

Numerical analysis on Smoke and Heat Control System and Sprinkler System in covered car parks

Mateusz Fliszkiewicz^{1,*}, *Karol Kreński*¹

¹The Main School of Fire Service, Faculty of Fire Safety Engineering, 52/54 Slowackiego, 01-629 Warsaw, Poland

Abstract. We provided numerical analysis using Computational Fluid Dynamics tools to find out the effects of the systems interaction in representative car park building and different configuration of smoke control systems. We conducted the qualitative and quantitative research to obtain the patterns and times of the sprinklers activation. We analysed the influence of Smoke Control System on the effectiveness of the Sprinkler System. As a results of the research we created general conclusions which can be used as a set of guidelines during designing process. Moreover some results can encourage other scientists for further numerical analysis or real scale tests.

1 Introduction

Interaction of Smoke Control System and Sprinkler System is still unresolved problem during designing process and creating the fire safety strategy of buildings [1-5]. Despite the past studies there is real necessary to research this field of fire safety. However, preparing real scale tests is very expensive and challenging task requiring appropriate infrastructure and equipment.

Both systems are providing different designing purposes which can affect the effectiveness of each other. The main aim of sprinkler system is to localize the fire origin and prevent further fire spreading - the sprinkler discharge is reducing the fire size [6]. However cooling effect of water spray can decrease the buoyancy of the smoke and increase the depth of the smoke reservoir as a result of descanting the smoke layer [7]. From the other hand, too early operating the Smoke Control System can affect the effectiveness of sprinkler system i.e. ceiling jet can be moved forward to the nearest vent and activate sprinklers localized further from the fire source or delay the activation process. Appropriate interaction of these systems is crucial for fire safety in cover car parks where fire load is extremally high (new cars are equipped with full of flammable materials) and can make real threaten for building users and fire safety crews. Therefore, a question arises: how to operate smoke control system to not affect effectiveness of sprinkler system? Another problem is the localization of the fire seat by sprinklers. To early operating can run sprinklers localized far from fire place. Moreover, directing the ceiling jet to exhaust point

* Corresponding author: mfliszkiewicz@sgsp.edu.pl

may have consequences in terms of the number of sprinklers activated. As a result it can decrease the effectiveness of sprinklers extinguishing.

1.1 Design objectives

Designing the Smoke Control System needs to choose appropriate designing purpose. Depending on the type of the building connected with covered car park and type of the occupancy we can distinguish three main objectives which should be considered during designing process [8-12]:

1. Clearing car park from smoke after the fire is extinguished.
2. Ensuring the relatively smoke free or temperature free approach for firefighters.
3. Providing appropriate conditions for evacuation purpose.

Ensuring the smoke clearance objective is mostly required in car parks functionally connected with residential or office buildings where users of the building are well known with available evacuation paths [10,11]. Moreover, smoke clearance systems are not specifically intended to maintain any area of a car park clear of smoke or high temperature. Smoke clearance systems are intended to assist fire-fighters by providing ventilation to allow speedier clearance of the smoke once the fire has been extinguished. It can also help reduce smoke density and temperature during the course of a fire.

Shopping malls and other public building require to treat occupants evacuation as the main safety strategy goal. The objective of the smoke and heat control system is to provide for the protection of escape routes within the same storey as the car on fire, to preserve a smoke-free path to either the exterior of the building, or to a protected stairwell which leads to a final exit to a place of safety [10]. This objective is difficult to meet, because it also need some architectural modifications for example appropriate height of compartment.

Despite the previous two designing objectives, safety of the firefighters should be always considered [9,10]. Comparing to other type of compartments fire load in covered car parks are relatively high which may affect on significant smoke and heat generation and finally safety of the firefighters. Without any ventilation system, there can be extremely dangerous conditions in short time i.e. flash-over phenomena occurrence.

1.2 Smoke and heat control systems

All previously mentioned designing objectives can be achieved by different solutions. Currently we can distinguish two main types of ventilation system in covered car parks:

1. Ducted mechanical Smoke and Heat Exhaust Ventilation System (SHEVS).
2. Impulse ventilation system.

In SHEVS hot gases are gathering beneath the ceiling and exhausted by several vents mounted on ducts network. This should maintain good visibility in the lower parts of car park beneath the smoke layer, allowing appropriate conditions for evacuation, or for firefighter access to the fire. However, these systems are intended to work well in high compartments where it is possible to create a deep enough smoke reservoir. Otherwise, there will be no clear separation between hot upper layer and cold lower layer.

For almost cases the main objective of impulse ventilation is to assist firefighters. The way of operation causes turbulent flow of smoky gases. However, higher velocities through the cross section of car park can ensure relatively free of smoke path to fire seat. This method was taken from longitudinal ventilations systems in tunnels.

Depending on designing objectives, parameters of smoke control system can differ significantly, i.e. ensuring the smoke clearance condition for impulse ventilation for 2000 m² and 3 m height car park need to design exhaust with capacity approximately 55 000 m³/h. For the same car park providing safe approach for firefighters needs to ensure

system with capacity 337 000 m³/h. These conditions may remarkably affect on sprinklers activation. It may influence on number of sprinklers activated and also proper localization of fire seat.

2 Method

Our method is based on comparing the number and times of sprinkler activation depending on different ventilation systems and its capacity. These two factors depends on a set of physical parameters such as Heat Release Rate (HRR), height of compartment, sprinkler type and others. We conducted seventeen Computational Fluid Dynamics (CFD) simulations to prepare comparative analysis. We ran all simulations on the Fire Dynamics Simulator (FDS) [8] software version 6.7.0. FDS is a computational fluid dynamics model of fire-driven fluid flow, with an emphasis on smoke and the heat transport from fires. Launching the FDS simulation requires a large number of input parameters. The parameters affect the simulation results. In order to simplify the conditions of experiment we divided the input parameters into invariants and variants.

In all cases we modelled the single car fire in representative smoke zone with area approximately 1900 m². The dimensions of smoke zone was 31.2 m width x 60.0 m long x 3.0 m high. From one side of computational domain boundary condition was “opened” that fresh air could flow into the compartment and also hot smoky gases could leave computational domain. Solid gypsum board curtain from 2.2 m height to ceiling was designed at the one edge of the smoke zone.

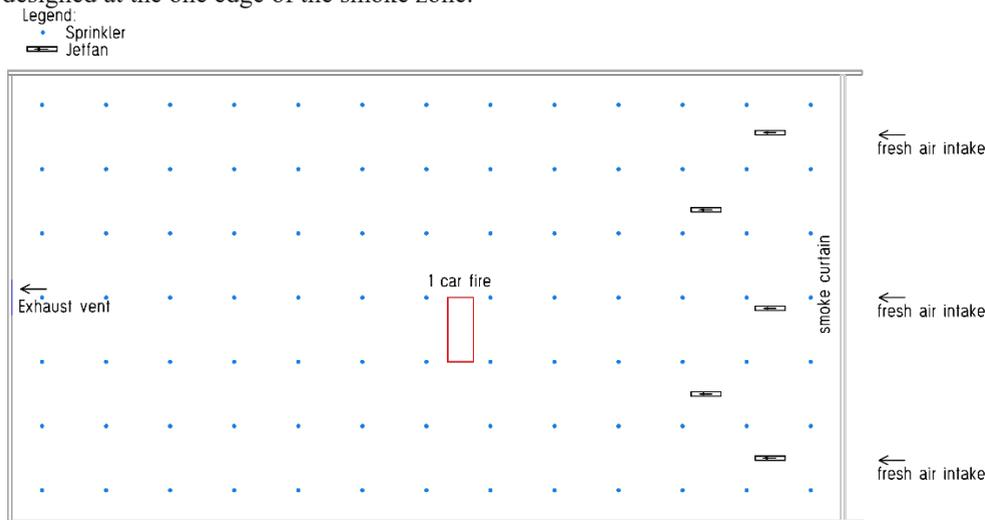


Fig. 1. General scheme of the car park.

As a variant parameters we assumed the type of the ventilation system, total capacity of exhausted gases and ventilation delay time. We considered two ventilation systems, i.e. ducted mechanical smoke and heat control system and impulse ventilation. For both systems four cases was examined. Firstly we analysed scenarios where no ventilation system was provided. Then ventilation system was operated immediately after the Fire Detection System signal was reached. We assumed 60 seconds. The third case provided operating ventilation system immediately after the first sprinkler was activated. The last one case ensures 180 seconds delay between activating first sprinkler and running ventilation system. We assumed that ventilation system as well as main exhaust vent and jet-fans will reach full capacity in 60 seconds.

In the table 1 we presented all considered scenarios. We began by checking number of activated sprinklers without any ventilation system. Then, we conducted simulations for ducted mechanical smoke and heat control system and impulse ventilation system.

Table 1. Analysed scenarios.

Simulation number	Ventilation capacity [m ³ /h]	Ventilation delay [sec]	Comments
No ventilation			
Simulation 1	-	-	No ventilation
Simulation 2	-	-	No ventilation, ducts modelled
Ducted ventilation			
Simulation 2a	55 000	60	10 air changes per hour
Simulation 2b	55 000	285	10 air changes per hour, ventilation starts after first sprinkler operates
Simulation 2c	55 000	465	10 air changes per hour, ventilation starts with 180 sec delay after first sprinkler operates
Simulation 3a	90 000	60	Total capacity calculated according to BS 7346-4
Simulation 3b	90 000	285	As above, ventilation starts after first sprinkler operates
Simulation 3c	90 000	465	As above, ventilation starts with 180 sec delay after first sprinkler operates
Impulse ventilation			
Simulation 4a	55 000	60	10 air changes per hour, ventilation starts after first sprinkler operates
Simulation 4b	55 000	300	10 air changes per hour, ventilation starts after first sprinkler operates
Simulation 4c	55 000	480	10 air changes per hour, ventilation starts with 180 sec delay after first sprinkler operates
Simulation 5a	180 000	60	Typical capacity in polish car parks
Simulation 5b	180 000	300	Typical capacity in polish car parks, ventilation starts with 180 sec delay after first sprinkler operates
Simulation 5c	180 000	480	Typical capacity in polish car parks, ventilation starts after first sprinkler operates
Simulation 6a	337 000	60	Approx. 1 m/s through cross-section of carpark
Simulation 6b	337 000	300	Approx. 1 m/s through cross-section of carpark, ventilation starts after first sprinkler operates
Simulation 6c	337 000	480	Approx. 1 m/s through cross-section of carpark, ventilation starts with 180 sec delay after first sprinkler operates

For all simulations we assumed a set of invariant parameters. We setup one car fire. Despite the wide range of available HRR curves for car we used NBN curve [8] with maximum HRR 6000 kW after 900 seconds. It is assumed that water spray from head will not effectively extinguish the car fire. Under normal conditions cars are considered to be waterproof, so in case of the cabin fire water will not infiltrate inside the vehicle. Therefore the HRR curve will not vary because of sprinkler activation.

As a burning material we used polyurethane foam with heat of combustion equals to 26 200 kJ/kg. Soot yield was 0.13 kg/kg and carbon monoxide yield was 0.01 kg/kg. All physical properties of obstructions (walls, ceiling, etc.) were assigned from reinforced concrete.

Sprinklers were distributed equally over the smoke zone. Maximum distance between sprinklers was 4.5 m and maximum distance from walls was 2.1 m. All used devices was upright sprinklers with RTI<50 and activation temperature 68 degree of Celsius.

Total simulation time was 20 minutes. Results were registered every second.

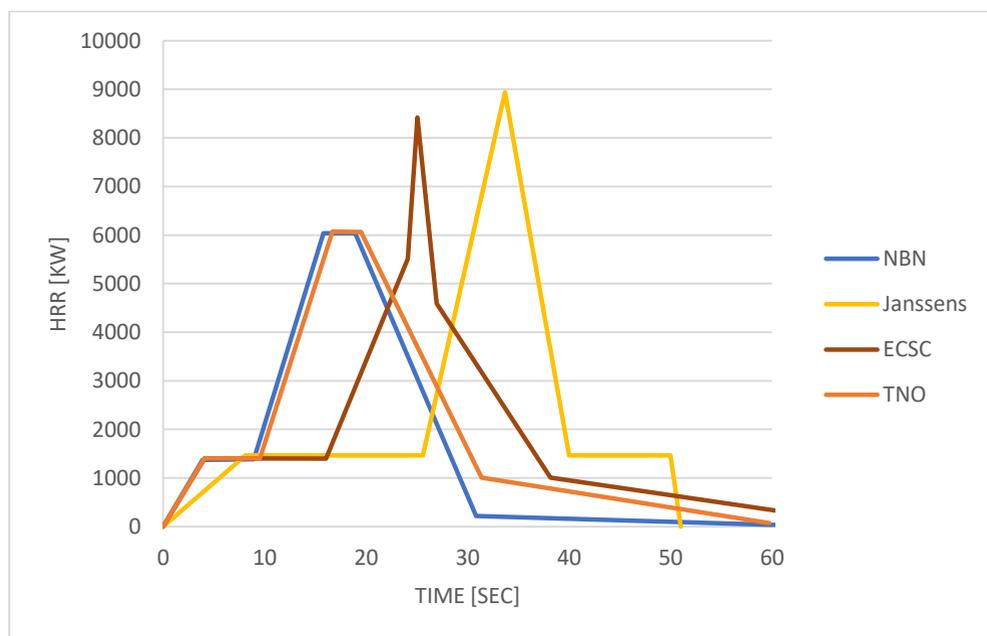


Fig. 2. Different HRR curves for one car fire.

3 Results

The results were collected for each simulation. Firstly we gathered the number of activated sprinklers for different type of ventilation system and its capacity. Than we checked whether the delay time influence on total number of sprinklers operated in each analyzed group. Finally we summarized the times of first and last sprinkler activated.

In table 2 we collected data from ducted mechanical ventilation systems. For almost all cases sprinklers activated in the same place and in similar time.

Table 2. Sprinklers activation for ducted mechanical ventilation.

Simulation number	Ventilation capacity [m ³ /h]	Ventilation delay [sec]	Total sprinklers activated	First sprinkler activation time	Last sprinkler activation time
Simulation 2	-	-	18	282	969
Simulation 2a	55 000	60	17	276	999
Simulation 2b	55 000	285	18	282	1076
Simulation 2c	55 000	465	18	282	977
Simulation 3a	90 000	60	17	302	1073
Simulation 3b	90 000	285	17	282	1081
Simulation 3c	90 000	465	17	282	1009

The results are different for impulse ventilation system. Depending on total capacity the number of sprinklers activated differ. For higher values the number of sprinklers operated decreases. On the figure 3 we presented protected area by sprinklers after 20 minutes of simulation for selected scenarios.



Fig. 3. Sprinklers activated after 20 minutes.

In Table 3 we collected data on interaction of impulse ventilation system and sprinkler installation.

Table 3. Sprinklers activation for impulse ventilation.

Simulation number	Ventilation capacity [m ³ /h]	Ventilation delay [sec]	Total sprinklers activated	First sprinkler activation time	Last sprinkler activation time
Simulation 1	-	-	21	296	964
Simulation 4a	55 000	60	18	298	1049
Simulation 4b	55 000	300	20	296	1148
Simulation 4c	55 000	480	19	296	1138
Simulation 5a	180 000	60	17	286	1007
Simulation 5b	180 000	300	16	296	973
Simulation 5c	180 000	480	16	296	1000
Simulation 6a	337 000	60	11	594	969
Simulation 6b	337 000	300	11	296	973
Simulation 6c	337 00	480	12	296	996

4 Discussion

Type of ventilation system and its operation delay time influence on number and times of activated sprinklers. However, for ducted mechanical ventilation system the difference is not significant, similar to other researches [1, 6]. In all scenarios the number of sprinklers activated was similar. Even first sprinkler activation time do not differ appreciably. Activation time of last sprinkler depends mainly on total capacity of ventilation system, i.e. the higher capacity, the later it operates. Nevertheless, the variation is negligible.

The situation is different in the case of impulse ventilation. The number of activated sprinklers and its localization strongly depends on total capacity of ventilation system. The higher capacity, the less sprinklers operated. The high flow of smoky gases also influence on the localization of the activated sprinklers, i.e. protected area moves to exhaust point. It strongly depends on ceiling jet direction and temperature [13].

Analysing the results the general conclusions can be stated for ducted mechanical system:

1. Delay time to lunch ventilation system is not necessary. If the designing purpose is evacuation safety, then the ventilation system can be operated immediately form Fire Detection System.
2. Number of activated sprinklers do not differ in case of the designing higher capacities.
3. The higher capacities are designed, the later time of last sprinkler activation was observed. However, in this situation ventilation system has the greater ability to exhaust heat and smoke what also influence on protecting of further fire spreading.

In case of impulse ventilation we observed the following dependencies:

1. It should be considered to design delay time of operating the ventilation system. The higher capacities, the later first sprinkler was activated. It is recommended to lunch ventilation system at least when first sprinkler operates.
2. Total exhaust capacity influence on total number of sprinkler activated and moves the protected region towards exhaust point.
3. Delay time do not influence on total number of sprinklers activated after the fire reaches maximum HRR.

Presented results are just introduction to further research on the problem. CFD simulations can bring closer to general dependencies in case of using these two fire protection systems. Nevertheless, the influence on water spray from sprinkler and

temperature distribution from ceiling jet should be further examined. Limitations of FDS model can affect the final results in real fire scenario.

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