REVIEW OF TECHNICAL STANDARDS AND CALCULATION METHODS FOR DIMENSIONING OF SMOKE AND HEAT CONTROL SYSTEMS IN CASE OF FIRE IN UNDERGROUND CAR PARKS

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Introduction

Underground car parks are challenging for fire protection engineers because of their location, specific fire load and ventilation needs.

The proper dimensioning and selection of the smoke and heat control equipment and systems in underground car parks limits the spread of smoke and toxic combustion products.

These systems increase visibility and allow quick and efficient intervention of fire-fighting units and safe evacuation of people.

Review of technical standards and regulations

Rulebook of technical requirements for the fire and explosion protection of car parks (2005).

According to the Rulebook car parks are classified as over ground, underground and combined over and underground car parks.

Car parks are classified as large (>1,500 m^2), medium sized (400÷1,500 m^2) and small car parks (<400 m^2).

The Rulebook defines number of entrances and exits, as well as requirements for approaching fire-fighting vehicles depending on the size of the car park.

Automatically stable fire extinguishing systems (i.e. sprinklers) and stable fire alarm systems must be provided in large and medium-sized garages.

Review of technical standards and regulations

Ventilation of underground car parks is usually recommended in order to limit concentrations of carbon monoxide (CO) and other vehicle emissions in the day to day use of car parks and to remove smoke and heat in the event of a fire.

For underground car parks mechanical or forced ventilation is mandatory. Forced ventilation should be dimensioned to limit half-hourly average concentration of carbon monoxide below 100 ppm. In order to achieve this, the ventilation system must discharge at least 6 m^3/h of air per square meter of useful car park area.

In all car parks with forced ventilation detectors of carbon monoxide must be installed and permanently in operation. If $C_{CO}>250$ ppm, the detectors automatically alert the alarm system which warns the car park users to turn off the vehicle engine and leave the car park.

Methodology for dimensioning of ventilation systems with respect to CO emissions in car parks can be found in textbooks or German engineers directive (VDI 2053).

Review of technical standards and regulations

Technical standard SRPS CEN/TR 12101-5:2009 gives recommendations and guidance on functional and calculation methods for smoke and heat exhaust ventilation systems for steady-state design fires. This standard is based on the text of British standard BS 7346-4:2003.

The most relevant international standard for smoke and heat control systems applied in covered car parks is BS 7346-7:2013. This standard gives guidance on functional recommendations and calculation methods for smoke and heat control systems for covered parking areas for cars and light commercial vehicles. The recommendations in this standard are provided for smoke and heat control systems installed in car parks, with or without sprinkler protection.

In USA NFPA 92 standard is commonly used. It establishes requirements for the design, installation, and testing of smoke control systems used to mitigate the impact of smoke from fire in general.

Dimensioning of smoke and heat control systems

The following types of ventilation might be considered as alternatives: 1. Natural ventilation, 2. Ducted mechanical ventilation, 3. Impulse ventilation, 4. Smoke and heat exhaust ventilation systems (SHEVS).

In this paper only SHEVS will be considered. These systems serve to extract smoke and toxic gases from the car park level at which the fire appeared.

The most preferable configuration combines general ventilation system and smoke and heat control system and thus requires less ducting and extraction fans. In this case it is necessary to mount a fan with speed control unit (two speed or modulating control).

Fresh air supply is carried out through elevator shafts, stairways and corridors at the car park level at which fire can occur.

Dimensioning of smoke and heat control systems

In order to protect the means of evacuation from smoke and toxic gases penetration, a higher pressure should be provided at the side of escape routes (i.e. stairways, corridors) in relation to adjacent rooms where fire can occur.

The value of the pressure difference should be from 20 to 80 Pa if all doors and openings on the evacuation routes are closed. A minimum air velocity of 0.5 m/s through the opened door at the level where the fire occurs should be provided.

Smoke extraction fans must operate in case of fire and must withstand temperatures up to 400°C for 90 minutes.

In addition to the automatic control of the forced ventilation system and SHEVS, it is also necessary to provide the possibility of manual start-up from a safe place. Ducts of SHEVS have to be fire resistant up to 90 min. Fire dampers also have to be fire resistant (up to 90 min) and equipped with automatic and remote control.

Dimensioning of smoke and heat control systems

The main extract system should be designed to run in at least two parts, such that the total exhaust capacity does not fall below 50% of the rates in the event of failure of any one part and should be such that a fault or failure in one will not jeopardize the others.

The system should have and independent power supply, designed to operate in the event of failure of the main supply.

Extract points should be arranged so that 50% of the exhaust capacity is at high level and 50% is at low level and evenly distributed over the whole car park.

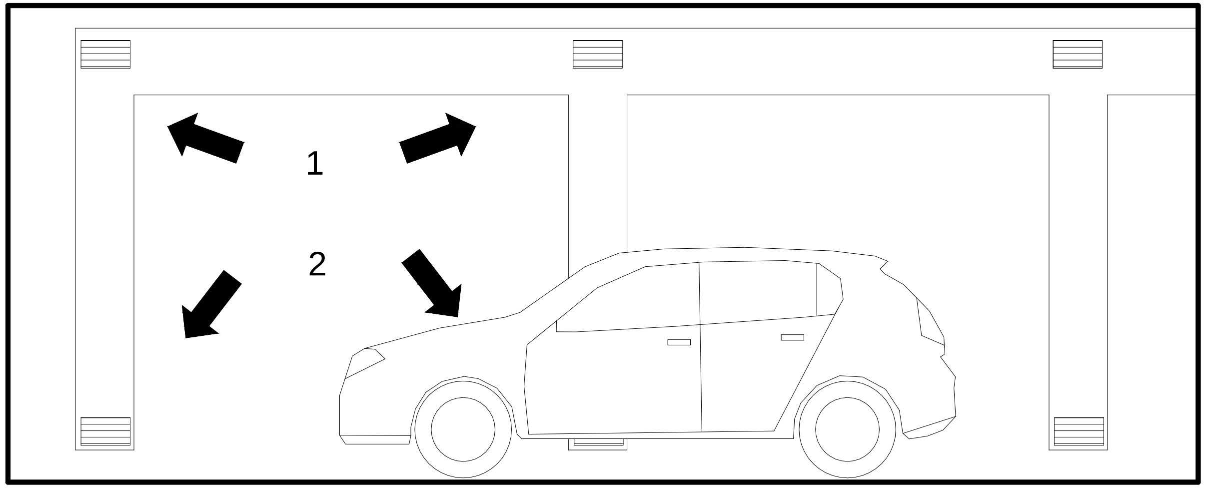

Figure. Typical mechanical ventilation using a ducted smoke clearance system: section view (Key: 1- 50% high level extract, 2- 50% low level extract)

Calculation of ventilation flow rate

Until recently common practice in Serbia was that the dimensioning of SHEVS was based on the recommended value of ventilation flow rate of **600 m^3/h** per one car parking lot.

Different approach would be dimensioning of SHEVS based on the **flow rate of smoke** that should be extracted from the car park in case of fire.

$$M_f = 3600 \cdot C_e \cdot P_f \cdot y^{3/2} \qquad (4)$$

Where

M_f – **mass flow rate of smoke** that is extracted from the car park [kg/h]
C_e – coefficient is equal to 0.19 for large-space rooms such as auditoria, stadia, large open-plan offices, atrium floors etc., where the ceiling is well above the fire;
C_e – coefficient is equal to 0.337 for small-space rooms such as unit shops, cellular offices, hotel bedrooms etc., with ventilation openings predominantly to one side of the fire.
P_f – perimeter of fire in the initial stage [m]
y – distance from the lower edge of smoke layer to the floor [m]

Calculation of ventilation flow rate

In temperature control designs the temperature of the smoke reservoir gases above ambient temperature (Θ) is specified. The convective heat flux in the smoky gases entering the buoyant smoke layer is also known. The mass flow rate entering the buoyant layer is calculated using the following equation:

$$M_f = Q_f/(c \cdot \Theta_1) \qquad (5)$$

Where

c – specific heat of air at constant pressure [kJ/(kg·K)]

Θ_1 – average temperature above ambient temperature of the gases in a buoyant smoke layer in a smoke reservoir [℃]

Calculation of ventilation flow rate

For different building types default values of perimeter and heat release rates are given in standard SRPS CEN/TR 12101-5:2009.

The convective heat flux (Q_f) carried by the smoky gases entering the smoke reservoir should be taken to be 0.8 times the heat release rate ($q_f \cdot A_f$) identified for the design fire, unless the designer provides evidence to support the use of a different value.

For steady state design fires in covered car parks fire parameters are set out in Table 1. Minimum clear height above escape routes (y) is defined as 2.5 m or 0.8·H [m], whichever is the smaller.

Table 1. Steady state design fires

Fire parameters	*Indoor car park without sprinkler system*	*Indoor car park with sprinkler system*	*Two car stacker with sprinkler system*
Dimensions/area	5x5m/25 m^2	2x5m/10 m^2	2x5m/10 m^2
Perimeter	20 m	14 m	14 m
Heat release rate	8 MW	4 MW	6 MW

Calculation of ventilation flow rate

For selection of the appropriate fans, the mass flow rate of smoke determined from previous calculation of entrainment into the rising smoke plume can be converted to the corresponding volumetric flow rate using equation:

$$V = M_f \cdot T_1 / (\rho_{amb} \cdot T_{amb}) \qquad (6)$$

Where
T_1 – absolute average temperature in a smoke reservoir's buoyant layer [K]
ρ_{amb} – density of air at ambient temperature [kg/m^3]
T_{amb} – absolute ambient temperature [K]

Finally, dimensioning of SHEVS can be done by using the recommended value of air change rate. According to standard [**BS 7346-7:2013**] the smoke and heat control system should be independent from any other system and be designed to operate at **10 air changes per hour**.

Case study

Three different underground car parks were considered, of which the first two are for residential buildings and the third for a commercial building.

The flow rate is calculated according to three different methods: 1. Based on the recommended value of 600 m^3/h per one car parking lot; 2. Based on the equation (4); 3. Based on the recommended number of air changes of 10 1/h.

Table 2. Ventilation, smoke and heat control system flow rates for three different car parks

Car park size by area [m^2]		*Area* [m^2]	*Height* [m]	*Number of parking lots* [-]	*Ventilation flow rate* [m^3/h]	*Smoke and heat control system flow rate* [m^3/h]		
						Method 1	*Method 2*	*Method 3*
Small	< 400	206	2.5	9	1,236	5,400	26,275	5,974
Medium	>400 < 1500	550	2.5	16	3,300	9,600	21,030	13,750
Large	> 1500	1578	3.6	44	9,468	26,400	29,390	56,808

Case study

SHEVS require several times larger flow rates than ventilation system which is in every day operation. In some cases this can be a limiting factor when fire protection engineers are considering the combined configuration of these two systems.

The first method gives the smallest volumetric flow rates (5,400÷26,400 m^3/h).

The second method gives volumetric flow rates that are in range from 21,030 to 29,390 m^3/h. It can be noticed that the calculated flow rates for small and large sized car parks do not differ considerably. Therefore, it can be concluded that according to this method only the parameters of design fire are relevant.

The third method gives moderate values of flow rates for small and medium sized car parks (5,974 and 13,750 m^3/h), but rather high value for large sized car park (56,808 m^3/h).

Conclusions

Based on the review of international and domestic standards and domestic regulations, three different calculation methods that are commonly used in fire protection engineering for dimensioning of smoke and heat control systems are discussed in the paper.

The method which implies the recommended ventilation air change rate of 10 1/h may be the best option for the medium and large sized car parks.

For small sized car parks it can lead to insufficient flow rates, as the fire load of a passenger car can be higher than in a large sized car park, due to the lack of a sprinkler system, with much smaller car park space volume.

Finally, it can be recommended that it is important for fire protection engineers to verify the calculated flow rates for each specific case by using a multi-criteria approach.

Thank you for your attention!

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