Fire Safety with Smoke and Heat Extraction Systems in Underground Car Parks

Les Baert

Supervisor(s): Bart Merci, Nele Tilley, Xavier Deckers

Abstract **This article discusses the design of smoke and heat extraction systems in underground car parks. Topics are back layering of smoke, influence of beam configurations on back layering and delay of detection systems. A survey of regulations , standards and experiments on HRR of cars was made.**

Keywords **large closed car parks, horizontal mechanical ventilation, backlayering, CFD, modeling, performance-based design, design fire**

I. INTRODUCTION

The nature of the enclosed space of an underground car park can cause severe threats to life safety when a car starts to burn in the compartment. Experiments have shown that, once a car is fully involved, fire spread to other cars is likely to happen due to heat feedback in enclosed spaces with low ceilings and nearby walls. When multiple cars are involved, HRR can peak to values exceeding 16MW.[1] Measures have to be taken to facilitate the intervention of fire brigades in order to extinguish the fire before these untenable conditions come up. Early detection of fire phenomena is an important factor in these.

Well designed Smoke and Heat Extraction (SHE) systems with horizontal mechanical ventilation can help to prevent extended backlayering of smoke in the access route to the fire. Prediction of smoke movement in car parks is difficult to capture in simple design rules. CFD is often necessary to demonstrate the behavior of smoke in complex geometries. This technique needs high skills from both designer and authorities. For the sake of simplicity, design rules can be made for a sub-geometry of 1000m² often encountered in underground car parks. We call it a smoke zone. The boundaries of this smoke zone can be either physical, by means of roller shutters or curtains, or virtual meaning that the velocities in adjacent zones are similar.

Les Baert is with Somati nv, Erembodegem, Belgium, and studied the postgraduate studies in Fire Safety Engineering at the Faculty of Engineering and Architecture, Ghent University (UGent), Gent, Belgium. Email: Lesley.Baert@telenet.be

II. FIRE MODELING

Defining the HRR curve is the first step to design a SHE system. A survey of experiments with burning cars throughout the world was made resulting in an overview of peak HRR values and time to reach this peak.[2][3][4][5]

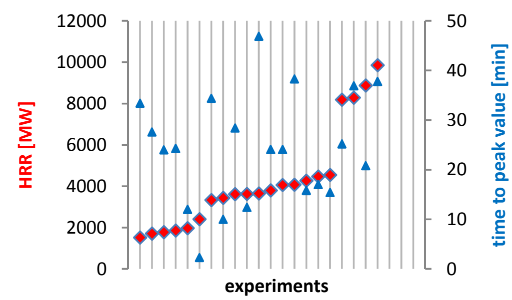

Figure 1: Overview of peak HRR and time to reach it on a survey of car burn experiments

Reference curves used for the design of SHE systems in Belgium [6], Netherlands [7] and UK [8] are summarized. We found that most curves are based on experiments from the late nineties by CTICM France and TNO Netherlands.

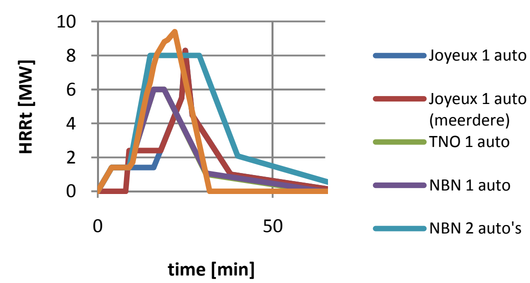

Figure 2: frequently used HRR for design fires in car parks

III. DETECTOR RESPONSE DELAY

Response times of detection devices to the above mentioned reference HRR curves were examined for both smoke and heat detectors. These devices were modeled in FDS with their respective Heskestad and RTI model.[9] Location of devices was done conform to the Belgian standard [10] on fire detection systems.

The influence of low velocity CO ventilation on the response times of smoke and heat detectors was investigated.

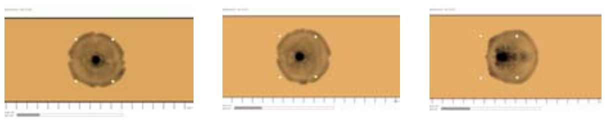

Figure 3: smoke distribution during development of ceiling jet under different comfort ventilation conditions

We observe a response time for smoke detectors of approx. 20s. and . For heat detectors, modeled by their RTI value, we observe a response time between 150s and 200s depending on their RTI value.
A negligible effect of the ventilation flow rate on the response time of both detectors was observed within the range of 0.8m³/s to 3.6m³/s.

IV. CRITICAL VELOCITY and BACKLAYERING

A series of about 400 CFD simulations were carried out to determine the backlayering in a 1000m² domain with 457728 cells under different configurations of transversal and longitudinal beams with different heights and spacing. For every single configuration a series of simulations with differing extraction flow rates and HRR was done. Varying the extraction rate and consequent upwards velocities within the same CFD calculation seems to generate difficulties with stabilization of the ceiling jet's leading edge. Therefore, separate CFD runs for 150s simulated time are done for each constant extraction flow rate.

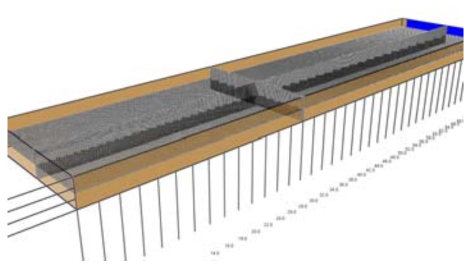

Figure 4: calculation domain for the analysis of critical ventilation velocities and backlayering distance

Exponential correlations for critical velocity were found for configurations with beams, unlike configurations with flat ceiling where a power law curve was the best match with observed data.

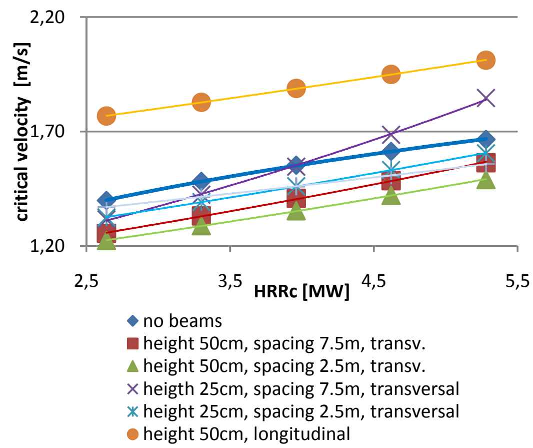

Figure 5: correlations for the critical velocity for different beam configurations

Backlayering distance can be expressed as function of a deficit in upwards velocity regarding the critical velocity v_{cr} as $d = a\,(v_{cr} - v_{in})\ \ [m]$.
We found expressions for a for different beam configurations and observed that backlayering distance becomes less sensitive to deficits in upward velocity regarding to the critical velocity when beams are involved. Unlike flat ceilings, sensitivity seems to decrease with increasing HRR.

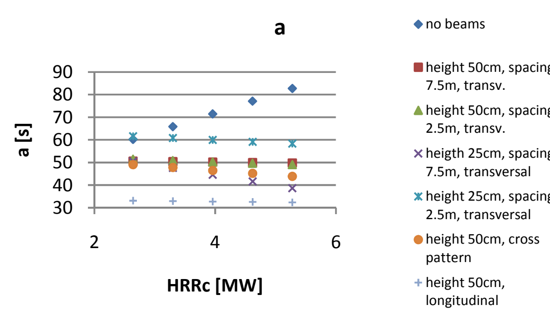

Figure 6: value for a: dependence on beam configuration and HRR

The CFD model FDS was used in this study. FDS uses a standard form of the Smagorinsky model for sub-grid turbulence modeling with LES. [11]
The setup used in this study was investigated for sensitivity on grid size and turbulent model parameters.

V. CONCLUSION

Well designed mechanical horizontal smoke and heat extraction (SHE) systems in car parks create tenable conditions for fire men along their access route to the proximity of burning car(s). A higher level of safety is achieved by creating acceptable temperatures in the back layering smoke layer and improved visibility at low heights. Even if the system is designed for backlayering distances up to 30m, the above mentioned conditions holds.

Systems designed with flow rates for the prevention of excessive smoke backlayering are also reducing thermal attack on building structures beyond the immediate fire source area. Temperatures lower than 250°C are found at ceiling height for a 8MW fire source.

Backlayering distance could be expressed as a linear function of deficit of the inlet velocity to the critical velocity, preceded by a sensitivity factor. This factor is increasing with increasing HRR for flat ceilings, however when transversal beams are involved, we found that this factor is decreasing with increasing HRR.

For the investigated configurations and heat release rates, transversal beams are reducing the critical velocity by approx. 10%, except for shallow widely spaced beams where the critical velocity is increasing by approx. 5 to 10% for a 8MW fire.
Longitudinal beams are increasing the critical velocity with approx. 20%.

Year to date full scale experiments without SHE systems have shown that fire spread to adjacent cars is possible once the first car is fully involved in fire [1]. At present, there is no sound basis to make conclusions about the influence of SHE systems on fire spread in car parks.
It seems evident that providing the fire with a forced flow of fresh air will accelerate the combustion and flames will be tilted towards downstream cars.
However, temperatures of smoke layers will be lowered drastically , resulting in an important reduction of downwards radiation to adjacent cars. Experiments have shown that in particular the pre-warming of adjacent cars due to downward radiation of ceiling jets is a major factor in reducing time to their involvement in fire [1]. Lowering smoke layer temperature will yield precious time in order to extinguish the fire before untenable conditions are reached.

Early detection of incipient fire is very important to extend the available for fire brigade intervention. Daily exhaust gas dilution ventilation designed according to applicable standards [12] [13] has no significant influence on response times of both smoke and fixed temperature heat detectors. We found that response times for optical smoke detectors are only 15% of response times for fixed temperature detectors based on their RTI value.

REFERENCES

1. BRE. BD2552 Fire spread in car parks. London. 2010.
2. JANSSENS, M. L. Development of a database of full scale calorimeter tests of motor vehicle burns. Southwest Research Institute. San Antonio USA. 2008.
3. JOYEUX, D. Natural Fires in Closed Car Parks. CTICM. France, p. 31. 1997.
4. OKAMOTO, K. Burning behavior of sedan passenger cars. Fire Safety Journal, Japan, n. 44, p. 301-310, 2009.
5. VANOERLE. Effectiviteit van stuwkrachtventilatie in gesloten parkeergarages, brandproeven en simulaties. TNO Nederland. Delft, p. 67. 1999.
6. NBN. NBN S21-208-2/pr A1:2010 Brandbeveiliging in gebouwen Ontwerp van rook- en warmteafvoersystemen in gesloten parkeergebouwen. [S.l.]. 2010.
7. NNI. NEN 6098 - Rookbeheersingssystemen voor mechanisch geventileerde parkeergarages - 2e ontwerp. Nederlands Normalisatie-instituut. [S.l.]. 2010.
8. BSI. BS 7346-7 - Components for smoke and heat control systems. Code of practice on functional recommendations and calculation methods for smoke and heat control systems for covered car parks. UK: BSI, 2006.
9. MCGRATTAN, K.; HOSTIKKA, S.; FLOYD, J. Fire Dynamics Simulator (version 5), Technical Reference Guide. Maryland, USA: NIST, v. Volume 1:Mathematical model, 2010.
10. NBN. NBN S21-100:1986 + addenda: Reddings-en brandweermaterieel - Opvatting van algemene installaties voor automatische brandmelding door puntmelder. Bureau voor Normalisatie. Brussel. 2006.
11. MCGRATTAN, K.; HOSTIKKA, S.; FLOYD, J. Fire Dynamics Simulator (Version 5.5) User's Guide. Maryland, USA: NIST, 2010.
12. NNI. NEN 2443:2000 - Parkeren en stallen van personenauto's op terreinen en in garages. [S.l.]. 2000.
13. VDI-GESELLSCHAFT TECHNISCHE GEBÄUDEAUSRÜSTUNG. VDI 2053 Air treatment systems for car parcs. [S.l.]: Verein Deutscher Ingenieure, 2004.