Evaluation of a Ventilating System for Indoor Air Quality and Smoke Exhaust during Fire inside an Underground Parking

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Abstract. Together with the modern urbanization development, the number of underground cars parkings has grown significantly. They are provided with ventilation systems to evacuate the cars emissions and with smoke exhaust systems which intervene in case of fire. Generally, the same exhaust system is used to evacuate the emissions and the smoke from a potential fire even if the working parameters are not the same for both scenarios. The paper deals with a case study regarding an underground parking designed for 15 cars. Numerical simulations using CFD tools have been performed to establish the CO concentrations. The results prove that the CO concentration limits are exceeded due to the positioning of the exhaust grills. In case of a fire, the temperatures are still high. The conclusion is that CFD simulations are needed for this type of ventilating systems design and that only following the regulation prescriptions is not enough in case of fires.

1. Introduction

The need for providing underground parking lots in urban areas grows continuously caused by the increasing number of cars. The ventilation systems should properly act to evacuate the cars emissions in order to preserve the good quality of the air and also to ensure the smoke evacuation during fire. The difficulty consists in the fact that the ventilation system should perform both tasks, despite the fact that the technical parameters in each case are different. Generally, the design documentation for the parking ventilation systems is made following national or international regulations. However, there are some particular cases in which the legislation does not provide clear specifications, especially in the case of buildings with special architecture. Almost every situation may be very particular and in order to be sure that the designed ventilation system performance is according to the specific demands, numerical simulations can be helpful.

In Romania (European Union) the NP24/1997 Regulation [1] provides limits for the maximum CO admitted concentration: the average CO concentration value should be less than 50 ppm during 8 hours exposure, less than 100 ppm during 20 minutes exposure and must not be higher than 200 ppm. According to ASHRAE [2] guide, the ventilation design in underground parking concerns only forced introduction of fresh air in the area and exhaust polluted air. It is obvious that the positioning of the
supply and exhaust air grilles and the amount of the air flowrate are very important in achieving all the conditions. In this case, good predictions concerning the indoor air parameters ensured by a ventilation system need numerical simulations.

Zhao [3] conducted a study regarding particle dispersion and particle exposure risk during and after transient vehicle exhaust in an underground parking lot. They have used CFD methods to characterize the dispersions of particles and their results are very useful for the positioning of the exhaust air grilles. Zhao [4] have evaluated the performance of a mechanical ventilation system proposed to solve the problems of high temperature and exhaust pollution in an underground bus terminal. They have demonstrated using CFD methods that a mechanical ventilation system with exhaust air grilles at the top of the bus terminal provide a significant improvement in thermal comfort and indoor air quality in the underground bus terminal.

Aminian [5] used CFD to study the effect of exhaust air grilles locations on increasing IAQ inside an underground enclosed parking lot and its effect on flow pattern and energy consumption. They found that the IAQ conditions inside the parking could be significantly improved and the energy consumption could be reduced if the exhausts grilles are installed at the appropriate height. Ahn [6] published a CFD study to provide some ventilations guidelines for underground parking lots for building designers. P. Sittisak [7] used CFD to show how to improve a conventional ventilation system in an underground car park using the installation of single and twin jet fans.

As a preliminary conclusion it is obvious that using CFD techniques for designing ventilations systems for complicated spaces like enclosed underground parks is very important, in order to achieve the indoor air conditions according to the national and international regulations.

The case study of an underground parking lot designed for 15 cars placed in Romania is presented in this paper. The performance of an existing ventilation system is evaluated regarding both the CO level of toxicity and the smoke exhaust capacity.

2. Materials/Methods

The underground enclosed parking is part of an apartment building with four floors which is not provided with water firefighting systems. The national regulations do not require these systems for this type of building. In this case the ventilation system is the only system acting in the case of a fire inside the underground parking.

Based on our previous experience on the numerical simulation side of flows involving combustion [8] we performed the study in Ansys Fluent; the geometry was realized in Ansys Workbench Design Modeler (Figure 1.a) and the numerical grid was created in Ansys Meshing (Figure 1.b). The initial mesh was composed from 7.4 million tetrahedral elements and was later converted in a polyhedral mesh with 3.5 million elements in Ansys Fluent. Realizable k-ε model was used for viscous modelling of the flow as it performs better than other viscous models in the free low and mixing zone [9][10].

The exhaust ventilation system is provided with 4 exhaust grilles at the ceiling and 4 exhaust grilles at the 20 cm height from the basement level in the same region as the ceiling exhaust grilles (Fig1a).

We have analysed two different cases: normal ventilation of the underground parking garage scenario and a fire scenario.

For ventilation scenario, the boundary conditions imposed was mass flow outlet for the extraction grilles using the air flowrates issued from the design prescriptions, i.e. 1181 m$^3$/h for each grill at the ceiling and 506.5 m$^3$/h for the low-level grilles.
These values are used only for the simulations of the ventilation system to ensure the IAQ conditions in case of normal use. Two cars have been simultaneously considered with the engine running (Vehicle 8 and Vehicle 13 in Figure 1a). A pressure inlet of 0 Pa is used for the inlet (Figure 1a). It was considered that the two analysed vehicles are running so the imposed CO emissions are calculated as a mean of the measured values for cold and hot running engine for winter period, [11] which is 11.67 gCO/min/vehicle. Considering the engine exhaust gases composition issued from one vehicle, this represents 5.68% CO by volume. The CO\textsubscript{2} emissions were calculated as 18.78% by volume. The temperature of the exhaust gases was imposed as 80°C. A mass flow rate of burned gases of 0.003425 kg/s (12.33 kg/h) was imposed for each vehicle.

In the second case, a fire was considered to have occurred in the parking, only the exhaust grilles at the ceiling are working and the flowrate is 3375 m\textsuperscript{3}/h per piece. Only one car is considered to burn (Vehicle 8, see Figure 1a) and the heat release rate is 4MW [12] [13]. For fire emissions, the research carried out by [14] was considered. Starting from the fact that burning for example 1kg of plastic, the gas emissions will be 2034 g CO\textsubscript{2}, 20 g CO and 5 g NO\textsubscript{x}, [14], and using the values for tyres, gas and wires, multiplying by the entire mass of each of these components in the vehicle, the following volumetric composition of the gases resulted from the vehicle fire was imposed: 24.15%CO\textsubscript{2}, 66.93%N\textsubscript{2}, 0.27%CO, 8.64%H\textsubscript{2}O. The mass flow rate of the flue gases was 1.354 kg/s at 800°C.

We have performed different simulations for the common ventilation scenario and for the fire scenario.

3. Results
The results are presented in terms of CO concentrations for the first analysed case which consists in two cars with running engines and normal working of ventilation system. The CO concentration levels of 500 ppm, 200 ppm, 100 ppm and 50 ppm are shown in figure 2a, 2b, 3a and 3b below. This type of representation could be somehow hard to understand because one could think that in figure 3b the CO concentration is below 50 ppm. In fact, the figure outlines that limit of 50 ppm and most of the volume inside the parking is characterized by CO concentration higher than 50 ppm except the fresh air inlet area. For example, in Fig 2a concentration higher of 500 ppm can be found inside the black enclosures. In Fig. 2b we can see that concentration larger than 200 ppm CO is occupying now much larger volume of the garage (around 20%), in Fig.3c we can see that concentration larger that 100 ppm is on more than 50% of the garage volume and in Fig 3b we can see that only the region through which the fresh air is entering has concentration of CO less than 50 ppm.
Figure 2. CO isoconcentration values (a) 500 ppm; (b) 200 ppm

Figure 3. CO isoconcentration values (a) 100 ppm; (b) 50 ppm

In order to better understand the CO distribution inside the parking, Figures 4, 5 and 6 show the CO concentration values calculated in a horizontal plane at 1.7 m height and in a vertical plane right below the line of the ceiling exhaust grilles. The differences between Figures 4, 5 and 6 is given by the threshold imposed to the colour scale for the highest value of the CO concentration. This kind of representation help the reader to easily observe the areas where the CO concentration is higher than the imposed threshold.

Figure 4. Contours of CO (0-1000ppm) (a) Horizontal at 1.7 m height; (b) Vertical

For example, in Figures 5 and 6 it is very easy to notice that the “transparent” areas are characterized by CO concentrations higher than 200 ppm respectively 100 ppm.
Considering the fire scenario with only one car burning, figure 7 shows temperatures values corresponding to a horizontal plane at 1.7 m height and to a vertical plane when all the ceiling exhausts grills are working at nominal flowrate after 11 minutes of vehicle fire.
4. Discussions
By analyzing the data and results presented in the article, it can be observed that if we consider two cars running inside the parking lot and the ventilating system is working at nominal parameters, the maximum allowed CO concentrations values are exceeded. We can observe the “transparent” area in figure 5a for example where the CO concentration value is higher than 200 ppm, the maximum value that should never be exceeded according to Romanian regulations.

The ventilating system does not cope with the smoke exhaust scenario either, the temperature reached at 1.7 m height after 11 minutes of vehicle fire is between 100 and 200°C, which is not suitable for people evacuation or fire brigade emergency intervention.

In the same time one can notice on the figure 7b that the temperature value drops under 100°C at 1 m height but the conditions are not appropriate for an emergency operation.

5. Conclusions
The results show that the considered ventilating does not cope with a proper evacuation of CO emissions. The problems are caused by the positioning of the exhaust air grilles which is carried out following Romanian standard. There are too many grilles placed at the ceiling level while CO is spreading rather at the lower level of the enclosure. An optimization study should follow to find the optimal height to place the exhaust grilles. The working scenario in case of fire requires keeping the ceiling grilles and eventually increase the air flow rate. It must be mentioned that the firefighting result could be very much improved by adding water firefighting systems without modifying the smoke exhaust system. The studies will be extended in the future in order to further analyze the fire scenario.

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