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Underground parking: requirements to TPRD size and release direction

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Ventilation in underground parking

BS 7346-7:2013 requirements

Underground parkings are generally equipped with **mechanical systems** to fulfil the ventilation requirements.

Requirements in normal working conditions:

- 6 air changes per hour (ACH) in the main parking area
- 10 ACH in the zones where vehicles may stop with running engines

Requirements in the event of fire:

- Provide **10 ACH**
- Maintain velocity lower than 5 m/s in the escape routes to not impede the occupants escape

Ventilation in underground parking

Damage and harm criteria

<u>Damage to ventilation system</u>

BS 7346-7-2013: Performance recommendations for equipment:

*"8.2.1 All fans intended to exhaust hot gases used within a car park ventilation system should be tested in accordance with BS EN 12101-3 to verify their suitability for operating at **300 °C** for a period not less than **60 minutes** (class F300)."*

<u>Harm to people</u>

Temperature higher than 70°C according to LaChance (2011).

Problem formulation

General scenario

Hydrogen release through the TPRD of a hydrogen-powered vehicle in an underground parking:

- TPRD diameters: 0.5 mm - 2 mm
- TPRD release angles: 0º, 30º, 45º, 60º
- Ventilation rate: ACH= 0, 10 (for considered car park)
- Ceiling height: 2.1 and 3 m
- Car location: middle vs close to the wall
- Pre-existing knowledge:
  - **"Perfect mixing" model** gives averaged concentration
  - **"HyIndoor" model** calculates maximum concentration in layered mixture
  - **CFD model** gives realistic distribution of hydrogen in assumption of good mixing and small enclosures
  - **Simple correlations for large volumes not applicable.**
  - **CFD is recommended as a reliable tool!**

Problem formulation

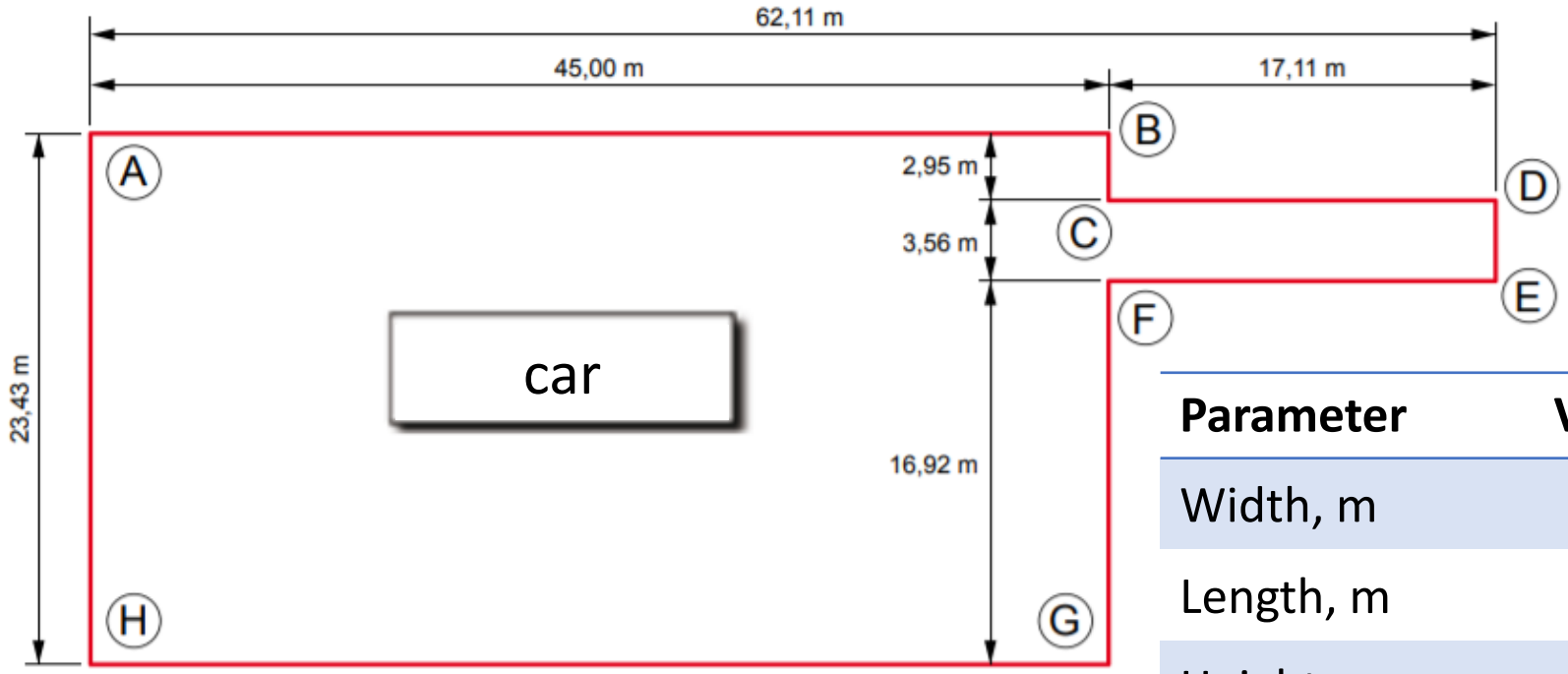
Aims of the study

- Perform transient blowdown release with presence of vehicle in order to give
  - true picture of the concentration distribution
  - the timing and location of the hazardous concentrations with distributed ventilation
- Most TPRDs installed on vehicles located in downward direction under the car and this scenario need to be simulated to account for the correct direction, angle and concentration decay of hydrogen before it will start to form hazardous concentration, layer and thermal hazards in ignited case
- Define maximum TPRD diameter to satisfy current ventilation requirements (without their change)

Case study

Layout of the underground car park

Real underground car park in St. Martnes Latem (Gent, Belgium)



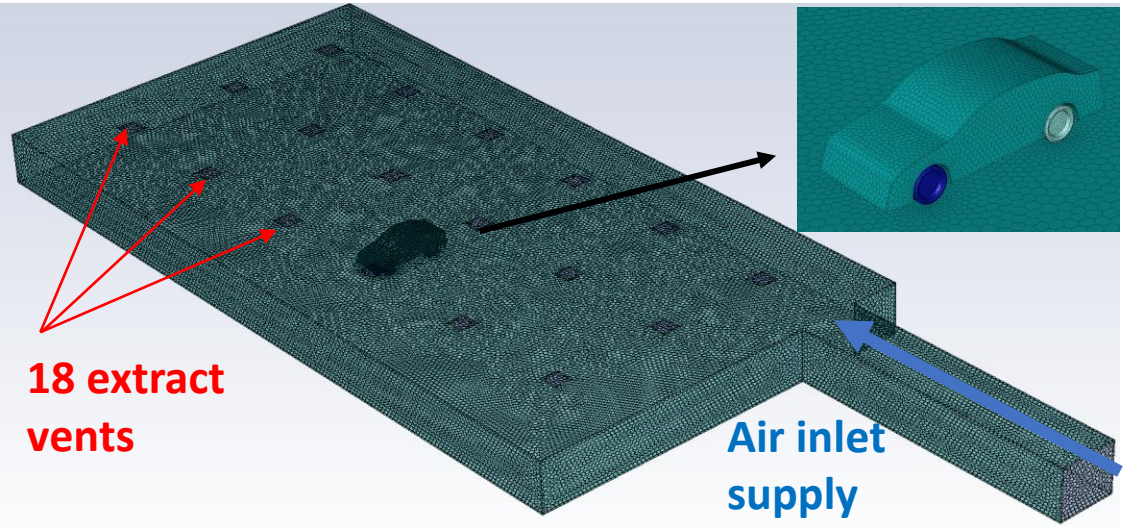
Parameter	Value
Width, m	23.5
Length, m	45
Height, m	3

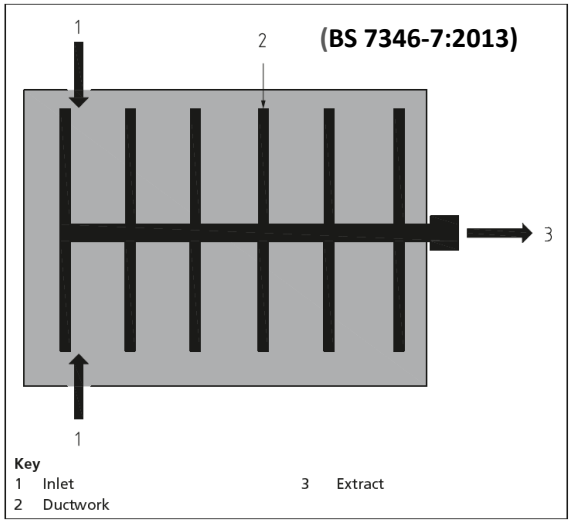
Arcelor-Mittal underground car parks

CFD model

Details

- **Numerical details:** transient formulation, with volumetric source (VS) for blowdown, pressure-based implicit solver, realizable k-ε for turbulence, second order upwind scheme for the momentum, species and energy equations. Mesh: 440,000 poly-hex-core CVs.
- **Geometry and ventilation:** ventilation 10 ACH, 18 evenly distributed extraction vents (BS 7346-7:2013)
- **Release scenarios:** 15 unignited and 19 ignited.





Mechanical ventilation

Release scenarios, 62.4L @700Bar

No.	D_{TPRD}, mm	ACH	Angle, °	Obstacle	Ceiling height
1	0.5	0	45	-	3
2	0.5	10	45	-	3
3	0.5	10	0	-	3
4	0.5	10	30	-	3
5	0.5	10	60	-	3
6	0.75	10	30	-	3
7	0.75	10	0	-	3
8	0.5	10	45	-	3
9	0.75	10	45	-	3
10	1.0	10	45	-	3
11	2.0	10	45	-	3
12	0.75	0	45	-	2.1
13	0.5	0	45	+	2.1
14	0.75	0	45	+	2.1
15	0.75	0	45	-	3
16	0.75	10	45	-	2.1

Effect of ventilation

Effect of TPRD angle

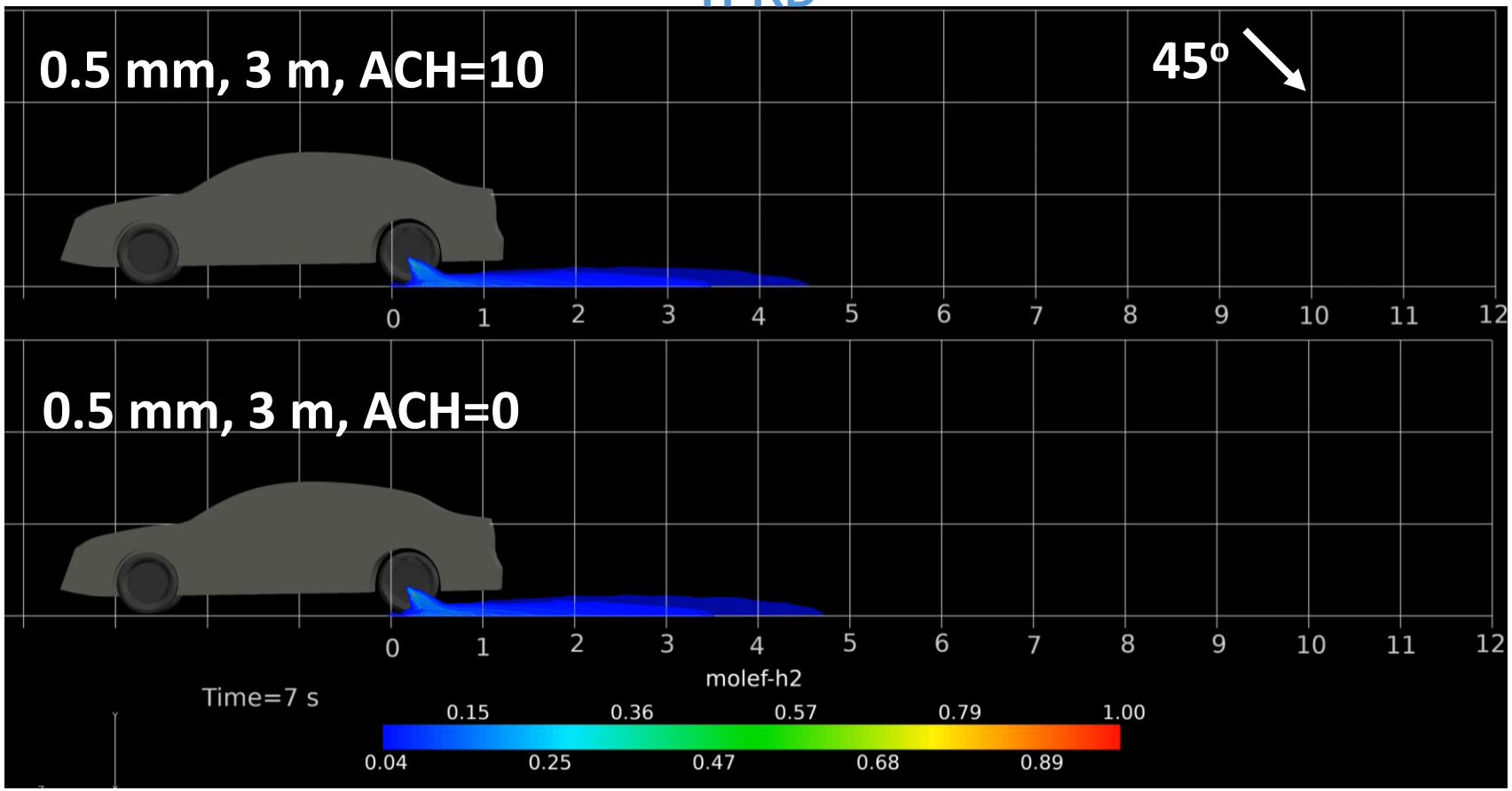
Effect of TPRD diameter

Effect of ceiling height

Limiting scenario

Results

Effect of ventilation D_{TPRD}=0.5

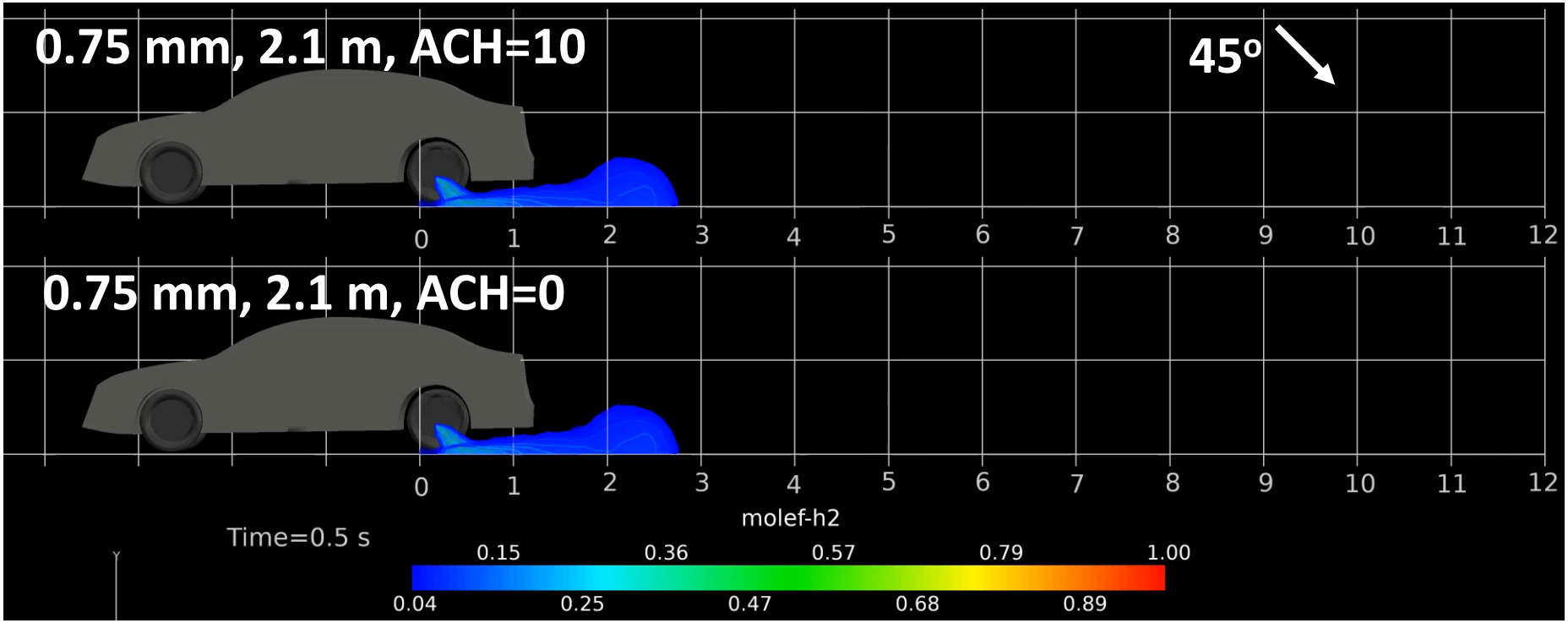


Release from 0.5 mm @45º

- does not create layer
- ceiling heigh does not effect the decay
- ventilation reduces the decay by about 20%

Results

Effect of ventilation D_{TPRD}=0.75

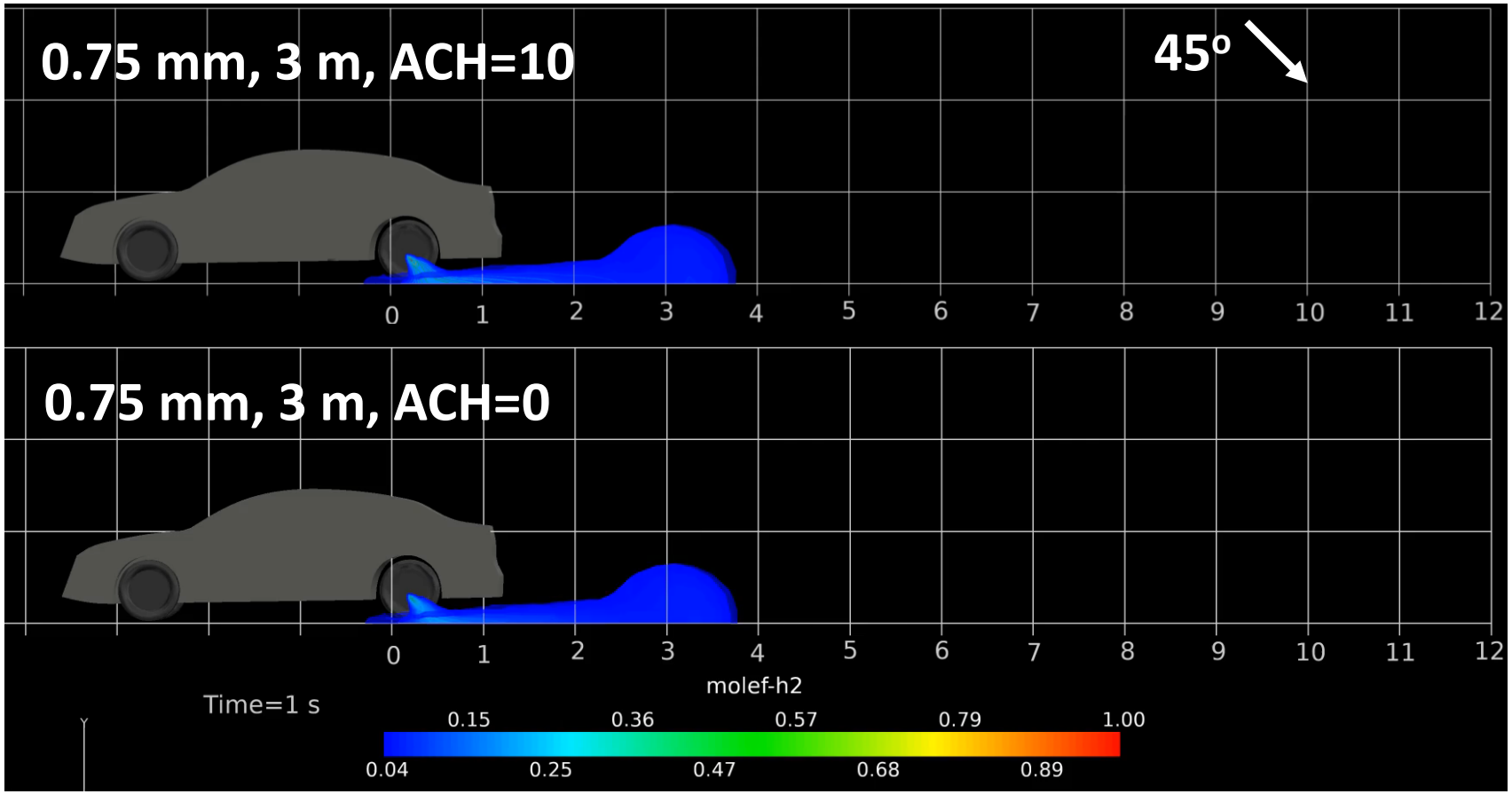


Release from 0.75 mm @45º

- does not create layer
- ceiling heigh does not effect the decay
- ventilation reduces the decay by about 20%

Results

Effect of ventilation D_{TPRD}=0.75

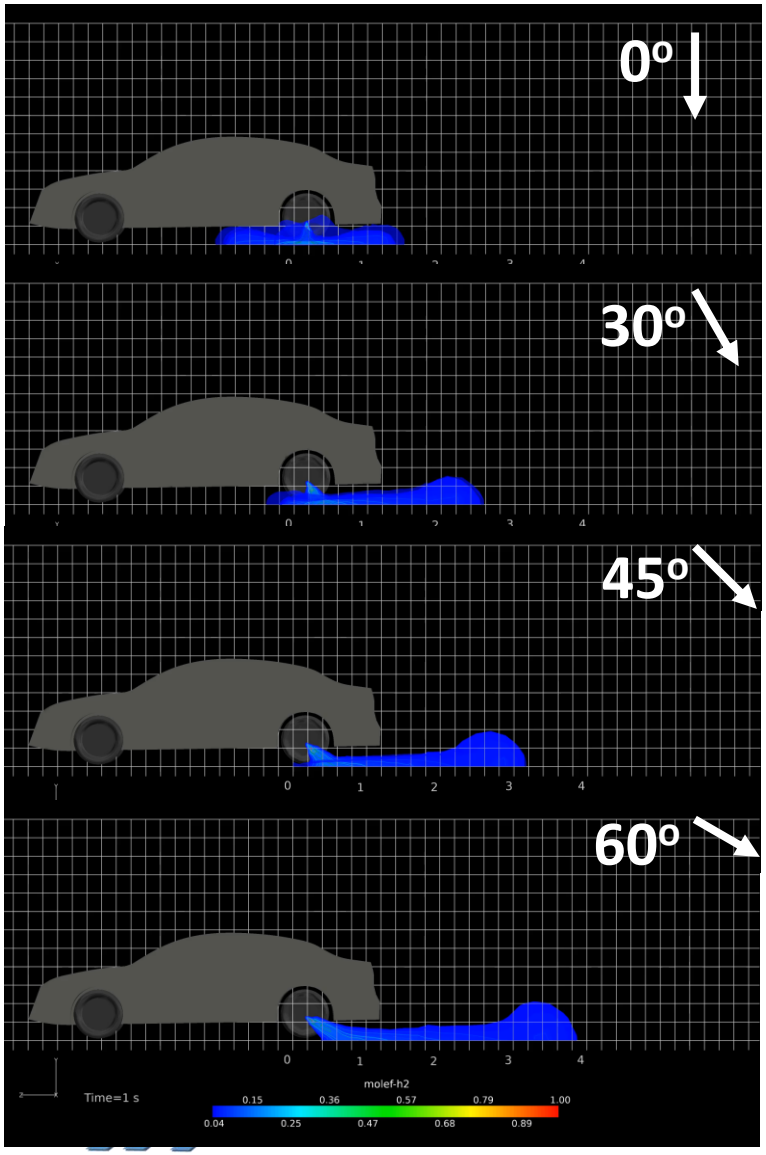


Release from 0.75 mm @45º

- does not create layer
- ceiling heigh does not effect the decay
- ventilation reduces the decay by about 20%

Results

Effect of release angle D_{TPRD}=0.5mm



Tank 70 MPa, V=62.4 L
TPRD=0.5 mm
ACH=10

Release at 0º

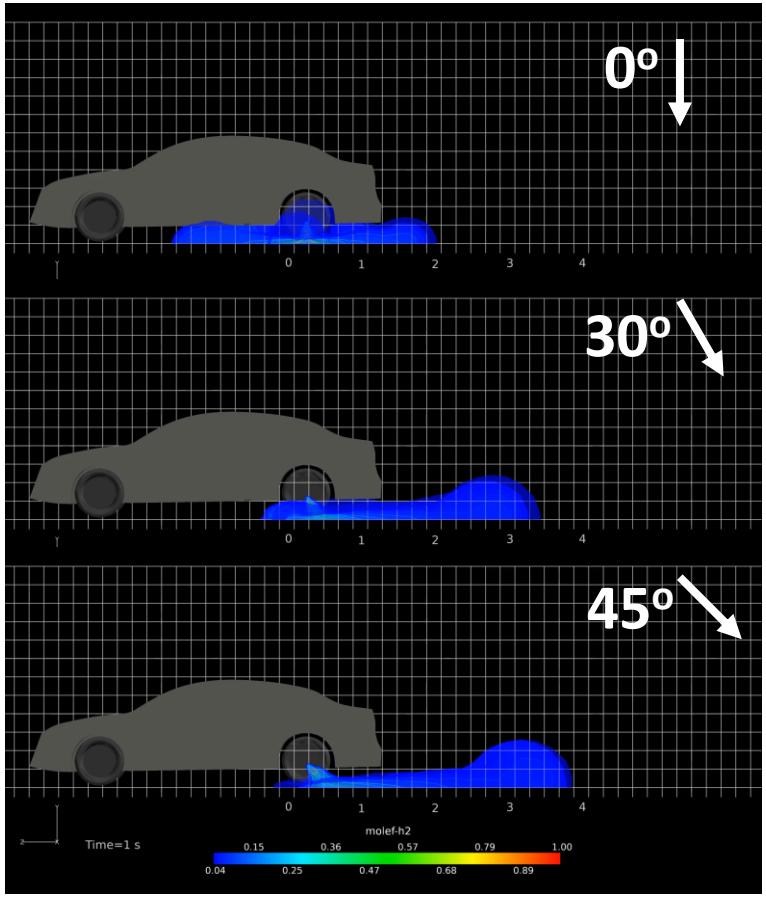
- Evacuation problem in case of fire
- Flammable layer formation

Release at 30º

- Shortest decay distance to 4% at 30 s

Results

Effect of release angle D_{TPRD}=0.75 mm (video)



Tank 70 MPa, V=62.4 L
TPRD=0.75 mm
ACH=10

Release at 0º

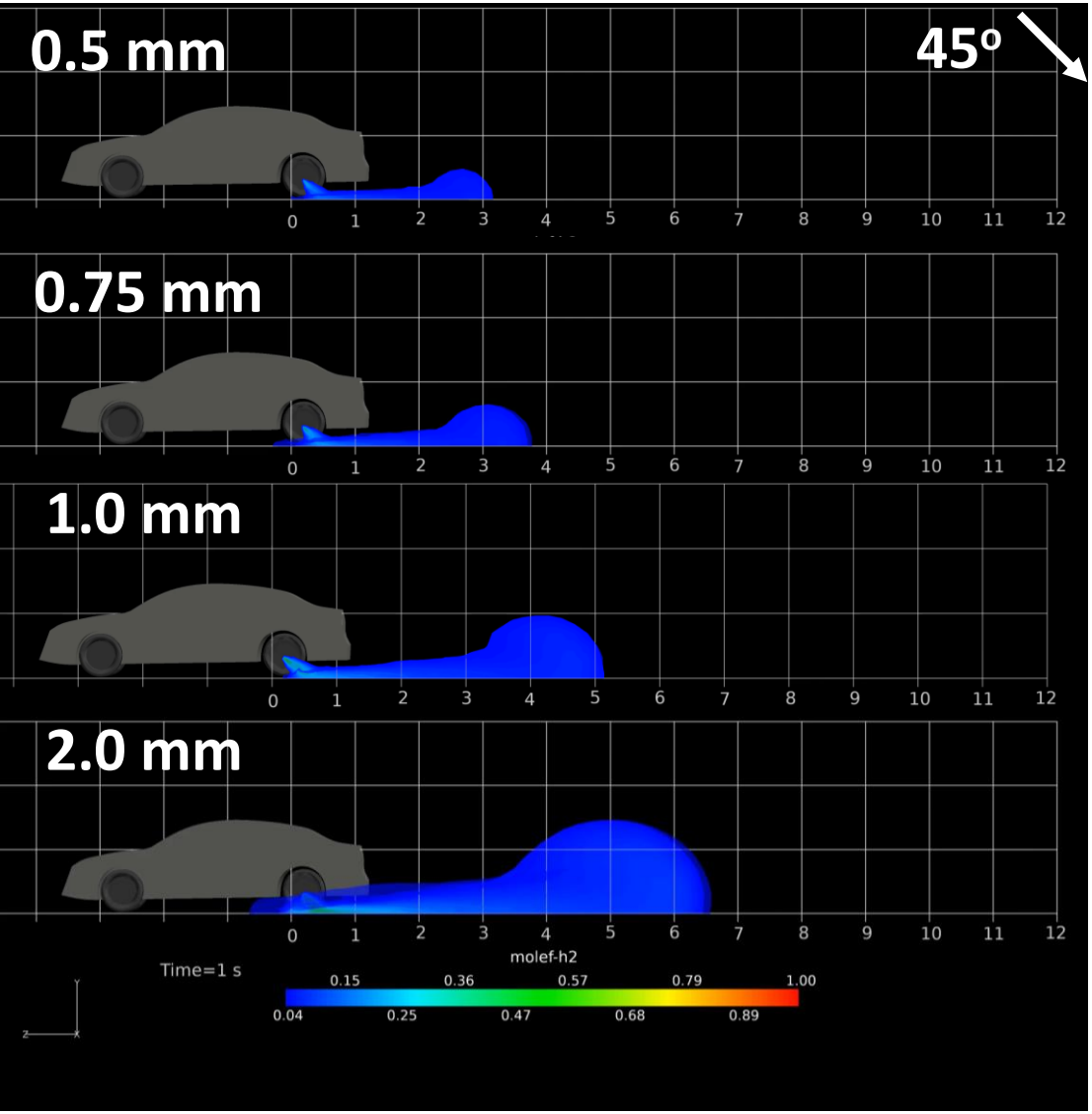
- Evacuation problem in case of fire
- Flammable layer formation

Release at 30º

- Shortest decay distance to 4%

Results

Effect of TPRD diameter (video)



Release from 0.5 – 1 mm

- does not create layer
- 0.5 shortest hazard distance

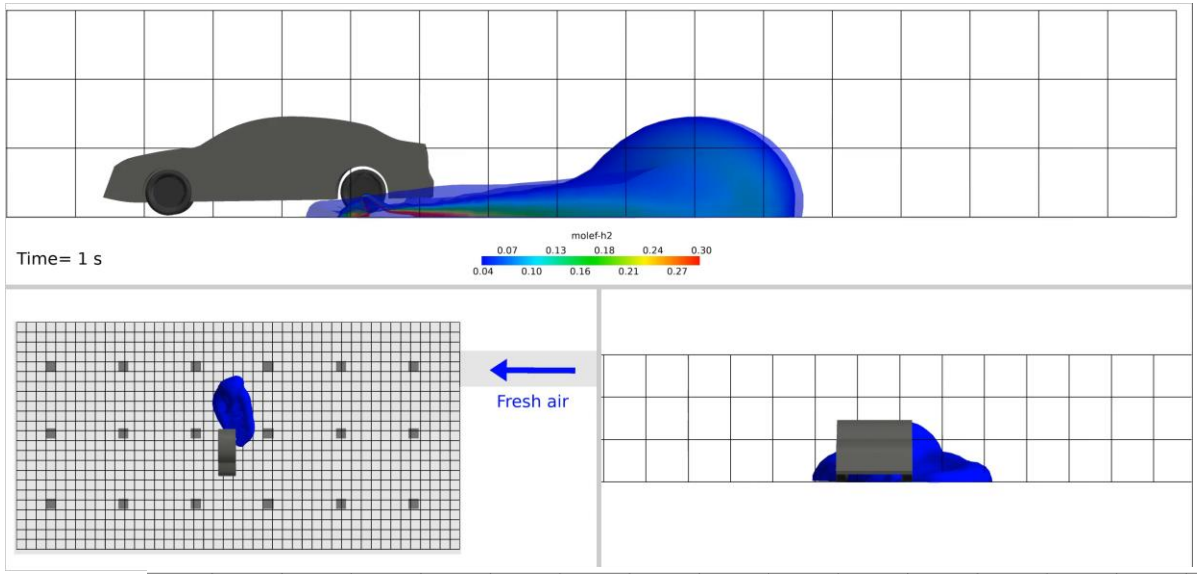
Release from 2 mm

- Long hazard distance
- Evacuation problem in case of fire
- Flammable layer formation

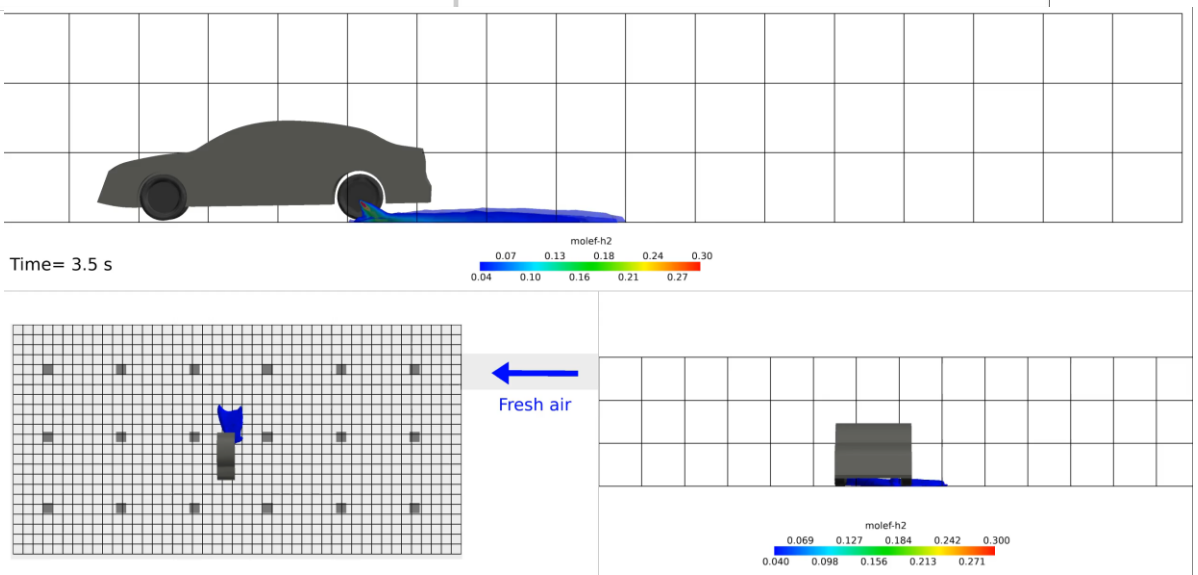
Results

Effect of TPRD diameter (hazards, 3D video)

TPRD=2 mm, 45º
70 MPa, 62.4 L
ACH=10

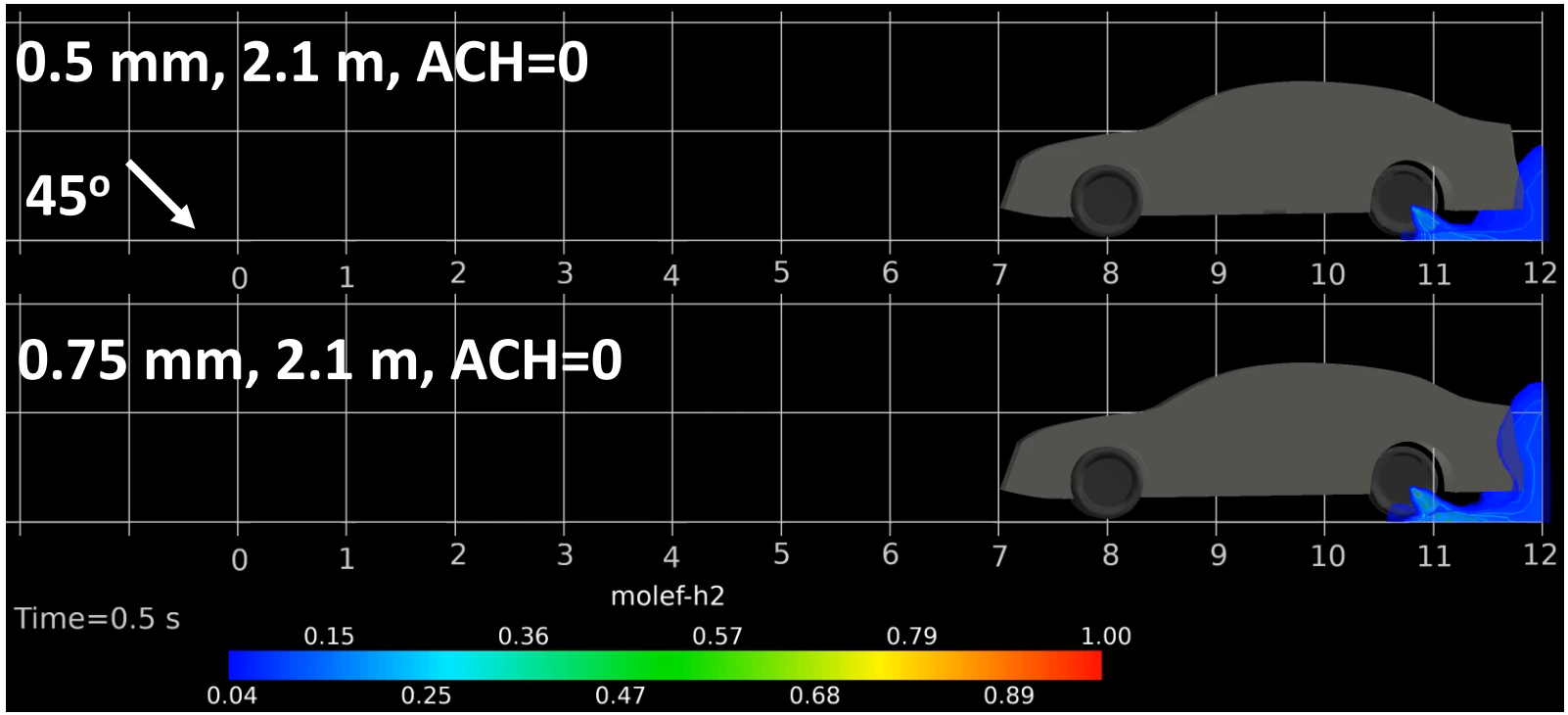


TPRD=0.5 mm, 45º
700 bar, 62.4 L
ACH=10



Results

Effect of obstacle (limiting scenario)



Presence of wall behind, results in formation of flammable mixture regardless of TPRD size.

Mechanical ventilation

Ignited release scenarios

No.	D_{TPRD}, mm	ACH	Angle, °	Obstacle	Ceiling height
1	0.5	0	45	-	3
2	0.5	10	45	-	3
3	0.5	10	0	-	3
4	0.5	10	30	-	3
5	0.5	10	60	-	3
6	0.75	10	30	-	3
7	0.75	10	0	-	3
8	0.75	10	45	-	3
9	1.0	10	45	-	3
10	2.0	10	45	-	3
11	0.75	0	45	-	3
12	0.5	0	45	Wall	2.1
13	0.75	0	45	Wall	2.1
14	0.75	0	45	-	3
15	0.75	10	45	-	2.1
16	0.5	10	45	-	2.1
17	0.6	10	45	-	2.1
18	0.6	10	45	-	3
19	0.5	10	45	Wall	2.1

Effect of ventilation

Effect of TPRD angle

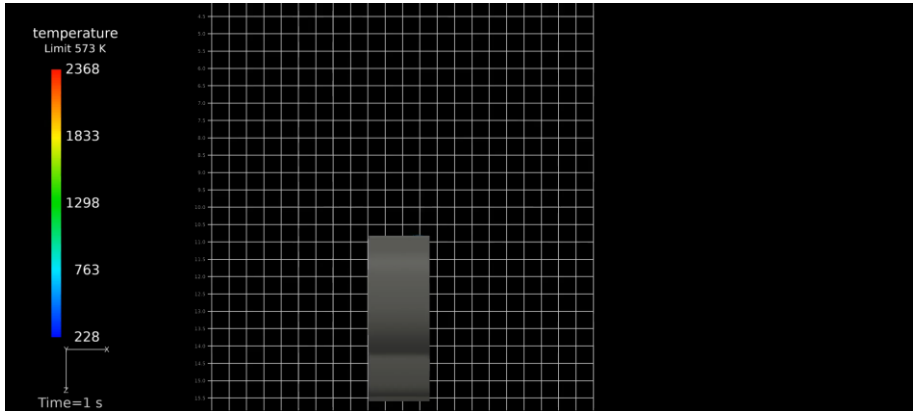
Effect of TPRD diameter: cases in bold: 2, 8, 9, 10, 18

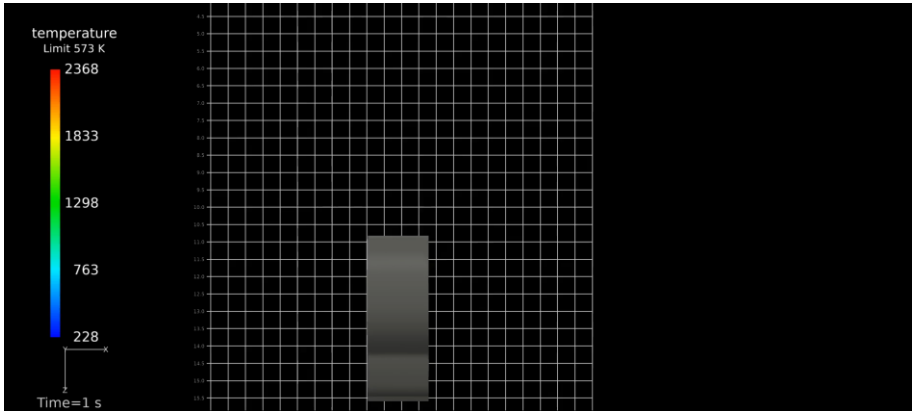
Limiting scenario

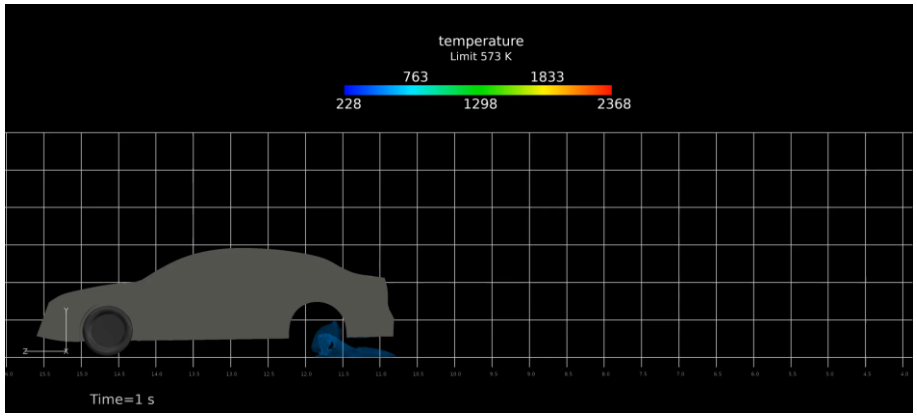
Effect of mechanical ventilation

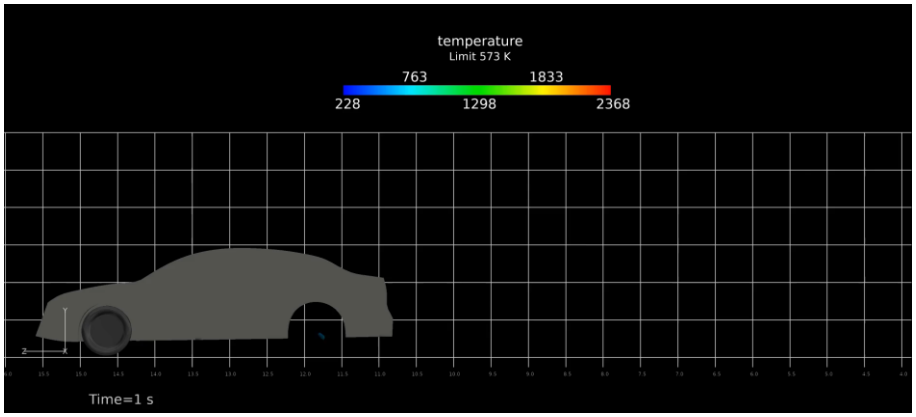
TPRD 0.5mm, 45° - Damage to ventilation (300ºC)

0 ACH | **10 ACH**





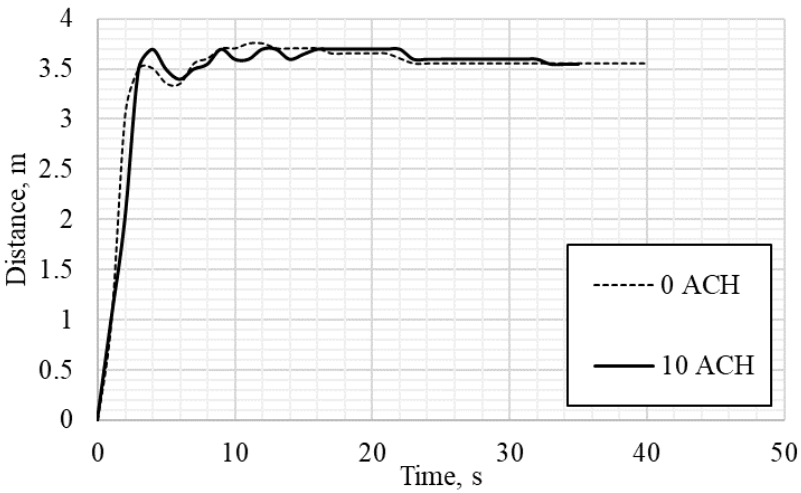


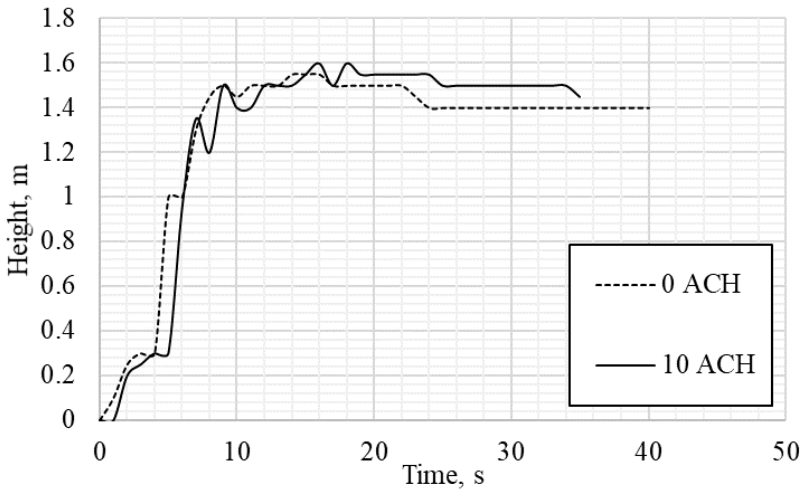


Effect of mechanical ventilation

TPRD 0.5mm, 45° - Compliance to BS

Maximum horizontal distance from the rear of a vehicle and maximum height reached by cloud with **T≥300°C**.



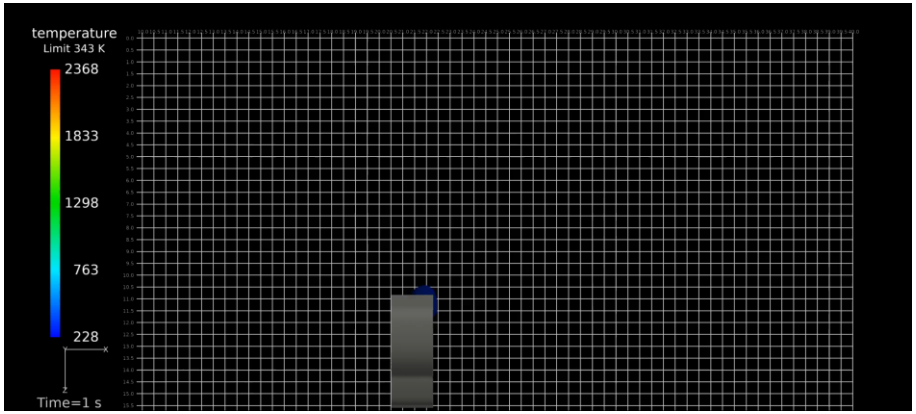


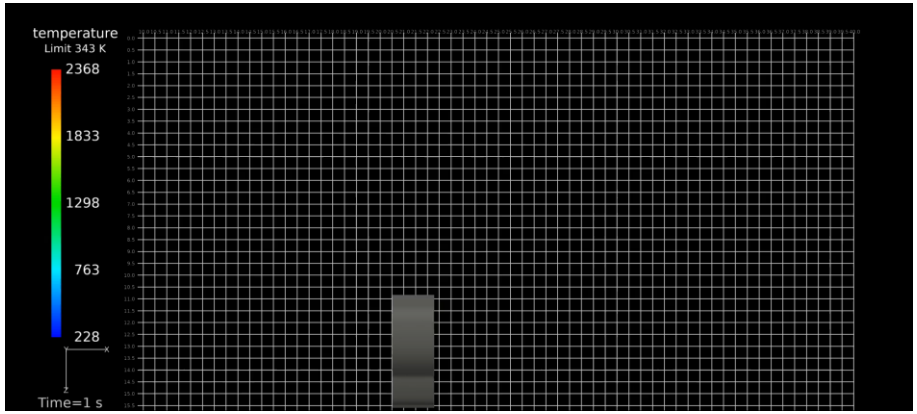
The **ventilation** does not affect significantly the hot combustion products with T ≥ 300°C distribution for TPRD ∅0.5 mm.

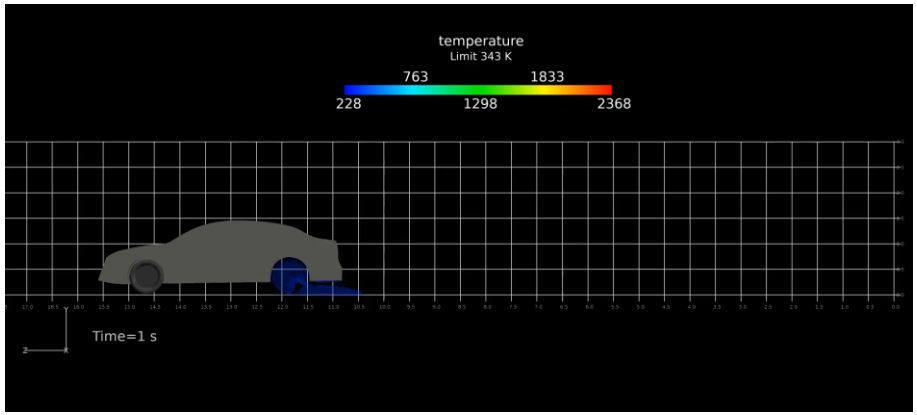
Effect of mechanical ventilation

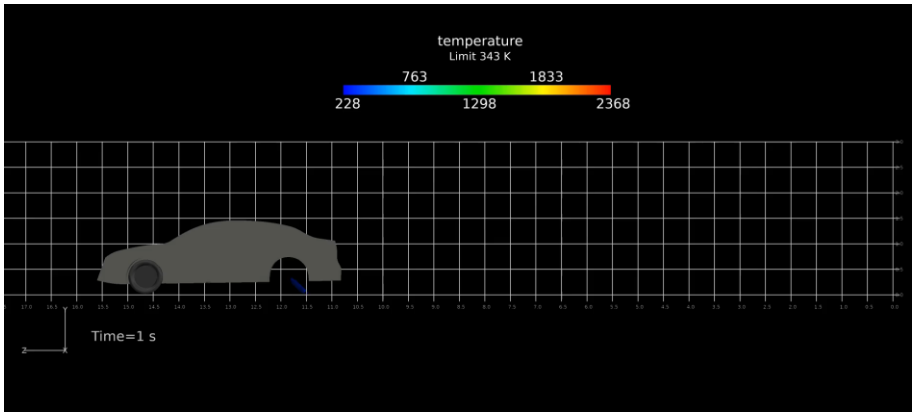
TPRD 0.5mm, 45° - Harm to people (70°C)

0 ACH **10 ACH**





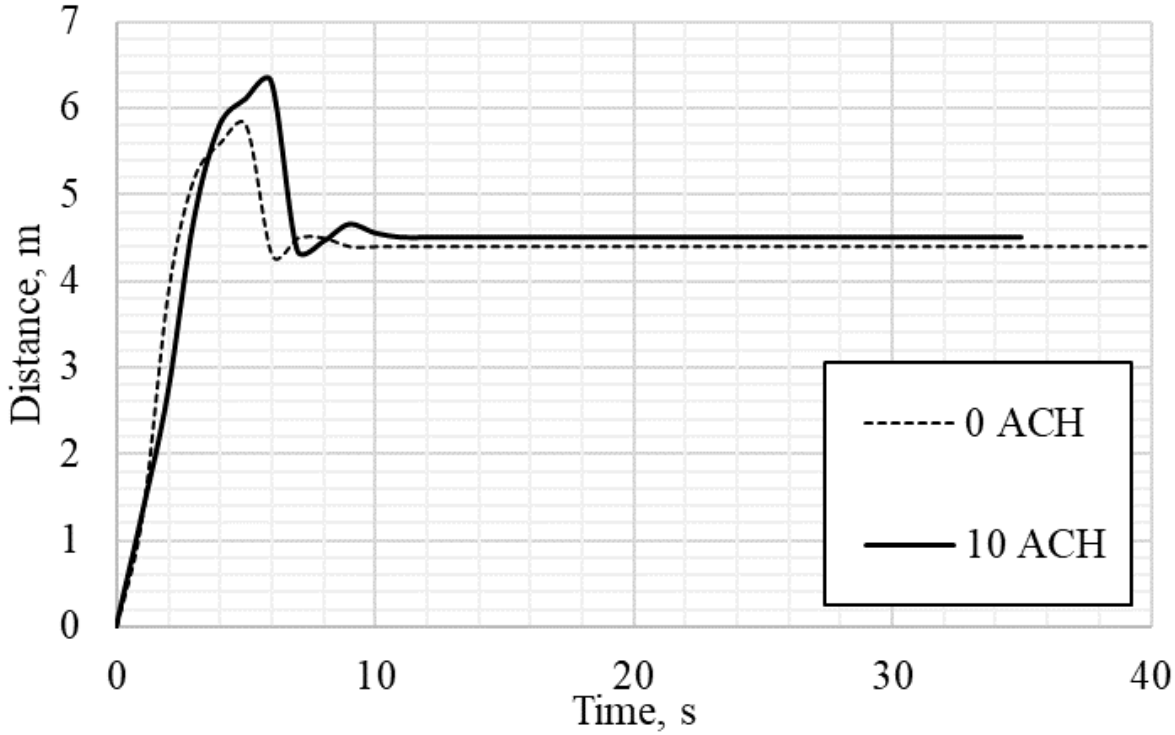




Effect of mechanical ventilation

TPRD 0.5mm, 45° - Harm to people

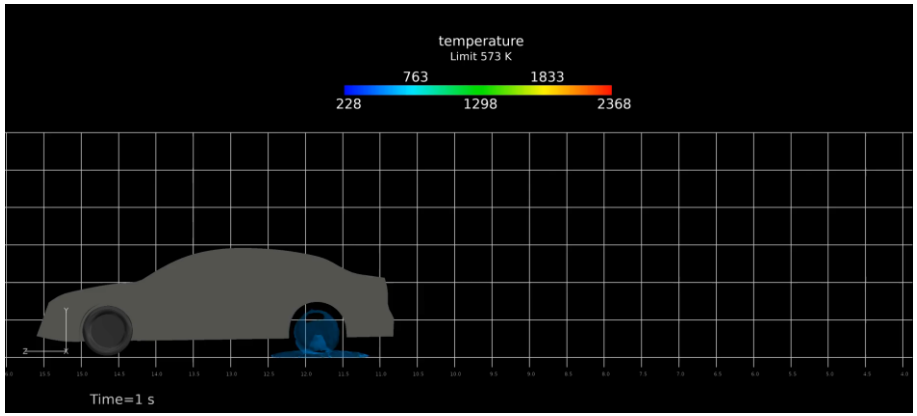
Maximum horizontal distance from the rear of a vehicle for a height within 0-2 m for the hot combustion products cloud with T≥70°C.



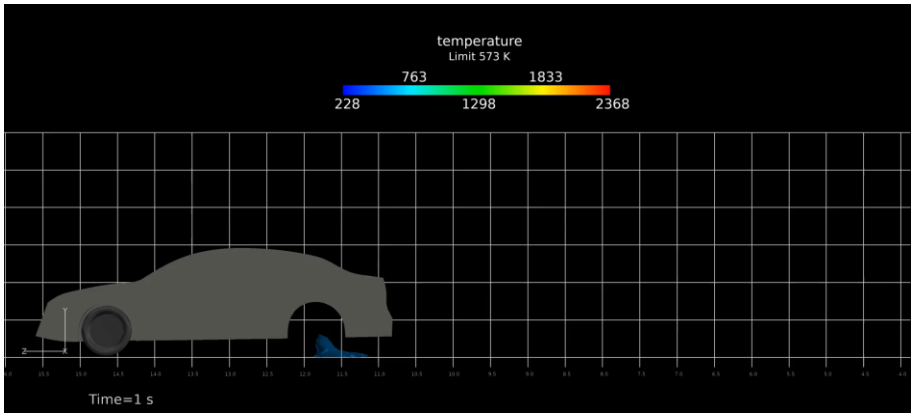
Effect of TPRD angle

D=0.5mm, 10 ACH - Damage to ventilation system

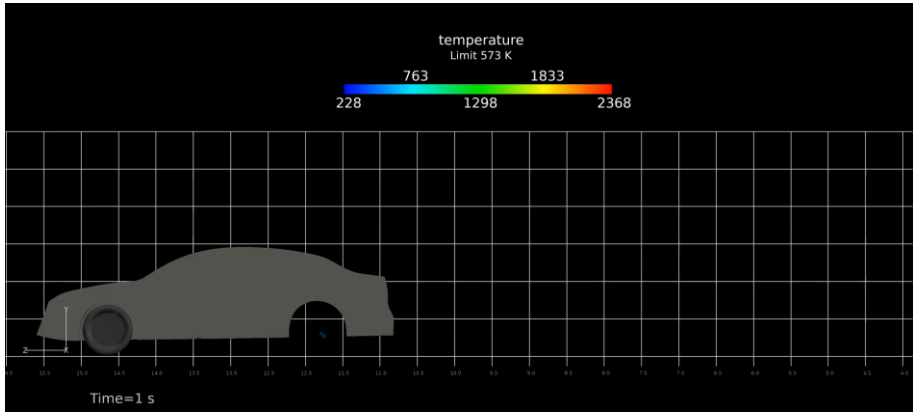
0° angle



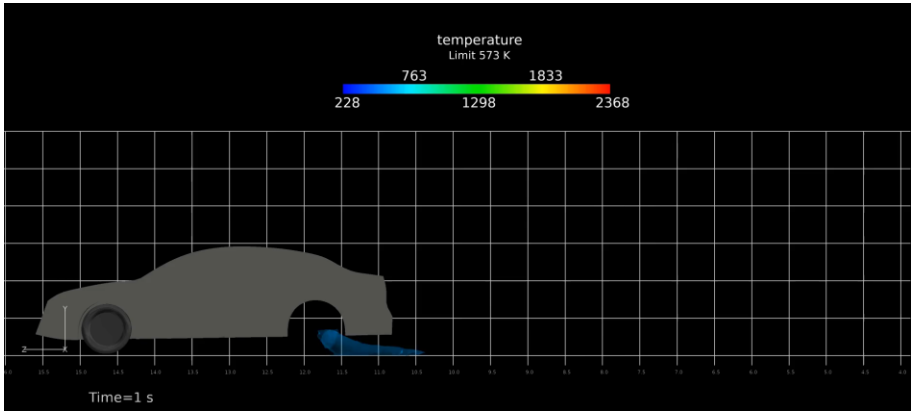
30° angle



45° angle



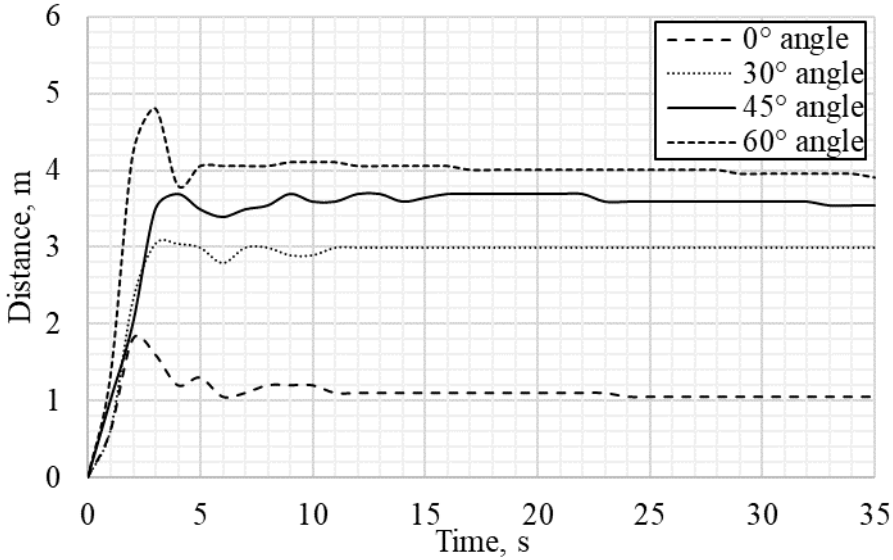
60° angle

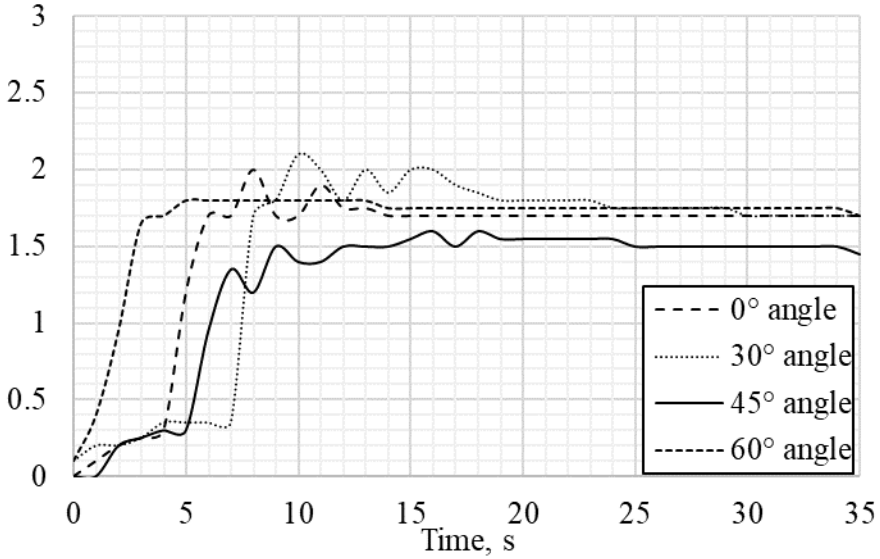


Effect of TPRD angle

D=0.5mm, 10 ACH - Damage to ventilation system

Maximum horizontal distance from the rear of a vehicle and maximum height reached by cloud with T≥300°C.





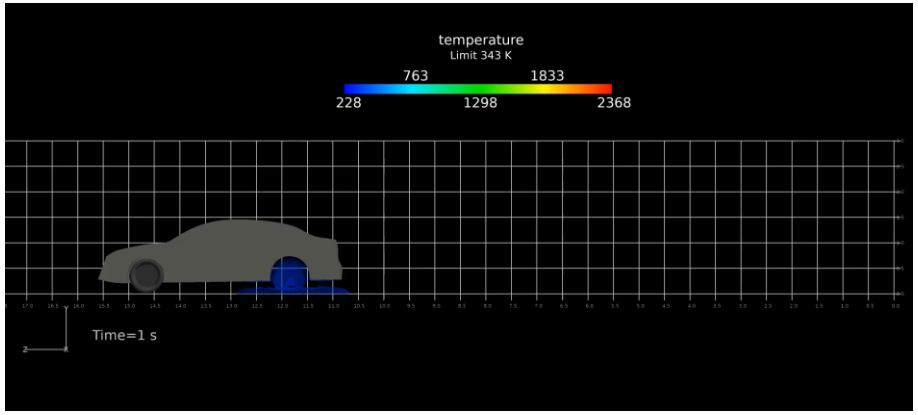
In all cases the damage level is not reached at the ceiling of 3 m.

- 0° angle: damage level is reached at a max height of 2 m, even if for a short time. However, the hot combustion products with temperature corresponding to fatality harm criteria envelop the vehicle and may prevent escape of the occupants.
- 30° angle: damage level is reached at a max height of 2.1 m, even if for a short time.
- 45° and 60° angle: damage level is reached at heights < 2 m.

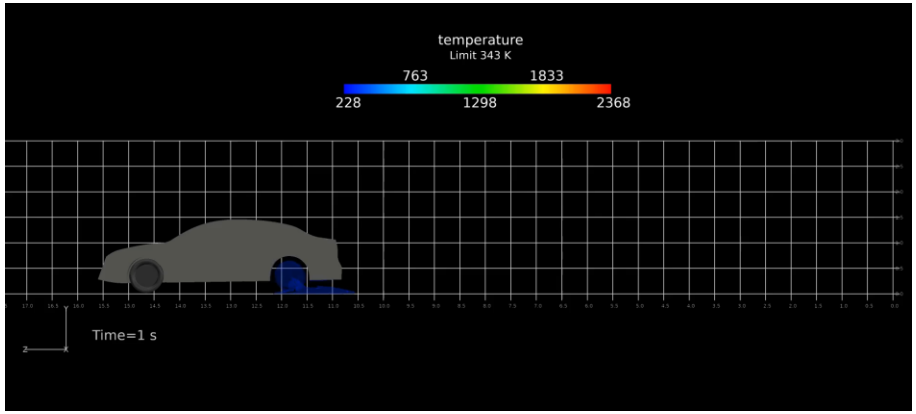
Effect of TPRD inclination

D=0.5mm, 10 ACH – Harm to people

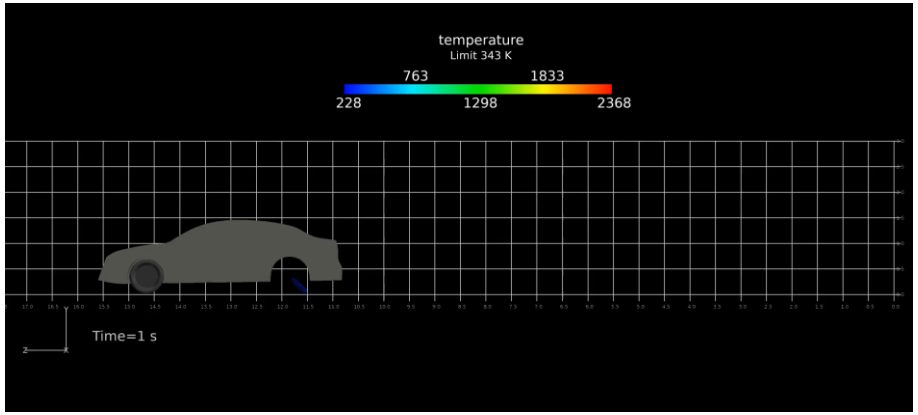
0° angle



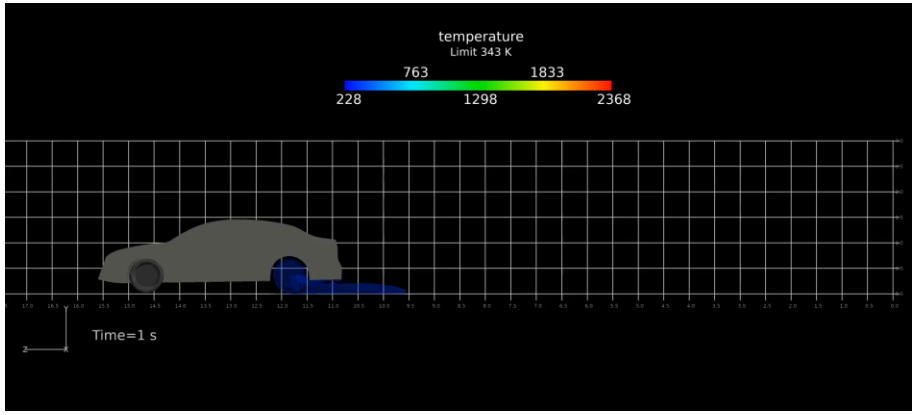
30° angle



45° angle



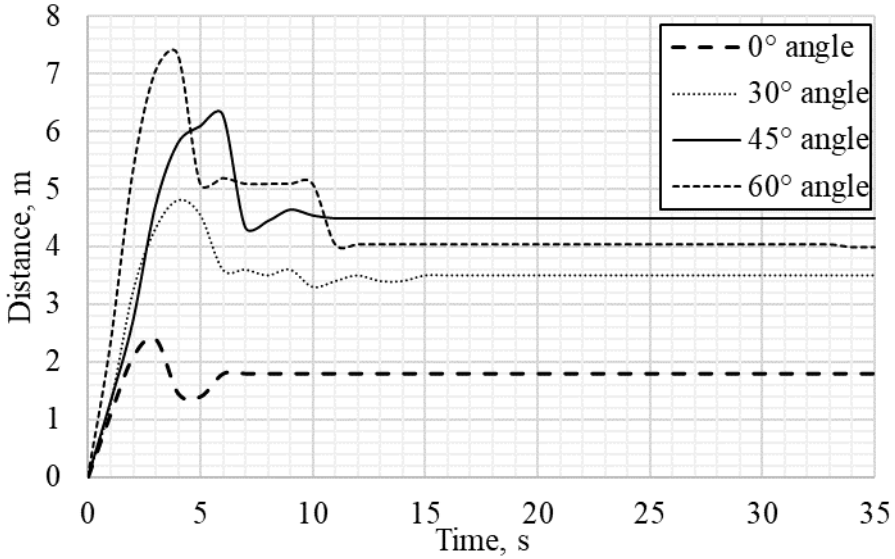
60° angle



Effect of TPRD angle

D=0.5mm, 10 ACH – Harm to people

Maximum horizontal distance from the rear of a vehicle for a height within 0-2 m for the hot combustion products cloud with T≥70°C.

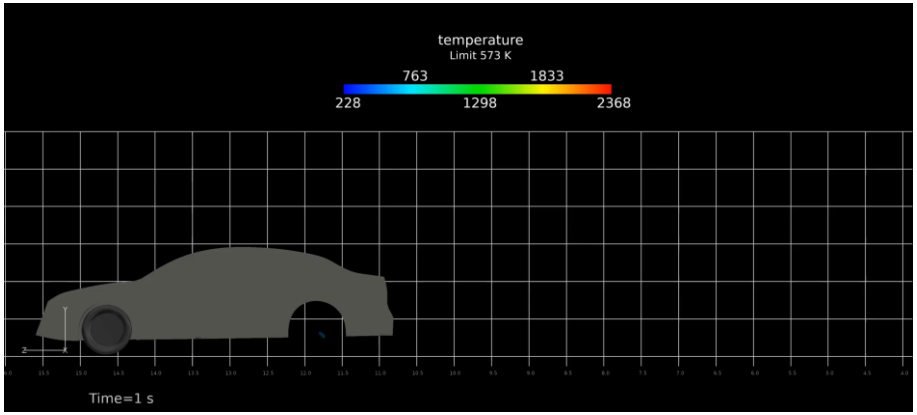


- 0° angle: No-harm distance is the lowest. However, the hot combustion products surround the vehicle, reaching the fatality harm level too, and may prevent escape of the occupants.
- 30° angle: No-harm distance is lower than 5 m.
- 45° angle presents no-harm distance of 6.2 m, which is lower than distance for 60° angle.
- Combining the conclusions reached for damage and harm criteria, 45° angle represents the best choice.

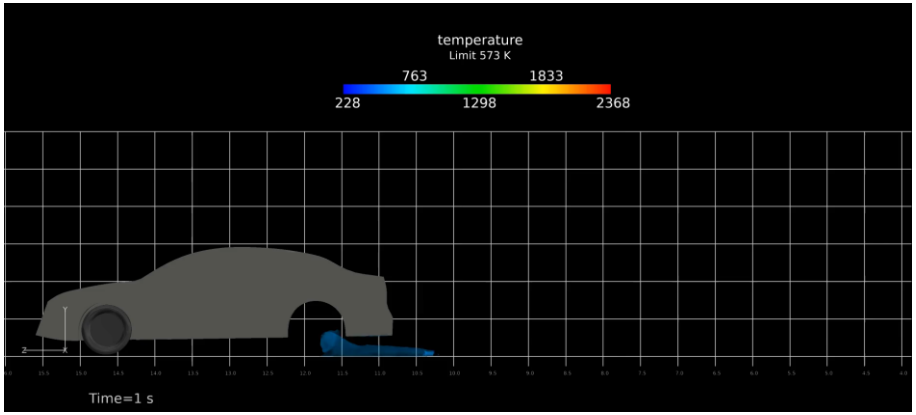
Effect of TPRD size

45° angle, 10 ACH - Damage to ventilation system

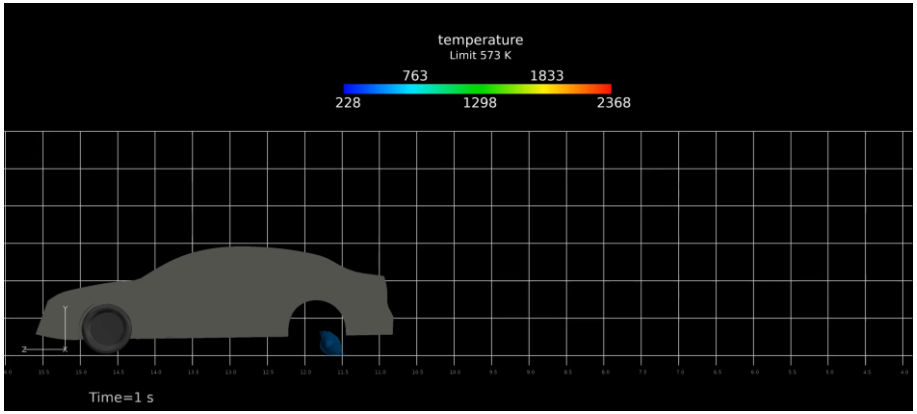
0.5 mm



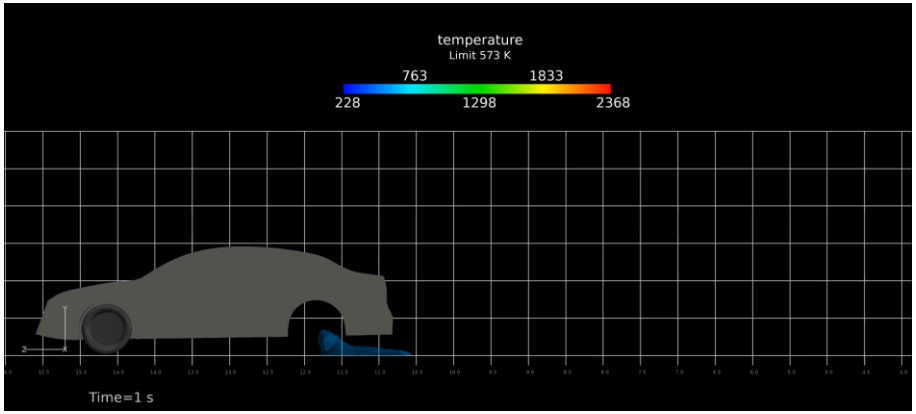
0.6 mm



0.75 mm

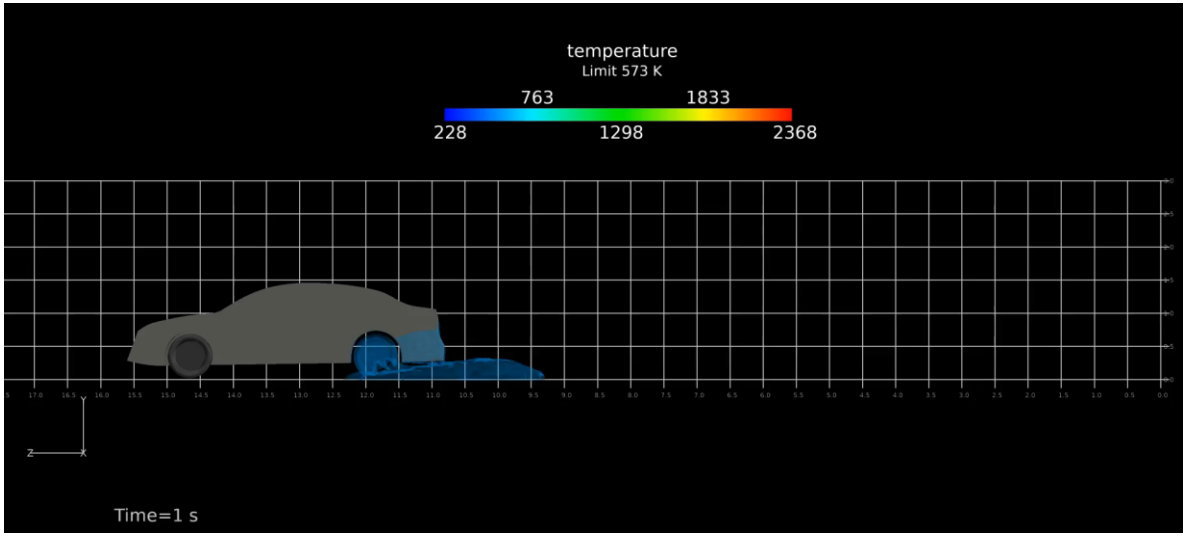


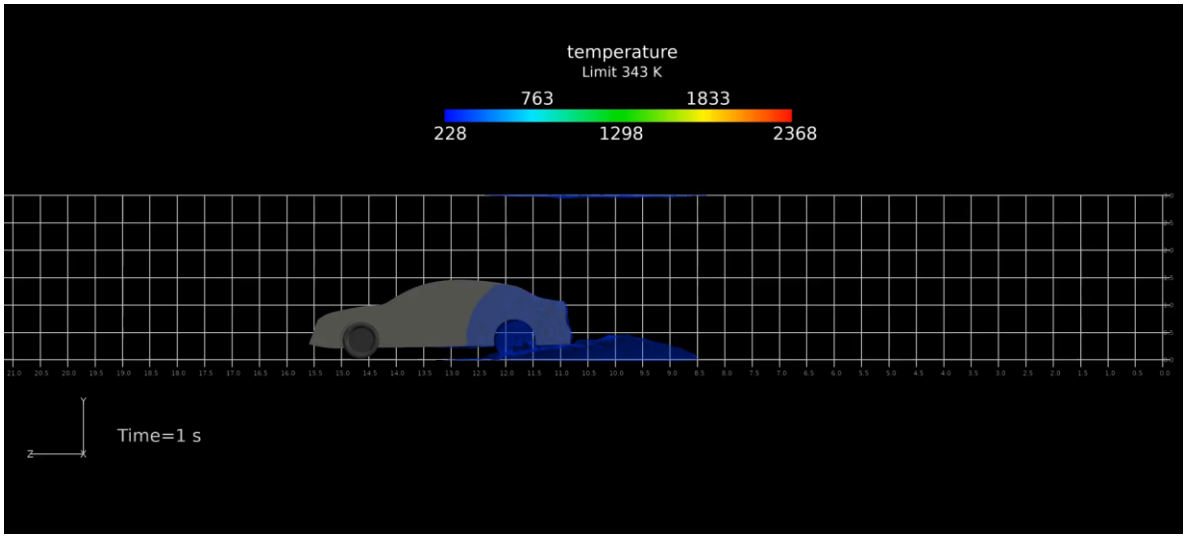
1 mm



Effect of TPRD size

D=2 mm, 45° angle, 10 ACH

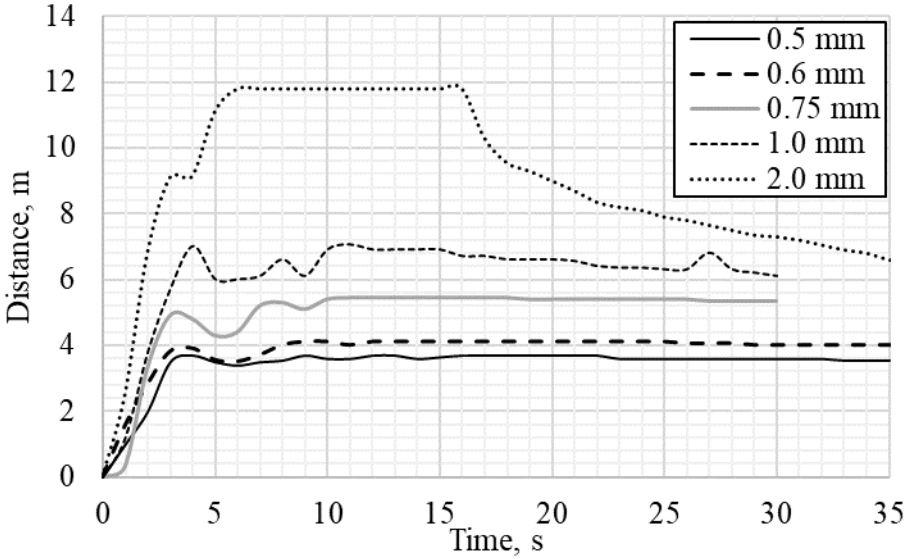


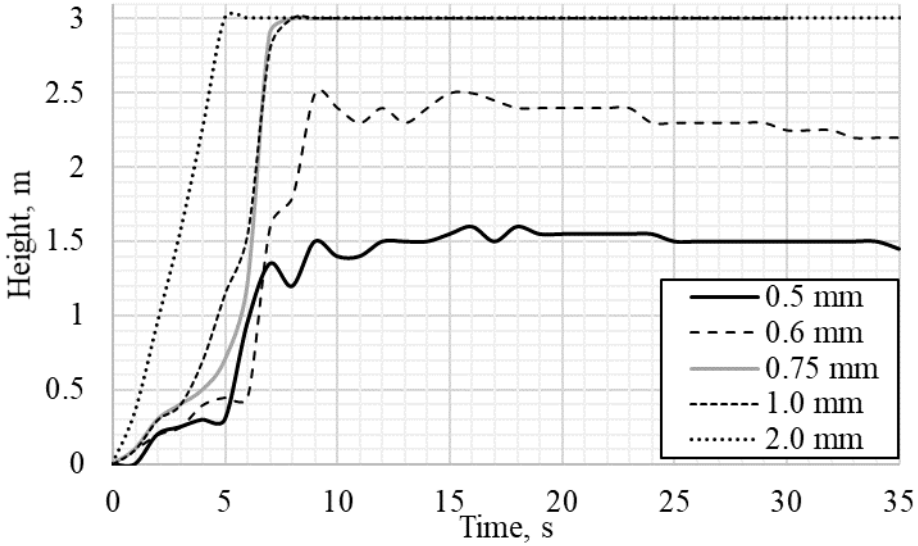


Effect of TPRD size

45° angle, 10 ACH - Damage to ventilation system

Maximum horizontal distance from the rear of a vehicle and maximum height reached by cloud with T≥300°C.



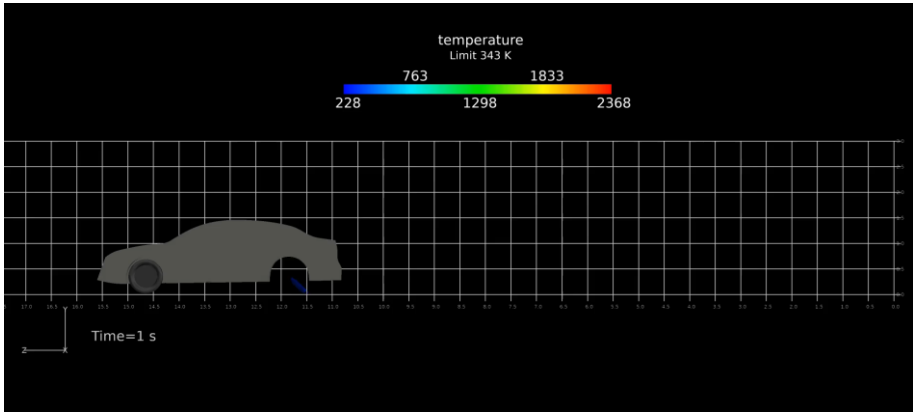


- TPRD ∅0.5 mm: damage level is not reached under the ceiling. T=300°C is reached at max 1.6 m height.
- TPRD ∅0.6 mm: damage level is not reached under the ceiling for a car park height of 3 m. However, T=300°C is reached at 2.5 m height, which could undermine safety for car parks with height 2.1 m..
- TPRD ∅0.75-1.0 mm: damage level under the ceiling is reached within 8 s.

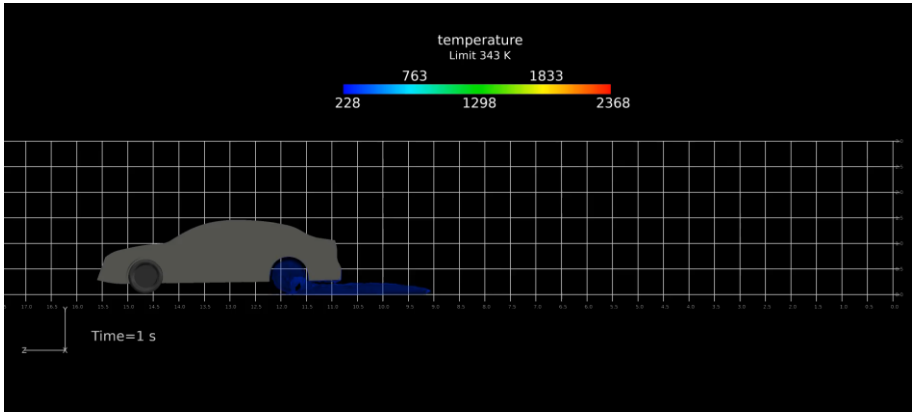
Effect of TPRD size

45° angle, 10 ACH – Harm to people

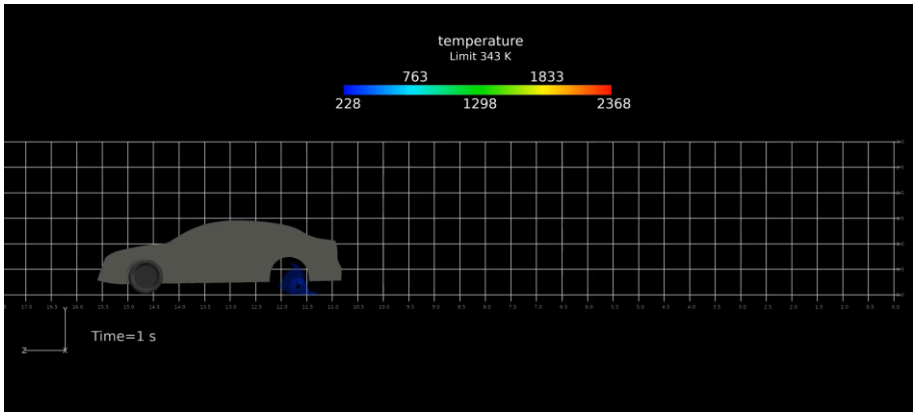
0.5 mm



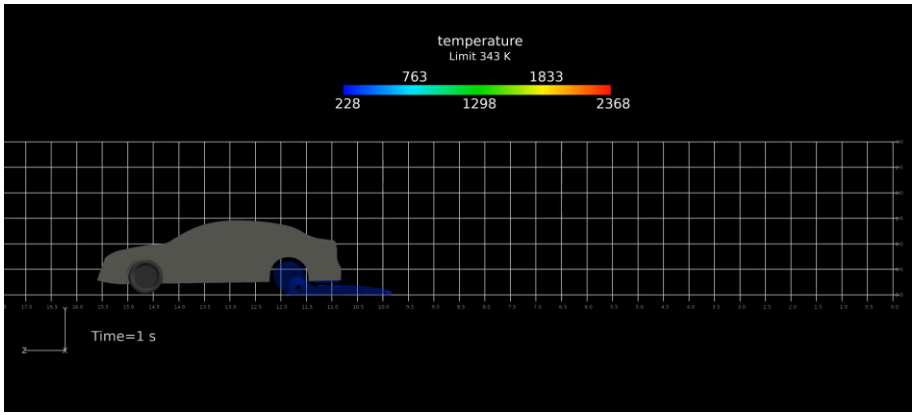
0.6 mm



0.75 mm



1 mm



Conclusions

- Only CFD model could be considered as reliable tool for design of mechanical ventilation in underground parking (especially to account for unsteady phenomena due to blowdown and large volume of parking).
- The ventilation does not affect the decay of concentration and hot combustion products distribution and the associated hazard distances for small releases from 0.5 and 0.75 mm TPRDs
- Release downward is subject for formation of flammable layer at the ceiling and problems with evacuation at considered parking hights even for small TPRDs of 0.5 mm
- **TPRD release direction** at the angle A=45° deem to be the overall best safety solution for both ignited and unignited jets. The ceiling height does not affect the decay as long as concentration reduces below LFL formation of flammable layer is excluded
- Presence of wall behind, results in formation of flammable mixture regardless of TPRD diameter.
- Releases from TPRD larger than Ø0.75 mm have potential to create flammable layer under ceiling
- It should be remarked that the used damage criteria is conservative and that jet fires will have much shorter duration compared to the resistance time (at least 60 minutes) and a general car fire.

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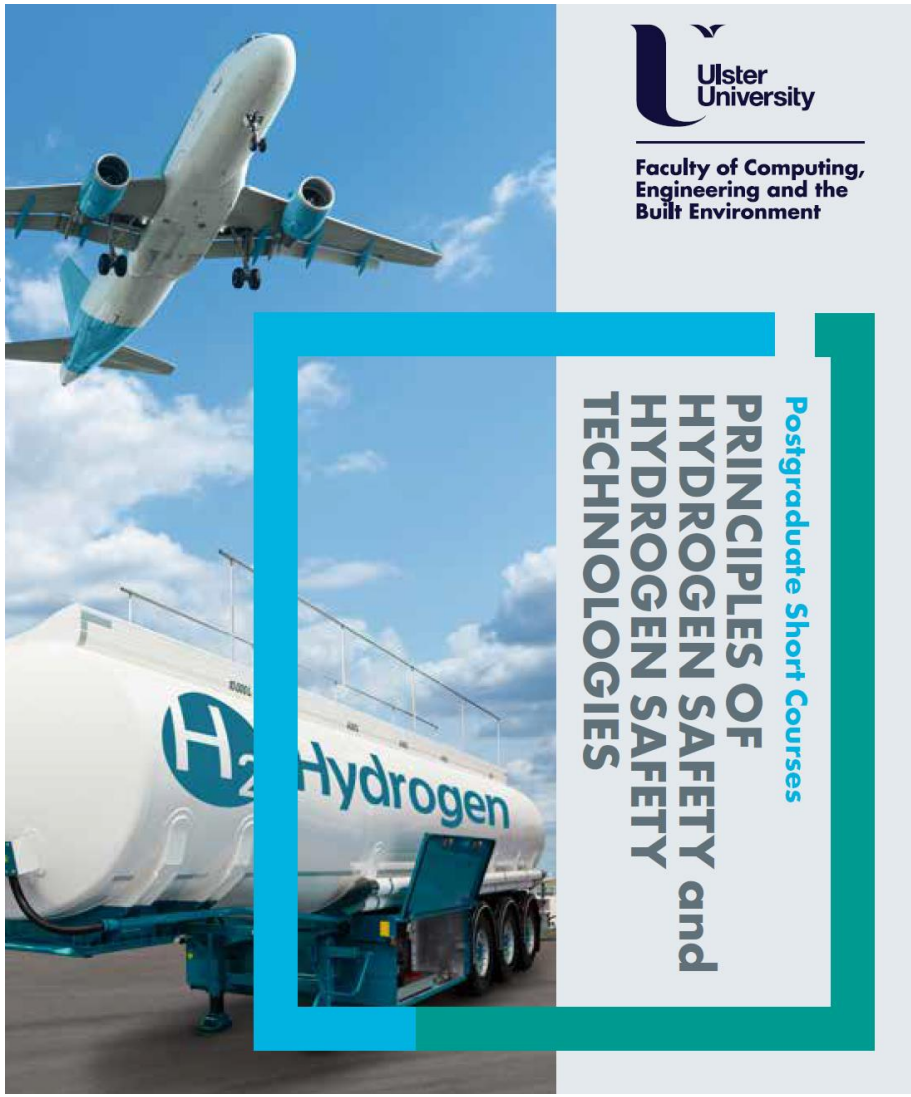

Get in touch

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