Analysis of Jet Fan Ventilation System installed in an Underground Car Park with Partition Walls

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ABSTRACT

The jet fan ventilation system is one of the various ventilation systems available for the purpose of carbon monoxide extraction in underground car parks. Such a system is dependent not only on the rules applied during the design but on the lalsothon e architecture of the underground car park. This paper describes a numerical model used to analyze air stagnation areas, airflow and streamline patterns, and the influence of partition walls on the jet fan ventilation system. The additional focus is on the validity of the choice of the jet fan ventilation system for the underground car parks with partition walls. Results show that t jet analyzability system is not suitable for all underground car park architecture layouts.

KEYWORDS

Underground car park, Partition wall, Jet fan ventilation system, Numerical modeling.

INTRODUCTION

Ducted ventilation systems, jet fan ventilation systems, and with extraction fans are mechanical ventilation systems available for day-to-day ventilation in underground car parks. Mechanical ventilation systems depend on the rules applied during the design and on the underground car park architecture. The main task of mechanical ventilation is to extract harmful exhaust gases from an underground car park. Exhaust gases, primarily Carbon monoxide (CO), Hydrocarbons (HC), Nitrogen oxides (NOx), Sulphur oxides (SOx), and Lead (Pb) cause poor air quality in an underground car park. CO is recognized as one of the most important pollutants, due to its toxicity and damaging impact on human health. This gas is colorless, odorless, and tasteless, but highly toxic. Therefore, CO poisoning is the most common type of fatal air poisoning. If mechanical or natural ventilation is not sufficient in enclosed environments, exhaust gas concentrations can cause problems to the human body and even lead to death [1].

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Different mathematical models for turbulence are used in Computational Fluid Dynamics (CFD). Their main objective is an analysis of air stagnation areas, the influence of fans positioning in the underground car parks to reduce and eliminate air stagnation areas, and, finally, mechanical ventilation system optimization. Numerical modeling is of great importance in the design of mechanical ventilation enabling healthy air quality and sufficient air flow rate. Comparing results obtained with the standard k-ε turbulence model to the Large Eddy Simulation (LES) shows the sensitivity of the results on the mesh cell size [2]. Although there is a similarity between jet fan ventilation systems in underground car parks with longitudinal tunnel ventilation, because of differences in aspect ratio and mechanical ventilation systems, an extensive numerical simulation analysis has been performed with CFD [3].

In order to guarantee healthy air quality in an underground car park, a necessary extraction velocity is required. Such velocity depends on the interaction between the ceiling jet and the flow driven by jet fans [4]. Parameters such as jet fan position, air velocity, fan orientation ns, and I,nlet and outlet positions have to be carefully determined [5]. Effects of flow generated by jet fans cause dilution of the pollution peaks, but removal efficiency depends on the distance between jet fans [6]. Extraction position has a great influence on the removal of pollutants from underground car parks [7]. CO concentration in the breathing zone has a strong relation to the fan position [8]. Stagnation areas, streamlines, and air quality can be checked separately for any time interval in any section of an underground car park. One of the numerical modeling challenges is to recognize those fans that do not contribute to mechanical ventilation efficiency [9]. CFD is a useful tool but requires validation by comparing the simulation results with the experimental data [10].

When the air quality in an underground car park is considered, the Local Mean Age (LMA) is one of the most important parameters [11]. The LMA is defined as the average time for the air to reach the arbitrary point of the underground car park since air entry into the underground car park. The concept of LMA helps reposition and determine the optimal number of jet fans. Increasing the number of jet fans does not improve mechanical ventilation system efficiency. Using the LMA concept in the design shows the length of time of the stagnation areas in different sections in an underground car park
[12].To improve air quality in underground car parks, various mechanical ventilation strategies have been developed. Periodically Reversible Supply/extraction Ventilation (PRESEV) has a potential advantage compared to conventional mechanical ventilation [13], but the implementation of the PRESEV strategy may have limitations [14]. Although CO is the most dangerous exhaust gas, SOx and NOx have an influence on air quality the underground car parks as well [15]. Usually, mechanical ventilation is switched on when CO concentration increases to a certain level. Therefore, natural ventilation is important as well. But

[13].when the difference between indoor and outdoor temperatures is small, the natural ventilation rate is the lowest [16]. In the winter tithe, the natural ventilation rate is significantly higher than in summer [17].

Accidents such as accidental releases of car air-conditioning refrigerants [18] or liquefied petroleum gas [19] also influence the air quality. The underground car parks for heavy-duty lorries with diesel fuel engines have lower air quality and a highelevelsel of air pollutants compared to the public or residential underground car parks [20]. Research shows that homes with attached garages have a higher benzene level than homes with no attached garages and the use of mechanical ventilation can reduce these benzene concentrations [21]. Current regulations are sometimes based on obsolete data. Therefore, in order to improve the mechanical ventilation system, it is necessary analyze lyse the factors that influence the ventilation system [22]. The measurements of CO concentration, tempera,ture and humidity show that the air quality in underground car parks has acceptable CO values [23].

People often do not spend much time in underground car parks, but if CO concentration increases to a dangerous level, it is necessary to evacuate people. The most important issue is the timely detection of an increase in CO levels. The same principles can be used for evacuation in the case of fire when people are expected to run to the exit [24]. Evacuation paths must be designed for all people, considering old and disabled [25].

JET FAN VENTILATION SYSTEM AND SIMULATION SETUP

In the past few decades, the practice of installing of jet fan mechanical ventilation systems in underground car parks has increased. The fundamental characteristic of the jet fan ventilation system is that the jet fans are used to accelerate the air below the ceiling to a sufficient velocity in order to extract air pollutants from an underground car park. That particular velocity is the lowest velocity required to extract air pollutants, primarily CO. Jet fans are installed close to the ceiling and they push the air to the extraction points. It is very important that the air pollutants are effectively removed and that no significant air stagnation areas remain. Jet fan ventilation systems typically consist of three elements: fresh air supply elements, jet fans, and extraction elements. Supply elements are, for example, entrance/exit ramps, ventilation shafts, side wall openings, and rarely supply fans. Extraction elements can be extraction fans, ventilation shafts, and wall openings.

At first sight, the jet fan ventilation system in an underground car park resembles tunnel longitudinal ventilation. However, there are differences between two systems. While tunnels typically have heights similar to widths and the lengths are very long, common underground car park heights are significantly smaller than widths, and lengths are similar to widths. In tunnels, vehicles movement is bi-directional at road speeds, while in the underground car parks is multidirectional at very low speeds. In the underground car parks passenger cars are dominant, while in the tunnels, lorries and buses account for a significant percentage. Due to an underground car park layout, airflow can be very complex. Therefore, jet fan positions, directions and speed must be carefully determined. The air flow in tunnels is essentially unidirectional, and mathematical models and equations developed for ventilation in the tunnels become unreliable for underground car parks. Numerical modelling is a more useful tool to accurately predict the air flow patterns.

These systems depend on the architecture of an underground car park. In this case study, numerical modelling has been deployed for an underground car park in Croatia. The main objective was to analyse air stagnation areas, airflow and streamline patterns and influence of partition walls on the jet fan ventilation system. Additional focus was on the validation of the choice of the jet fan ventilation system for ventilation of underground car parks with partition walls. Humans typically do not spend much time in the underground car parks and, therefore, carbon monoxide poisoning in the underground car parks is very rare. Thus, designs differ between day-to-day ventilation (carbon monoxide extraction) and smoke extraction ventilation (in the case of fire). Design differences are, for example, number of fans and fan positions. The jet fan ventilation system designed for smoke extraction must be also suitable for day-to-day ventilation.

In this case, installed jet fan ventilation system is used only for day-to-day ventilation and for carbon monoxide extraction. Smoke extraction is not considered in the modelling. Fire protection is provided with installed sprinkler installation. Therefore, installed fans are not high-temperature rated (neither extraction fans nor jet fans), and the jet fan positions are not designed for smoke extraction.

An underground car park features one underground level intended as a parking area, as shown in Figure 1. Vertical evacuation stairs are denoted with letters A-D. Evacuation stairs entrance directions are:

Fresh air ventilation shafts, entrance/exit ramp, extraction fans and jet fan positions are shown in Figure 2. Entrance/exit is modelled as the opening (width × height). All other openings have no influence on the mechanical ventilation system and are not considered. Underground car park floors analysed in this study are the below-ground level (−1) and the ground floor above the ceiling of −1 level. All walls and beams are made of concrete.

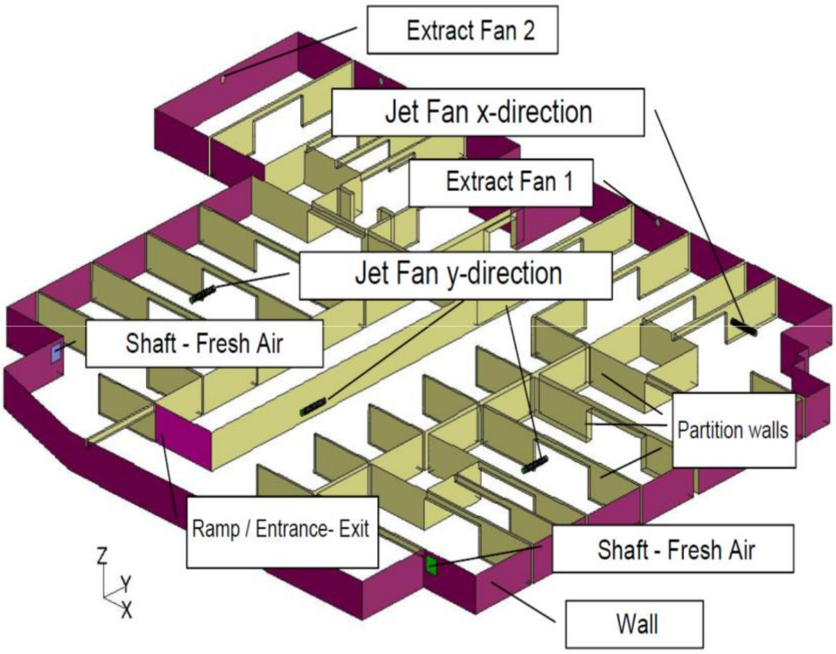


Figure 2. Ventilation shafts and fans position

Installed jet fan ventilation system provides 18 m^3/h per m^2 of floor area. Jet fans are mounted 0.05 m below the ceiling and jet fan outlets are equipped with deflectors, which direct outlet air flow at the angle of five degrees downward. Jet fan operating directions are shown in Figure 3.

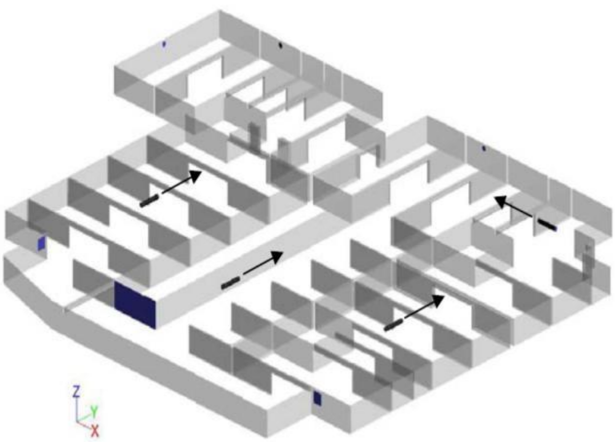


Figure 3. Jet fan operating x and y directions

The CFD analysis has been carried out using commercial Ansys/Fluent software. The main features of numerical simulations were three-dimensional spatial discretization, unsteady time modelling scheme, viscous turbulent flow type and k-ε turbulence model. Analysis has been characterized by the acceleration of fluid inside of the domain via mechanical ventilation. Initial velocity field, induced by density gradient,

was superimposed on the velocity field caused by the mechanical ventilation system. Jet fans operated at maximum speed from the moment of activation to the end of the simulation. The mesh used for computations was of unstructured prismatic, tetrahedral and hexahedral type, consisting of approximately 2.3 million cells. Computational domain outline and detail are shown in Figure 4.

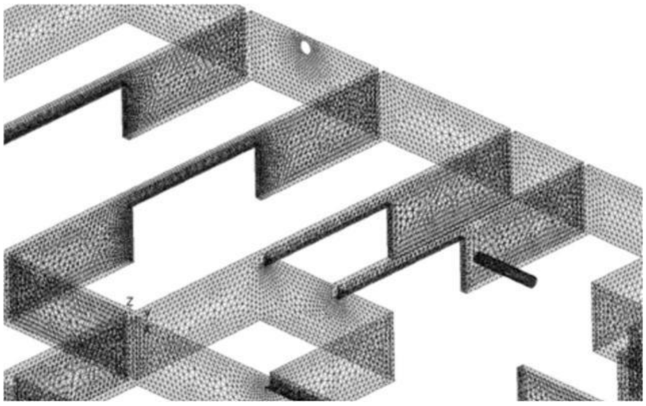


Figure 4. Computational domain outline and detail

Boundary conditions determine parameter values necessary for initializing solution and executing the simulation. Implemented boundary condition types were: extraction fan and jet fan velocities and the value of the fresh air inlet pressure. All boundary conditions are shown in Table 3. The natural ventilation is not considered in this study that has been limited to mechanical ventilation. The results are valid for air at the temperature of 15 °C, density 1.225 kg/m^3 and air humidity 50% RH. All parameters remain constant in the simulation.

During analysis, the time step was kept constant and set to 0.2 seconds. During each time step, the velocity and pressure in the computational domain have been solved iteratively. A maximum number of iterations during one-time step was 10 and was held constant during the entire simulation. Convergence criterion of 10^{-5} for all variables has been achieved during each time step. The results are valid for the air temperature of 15 °C. Relevant parameters to observe from calculations were velocity contours (< 0.1 m/s) and the air stagnation areas. Velocities up to 0.1 m/s are insufficient for CO extraction.

Table 3. Boundary conditions

Ordinal	Name	Type	Scalar formulation	Value
1.	Shaft – fresh air	Velocity – inlet	Normal to boundary	2.0 m/s
2.	Shaft – fresh air	Velocity – inlet	Normal to boundary	2.0 m/s
3.	Ramp/entrance	Pressure – inlet	Total gauge pressure	0.5 Pa
4.	Extraction fan − 1	Velocity − inlet	Normal to boundary	−16.0 m/s
5.	Extraction fan − 2	Velocity − inlet	Normal to boundary	−16.0 m/s
6.	Jet fan – x-direction	Velocity	Inlet – normal to boundary	−7.98 m/s
			Outlet – x-direction	0.0 m/s
			Outlet – y-direction	7.93 m/s
			Outlet – z-direction	0.69 m/s
7.	Jet fan – y-direction	Velocity	Inlet – normal to boundary	−7.98 m/s
			Outlet – x-direction	7.93 m/s
			Outlet – y-direction	0.0 m/s
			Outlet – z-direction	0.69 m/s

RESULTS

In the Figures 5a, 5b, 6a, and 6b, air stagnation areas are presented through velocity contours at different heights. Velocity contours show the air movement in an underground car park. Different colours present velocity values between v = 0-0.1 m/s. Areas with no colour show velocities above 0.1 m/s. Due to the jet fan influence, velocity value at 2.0 m height is very high. It is observed that up to 45% of the air in an underground car park has velocity lower than 0.1 m/s.

Velocity v [m/s]

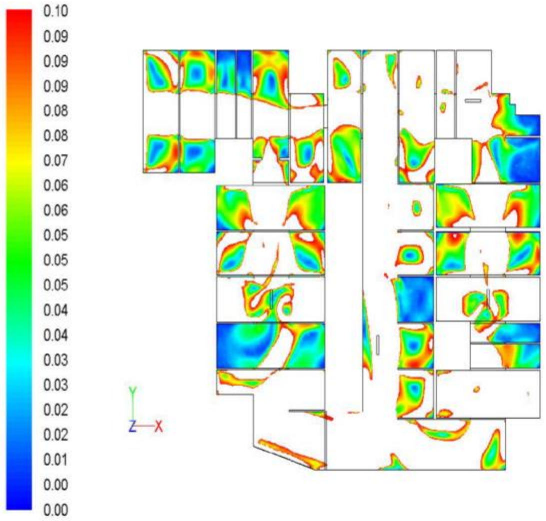


Figure 5a. Air stagnation areas, height 0.5 m

Velocity v [m/s]

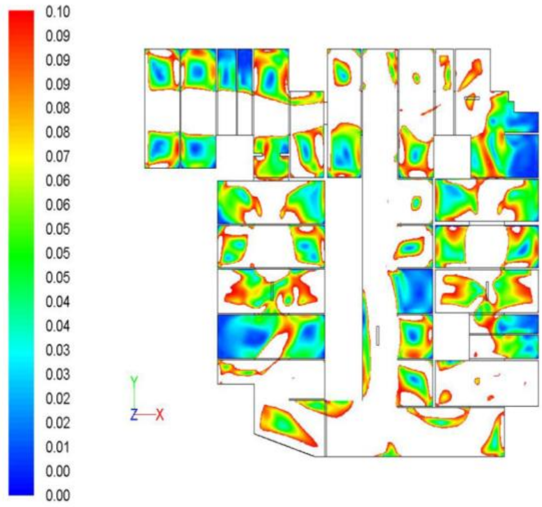


Figure 5b. Air stagnation areas, height 1.0 m

Velocity v [m/s]

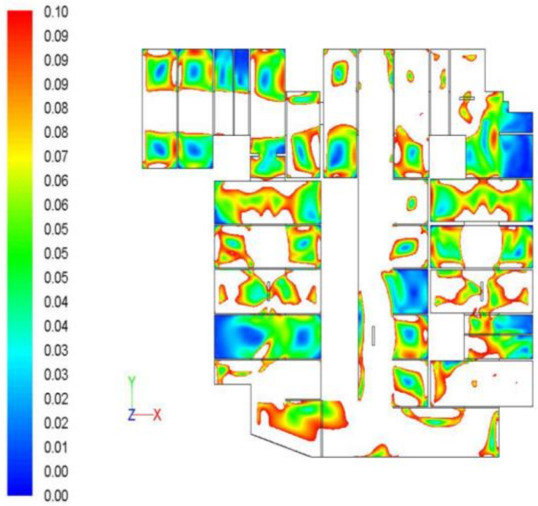


Figure 6a. Air stagnation areas, height 1.5 m

Velocity v [m/s]

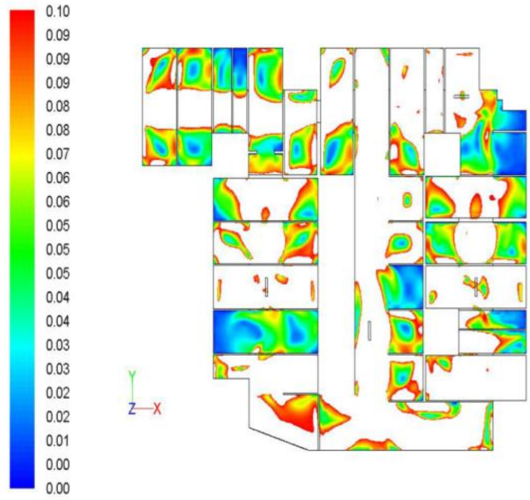


Figure 6b. Air stagnation areas, height 2.0 m

In Table 4 air stagnation areas and maximum velocity values at different heights are shown. Although maximum velocity values reach up to 2.6 m/s, almost 50% of the air has insufficient extraction velocity. Between partition walls, air movement is significantly low. Only the places in an underground car park with no partitions walls have sufficient extraction velocity. Beams have no influence on jet fan ventilation system in this case. Results in Table 4 show that air stagnation areas are smaller close to the floor of an underground car park. The largest air stagnation areas (44.74%) form in the breathing zone, at approximately 1.5 m height.

Table 4. Max. velocities and air stagnation areas

Ordinal	Height from the floor [m]	Max. velocity [m/s]	Air stagnation area [m²]	Air stagnation area [%]
1.	0.5	1.231	996.00	37.56
2.	1.0	1.578	1,165.00	43.93
3.	1.5	2.582	1,186.50	44.74
4.	2.0	17.016*	1,042.00	39.30

* Due to the jet fan influence, the velocity value at 2.0 m height is very high

Figures 7a and 7b show that, although air velocity increases closer to the ceiling where jet fans are installed, the percentage of air stagnation areas increases as well. Only above 1.5 m, air stagnation area decreases, due to the jet fans influence. Air velocity in an underground car park increases from the floor to the ceiling, but that increase has no effect in reducing air stagnation area. Therefore, a huge impact of partition walls on jet fan mechanical ventilation system is obvious.

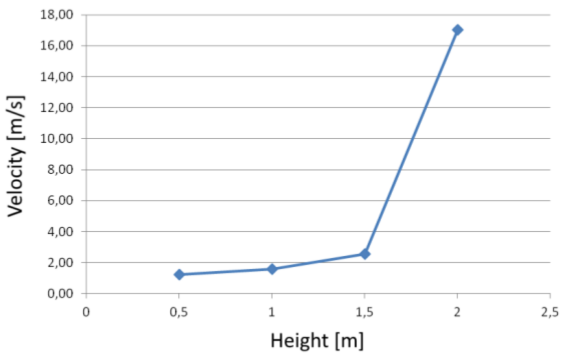


Figure 7a. Air velocity as a function of height

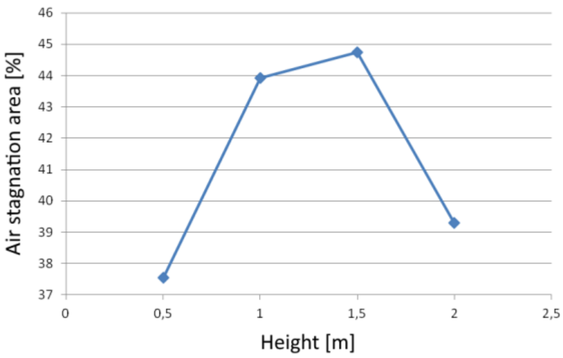
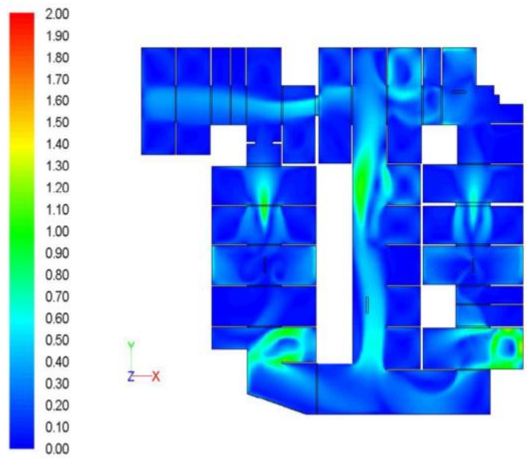


Figure 7b. Air stagnation area as a function of height

In the Figures 8a, 8b, 9a and 9b, air flow patterns are presented via velocity contours at different heights. Velocity contours show the air movement in an underground car park produced by both jet fans and extraction fans. Different colours present velocity values between v = 0-2.0 m/s. The huge stagnation air areas with no velocity at all are clearly visible. Only close to the jet fan outlets, air velocity is approximately up to 2.0 m/s. Even on the extraction fan inlets, air velocity cannot reach 1.5 m/s.



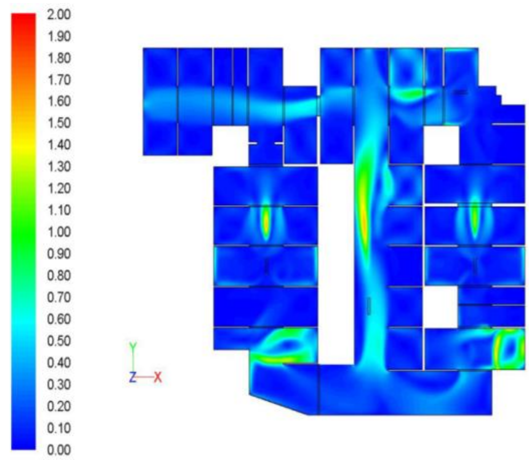
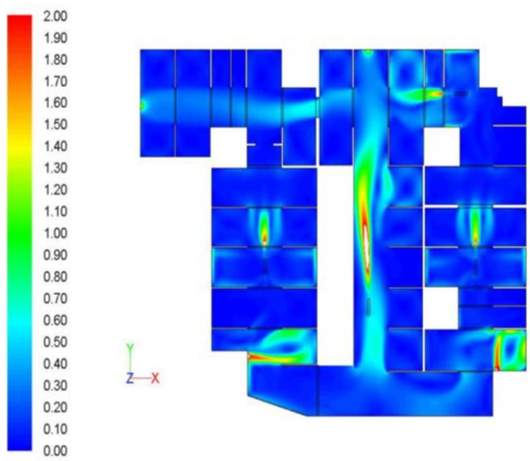


Figure 8a. Airflow pattern, height 0.5 m Figure 8b. Airflow pattern, height 1.0 m

Velocity *v* [m/s] Velocity *v* [m/s]



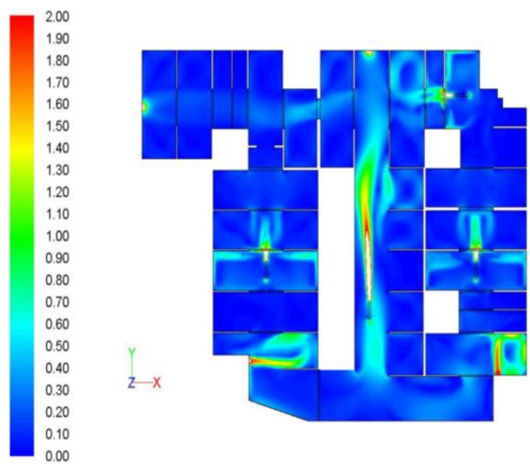
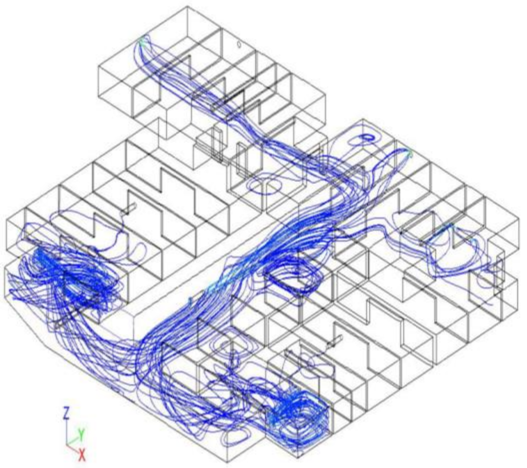


Figure 9a. Airflow pattern, height 1.5 m Figure 9b. Airflow pattern, height 2.0 m

Streamline patterns are presented in Figures 10a, 10b, 11a, and 11b. Streamlines are curves drawn through a fluid to indicate the motion direction in various sections of a fluid system flow, in this case, air direction in an underground car park. Air movement produced only by extraction fans is shown in Figures 10a and 10b. In Figure 10a, air movement from the fresh air shaft is shown and Figure 10b depicts the air movement from the entrance/exit ramp, both produced only by extraction fans. Partition walls block air movement and direct air from shafts and entrance/exit ramp to the extraction fans. Obviously, that system is inappropriate for underground car parks with partition walls. Only a conventional ductwork system does not depend on the partition walls.

The entire space between the partition walls can be covered with exhaust grills. Therefore, CO can be sufficiently extracted from the underground car park.



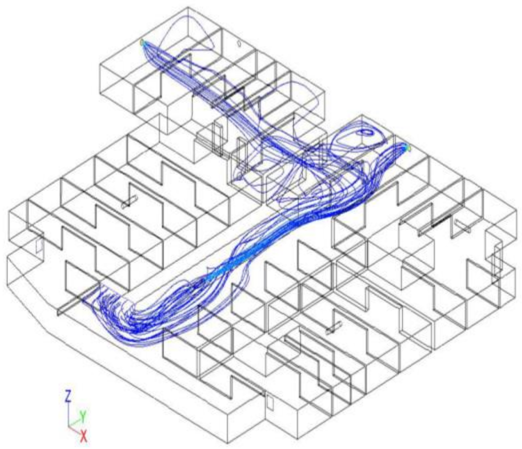
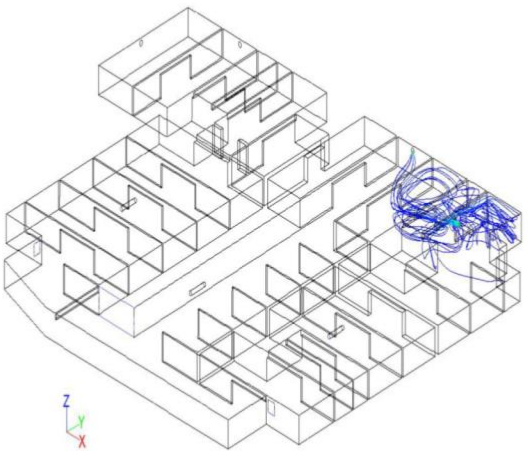


Figure 10a. Extraction fans/fresh air shafts Figure 10b. Extraction fans/ramp

Figure 11a shows air movement produced only by a jet fan in the horizontal direction and Figure 11b shows air movement produced by all jet fans. Jet fan installed to the right from the entrance/exit ramp, where no obstacles are present, provides sufficient air velocity for carbon monoxide extraction. Partition walls block the air movement produced by other jet fans and they do not contribute to the air movement, especially jet fan in the x-direction. Comparing Figures 11a and 11b, it is obvious that jet fan installed to the right from the entrance/exit ramp influences the air movement produced by a fan in the x-direction.



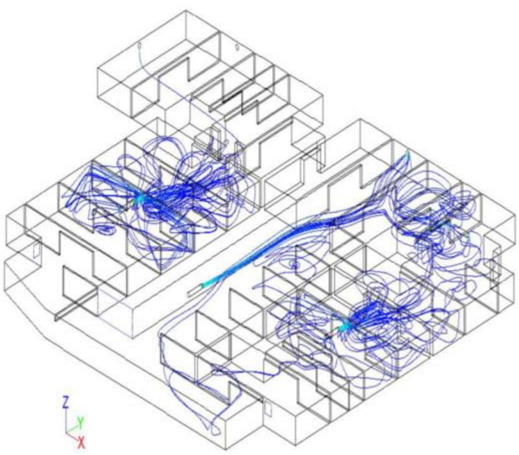


Figure 11a. Jet fan, x-direction Figure 11b. All jet fans

CONCLUSION

Various mechanical ventilation systems are available for air pollutant extraction in underground car parks: jet thrust fan systems, ducted ventilation systems, and systems with extraction fans. A comparison of the extraction effectiveness of mechanical ventilation systems shows that the jet thrust fan system seems in many cases superior to the conventional ductwork system or to the system with extraction fans. But these systems depend not only on the rules applied during the design but also on the underground car park architecture. The hypothesis for this research is that the jet fan ventilation system is not suitable for all underground car park architecture layouts. The main objective of the research has been to analyze the influence of partition walls on the jet fan ventilation system. The additional focus was on the validity of the choice of the jet fan ventilation system for the underground car parks with partition walls for day-to-day ventilation. An analysis of the influence of partition walls on jet fan ventilation systems shows that selecting a jet fan ventilation system for underground car parks with partition walls is questionable. Up to 50% of the air in an underground car park has insufficient extraction velocity, especially in the breathing zone. Partition walls are obstacles to the airflow produced by both jet fans and extraction fans. The huge impact of partition walls on the airflow produced by the jet fan mechanical ventilation system is demonstrated in the paper. If possible from the construction aspect, erecting columns or walls with openings is preferred instead of partition walls. As the streamline pattern analysis showed, a system with only extraction fans is inappropriate for underground car parks with partition walls as well. Only a conventional ductwork system does not depend on the partition walls. If requested, all day-to-day ventilation systems can be part of an active fire protection system. The main tasks of smoke extraction systems are life safety and reducing damage to the building in case of fire. Longer exposure of partition walls and ceiling to the hot gases can cause concrete spalling and dangerous conditions for the firemen. Therefore, the choice of the jet fan ventilation system as the mechanical system for ventilation in an underground car park with partition walls should be reconsidered.

REFERENCES

1. Demir, A., Investigation of Air Quality in the Underground and Aboveground Multi-Storey Car Parks in Terms of Exhaust emissions, *Procedia – Social and Behavioural Sciences*, Vol. 195, pp 2601-2611, 2015,
2. Deckers, X., Jangi, M., Haga, S. and Merci, B., Numerical Simulations of Flow Fields in Case of Fire and Forced Ventilation in a Closed Car Park, *Proceedings of the 6th International Seminar on Fire and Explosion Hazards*, Leeds, UK, pp 1104-1115, 2010.
3. Tilley, N., Deckers, X. and Merci, B., CFD Study of Relation between Ventilation Velocity and Smoke Backlayering Distance in Large closed Car Parks, *Fire Safety Journal*, Vol. 48, pp 11-20, 2012,
4. Viegas, J. C., The use of Impulse Ventilation for Smoke Control in Underground Car Parks, *Tunnelling and Underground Space Technology*, Vol. 25, No. 1, pp 42-53, 2010,
5. Aveiro, J. L., and Viegas, J. C., Smoke Control in an Underground Car Park with Impulse Ventilation, *V European Conference on Computational Fluid Dynamics*, Lisbon, Portugal, 2010.
6. Viegas, J. C., The use of Impulse Ventilation to Control Pollution in Underground Parks, *International Journal of Ventilation*, Vol. 8, No. 1, pp 57-74, 2009,
7. Shang, S. W. and Xing, Y., Comparison of Air distribution of induced Ventilation System's different Exhaust Way in Underground Garage, *International Conference on Advances in Energy and Environmental Science (ICAEES)*, Guangzhou, China, 2013,
8. Elsafty, A. F. and Abo Elam, M. M., Improving Air Quality in enclosed Parking Facilities using Ventilation System design with the aid CFD Simulation, *International Review of Mechanical Engineering*, Vol. 3, pp 796, 2009.
9. Immonen, E., CFD optimization of Jet Fan Ventilation in a Car Park by Fractional Designs and response Surface Methodology, *Building Simulation*, Vol. 9, No. 1, pp 53-61, 2016,
10. Brzezinska, D. and Sompolinski, M., The accuracy of mapping the Airstream of Jet Fan Ventilators by FDS, *Science and Technology for the Built Environment*, pp 1-12, 2016.

11.Gomma, S. M., Khalil, E. E., Fouad, M. and Medhat, A., Ventilation System design for Underground Car Park, *Open Journal of Technology & Engineering Disciplines*, Vol. 1, pp 30-41, 2015.

12. Gomma, S. M., and Fouad, M., Design of the Ventilation System in an Underground Car Park: Local Mean Age of Air, *13th International Energy Conversion Engineering The conference*, Orlando, USA, 2015,

13. Chen, D., Periodically reversible Supply/exhaust Ventilation Strategy, *Building and Environment*, Vol. 46, No. 12, pp 2590-2597, 2011,

14. Said, A. O., Khalil, E. E., Medhat, A. and El-Bialy, E., Effect of using Grilles in Car Park through reversible Supply Exhaust Ventilation Strategy, *Proceedings of the ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis*, Copenhagen, Denmark, 2014,

15.Izumi, M., Nurfadhilah, O. and Khairul, B. B., Air Quality Profile in an enclosed Car Park, *International Review of Mechanical Engineering*, Vol. 3, pp 796-807, 2009.

16. Se-Jin, A., Hyuk-Min, K., Geum-Hee, K. and Jeong-Hoon, Y., Study of securing required Ventilation Rates and improving Mechanical Ventilation Systems for Underground Parking lots, *Journal of Asian Architecture and Building Engineering*, Vol. 15, No. 3, pp 659-665, 2016,

17. Ge, F. H., Liu, C. J., Yu, Q. S., Ma, C. X. and Wang, C. Q., Air pollution and Ventilation Rates in an Underground Car Park, *5th International Workshop on Energy and An environment of Residential Buildings and 3rd International Conference on Built Environment and Public Health*, Guilin, China, 2009.

18. Koban, M. and Herrmann, D. D., Warming Potential Refrigerant HFO-1234yf in an Automobile Garage, *Process Safety Progress*, Vol. 30, No. 1, pp 27-34, 2010,