suspended completely freely. In practice, they are installed as close to the ceiling as possible to provide maximum clearance beneath the fans. Air tends to adhere to even surfaces. This phenomenon, known as the Coanda effect, is of great importance for overall efficiency. To compensate for this, jet fans are equipped with directional grilles that bend the air flow away from neighboring surfaces. Overall efficiency is also affected by inlet and outlet conditions. Compensation must be made for obstacles in the vicinity of the fans. As previously mentioned, nominal thrust equals mass air flow times the outlet velocity. The effective thrust is the product of the nominal thrust and a "system efficiency factor", and is always less than the nominal thrust [5] and [6]. In car parking facilities, jet fans can be used to replace ducts for the extraction of both CO and explosive petrol fumes (CH_4). The presence of CO in a car park indicates that other hazardous fumes (e.g. benzene) are also present. As a result of this, the German authorities have reduced the limits for CO in car parking facilities from 100 ppm to 50 - 60 ppm, depending on the federal state in question. Ventilation is activated by sensors in the car park for monitoring the level of CO and CH_4. The necessary number of sensors depends on the layout of the car park and varies between one per 100 m² to one per 500 m². CH_4 sensors are normally installed close to the ground (approx. 30 cm above the ground) while CO sensors are installed at head height (approx. 150 cm above the ground). If sensors with 4 - 20 mA output are used, these can be connected to a CTS control system, thus allowing limits to be adjusted.

Figure 5 illustrates the possible design of a closed system consisting of jet fans and an exhaust fan installed in a shaft. The extraction unit typically consists of a grille, an exhaust fan and, if necessary, a sound attenuator. When the set limit is exceeded, the exhaust fan is started first, followed by the jet fans. In open car parks, where no ventilation is required, natural ventilation can be assisted by jet fans, thus preventing the occurrence of "dead" areas. The same applies to parking facilities that only just fail to meet the requirements on open car parks. Here too, requirements can often be met using jet fans alone. In such cases it is often best to use 100% reversible fans. These fans are capable of providing the same thrust in either direction so that the direction of flow can be changed to suit wind conditions.

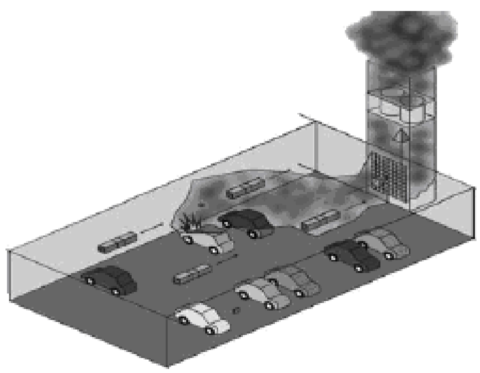


Fig. 5. Jet ventilation.

4. DESIGN CRITERIA

Regarding the practical design of jet ventilation systems, determining the following five factors is of particular importance:

1. CO production;
2. Ventilation quantity;
3. Direction of air movement;
4. Noise levels within and outside the car park;
5. Ventilation and extinguishing strategy in case of fire.

4.1. CO production

Several factors affect the amount of CO produced. More modern cars produce less pollution than older models as a result of improved combustion and the use of catalytic converters. Cold engines produce more CO than hot engines. Speed also affects CO production. All these factors must be taken into account when designing ventilation systems. They also explain why CO production values differ from country to country. Some countries have relatively many old cars while in other countries, a greater proportion of the cars are new. There are no standardized regulations in the Nordic countries, but a model for calculating the required air quantity for CO ventilation is normally used. The model calculates a necessary ventilation flow on the basis of the number of parking spaces, the distance traveled to reach them and the number of cars arriving and leaving per hour. The input data on CO production does not differentiate between cold and hot starts. Nor does it take into account the acceptable CO concentration within the car park, the CO concentration of the air outside the car park, or whether the car park is part of a shopping center or housing complex. Since catalytic converters were introduced, the production of CO by cars has fallen dramatically in relation to other combustion products. In Germany this has meant that CO is now considered as an indicator for other hazardous gases, including NO_x. As a result, permissible CO limits have been reduced from 120 ppm to 50 - 60 ppm which, with certain modifications, applies in the individual federal states. The specified limit is an average value for a 30 minute period. If the fresh-air intake is from a street with heavy traffic, the CO concentration of the intake air should be set to 5 ppm, while in suburban areas with light traffic, the CO concentration can be assumed to be zero. An engine produces more CO when it is cold than when it is warm. The German Association of Engineers recommends the following engine emission values (e):

Hot engine:	$0.008 \cdot s$	[g];
Cold engine, s <80 m:	7.6	[g];
Cold engine, 80 m< s <500 m:	$0.89 \cdot s^{0.49}$	[g];

where "*s*" is the distance driven inside the car park.

4.2. Ventilation quantity

The following calculations are in accordance with the German standard VDI 2053 [7]. Formula for determining the quantity of CO, q_{CO} :

$$q_{CO} = \frac{P \cdot e}{\rho_{CO}} \left[m^3/h\right] \tag{1}$$

were:

P represent the percentage of parking spaces vacated or occupied per hour (kg/h);
e - emission value;
ρ_{CO} - density of CO (kg/m^3); ρ_{CO} = 1.16 kg/m^3 at 20 °C.

Note that q_{CO} is calculated for all cars in motion, cars that start and leave, and cars that arrive and are therefore hot.

Formula for calculating the necessary ventilation quantity, *Q*:

$$Q = \frac{\sum q_{CO} \times f_g}{CO_{perm} - CO_{out}} \left[m^3/h\right] \tag{2}$$

were:

CO_{perm} = the permissible CO concentration in ppm;
CO_{out} = the concentration of the outside air in ppm;

There are no standard for CO_{perm} and CO_{out} in many countries, but VDI 2053 provides recommended limits:

- f_g = a system factor, varying from 1.0 to 1.5 ;
- f_g = 1.0 for jet systems;
- f_g = 1.25-1.5 for duct-based systems;

$$\sum q_{CO} = \left(q_{CO} \times n_1 + q_{CO} \times n_2 + \ldots + q_{CO} \times n_n\right) \tag{3}$$

were:

n_1 is the number of parking spaces to be ventilated in the level/section under consideration;

$n_2...n_n$ - the number of parking spaces in other sections accessed through n_1;

s_1 - the average distance driven in n_1;

s_2 - the average distance driven in n_1 by cars entering/leaving n_2.

As previously mentioned, *P* is the percentage of all parking spaces that are vacated/occupied per hour. It is also known as the parking frequency. *P* varies greatly, depending on the location of the car park. With certain reservations, the following *P* values may be used:

- Housing complexes 20 – 60 %;
- Shopping centers 70 – 150 %;
- Office blocks 50 – 70 %;
- Sports centers 100 %;
- Theatres 100 %;

With regard to housing complexes, the parking pattern must be determined. Is there a steady stream of traffic throughout the day, or do all cars leave at the same time in the morning and return together in the evening? The parking pattern may thus result in considerable fluctuation in the quantity of fresh air required to ventilate the car park, and *P* must therefore often be evaluated from case to case. Note that parking frequency is based on the total number of entries and departures per hour. If 25 % of the parking spaces are vacated per hour and 25 % become occupied, the parking frequency is 50 %. In this case, CO production must be calculated for both cold and hot engines.

An example of calculating ventilation requirements.

Consider a two-storey car park (levels 1 and 2) with the following characteristics:

a) Morning traffic
Type: Housing complex parking facility.

- f_g = 1.25 (well designed duct-based parking facility, optimum design with respect to ducts);
- *P* = 60 % (per hour);
- n_1 = 174 spaces;
- n_2 = 106 spaces.

The total average distance driven (*S*) is calculated as half the distance traveled (s_n) plus a distance for parking maneuvers (s_{man}) plus the length of the entry/exit ramp (s_{rmp}).

$$S_n = (s_{man} + ½ \times s_n + s_{rmp}) \tag{4}$$

were:

s_1 = 134 m;

s_2 = 156 m;

s_{man} = 10 m;

s_{entry} = 40 m and s_{exit} = 40 m for ramps.

Note that the distance driven within the car park can only be calculated correctly from drawings containing the routes taken. On the basis of the above data, the total average distance driven (*S*) for the two levels can be calculated as follows:

$$S_1 = (10+134/2+40) = 117 \text{ m} \tag{5}$$

$$S_2 = (10+156/2+40) = 128 \text{ m} \tag{6}$$

As the traffic under consideration is morning traffic with cold engines:

$$q_{CO} = \frac{P \cdot e}{\rho_{CO}} \left[m^3/h \right] \tag{7}$$

$$q_{CO} = 0.6\times0.89\times117^{0.49}/(1.16\times10^3) = 0.0048 \text{ m}^3\text{/h/car for } S_1 \tag{8}$$

$$q_{CO} = 0.6\times0.89\times128^{0.49}/(1.16\times10^3) = 0.0050 \text{ m}^3\text{/h/car for } S_2 \tag{9}$$

In this example, CO_{perm} is assumed to be 50 ppm and CO_{out} to be 0 ppm.

The necessary ventilation quantity (Q) can then be calculated as:

$$Q = \frac{(q_{CO1} \times n_1 + q_{CO2} \times n_2) \times f_g}{CO_{perm} - CO_{out}} \tag{10}$$

$$Q = \frac{(0.0048\times174 - 0.005\times106)\times1.25}{(50-0)\times10^{-6}} \tag{11}$$

$$Q = 34{,}130\, m^3/h$$

Had the parking pattern been different, for example more evenly distributed throughout the day, the parking frequency, P, could have been halved to 30%. This would also halve the necessary ventilation air quantity, to approx. 17,000 m^3/h.

b) Evening traffic

The necessary ventilation quantity in the evening when the cars return can similarly be calculated as follows:

$$q_{CO} = 0.6\times0.008\times117/(1.16\times10^3) = 0.00048 \text{ m}^3\text{/h/car for } S_1 \tag{12}$$

$$q_{CO} = 0.6\times0.008\times128/(1.16\times10^3) = 0.00053 \text{ m}^3\text{/h/car for } S_2 \tag{13}$$

$$Q = \frac{(0.00048\times174 - 0.00053\times106)\times1.25}{(50-0)\times10^{-6}} \tag{14}$$

$$Q = 2{,}800\, m^3/h$$

It is extremely important that the correct assumptions be used when designing car park facilities. Such information is only available from the car park owner and the consulting engineer as they know the assumptions made for the project.

Please note that the calculations in the above example are only applicable to CO ventilation and must not be used for smoke extraction or control in case of fire. Significantly greater ventilation quantities are required for smoke control purposes and the technical installations used must meet special requirements on heat resistance.

4.3. Direction of air movement
The greatest possible distance between fresh air intake and spent-air discharge must be ensured. Usually, the access ramp is used as the fresh-air intake, while an exhaust fan is installed in the opposite corner.

4.4. Noise levels within and outside the car park
It is important that requirements on noise levels within and outside the car park and the most expedient location for the exhaust system be considered early in the project planning phase. Usually, it will be necessary to use sound attenuators, and space must be set aside for these and for a shaft.

4.5. Ventilation and extinguishing strategy in case of fire
If the system is to be used for smoke control, it is important that the local fire authority be involved at an early stage so that the most suitable strategy can be determined. For smoke control, the exhaust fans must have a capacity of at least 250,000-400,000 m^3/hour, depending on fire size and car park layout.

5. CONCLUSION

Closed car parking facilities are ventilated more efficiently by jet fans than by conventional duct-based systems. In comparison with conventional systems, space can be saved, and installation and running costs reduced. Thanks to the design of the jet fans, most current requirements on sound emission can be met. Large differences exist in ventilation requirements for CO ventilation and smoke control, particularly in small car parks.

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