Article no. 8

THE CIVIL ENGINEERING JOURNAL 8-2015

LARGE – SCALE FIRE TEST WITH A PASSENGER CAR IN AN OPEN AREA

Otto Dvořák[1], *František Wald*[1]

1. *University Centre for Energy Efficient Buildings of Czech Technical University in Prague, s. Třinecká 1024, 273 43 Buštěhrad, Czech Republic, otto.dvorak@uceeb.cvut.cz*

ABSTRACT

This article briefly presents the results of measurements of the temperature field, the heat flux density field and chemical analyses of sampled smoke for the content of selected toxicants during large-scale fire test carried out with a passenger car in an open area. The measured values are compared with the values calculated from numerical modelling using the FDS computer software. The severity of the problems is documented by selected data from the statistics of fires of cars in the Czech Republic in the period of 2004-2013 and by the devastating effects of fires on their crew and its surroundings.

KEYWORDS

Fire test, passenger car, open area, measurement, temperature, heat flux density, chemical analyses of fire effluents, computer modelling

INTRODUCTION

Car fires represent a serious danger for their crews and for the environment, which can be documented by the statistics of fatalities (F) and injured (I) persons and the direct damage caused by the fires in the Czech Republic and in the world [1], see also chapt. 2. Whilst motor vehicles passed the homologation (approval of technical competence in road traffic) as the type and subsequently operate the STK (State Technical Inspection) controls [2], then can start a fire consequently spreading to the whole vehicle i. e. into the interior due to impact in a crash or technical failures or human error. The highest fire load in the vehicle no longer represents only the fuel in the fuel tank, but also a relatively large weight / proportion of combustible plastics, upholstery materials and coatings in construction including electrical wiring insulation that do not pass in the M1 type passenger cars mandatory laboratory tests for flammability, ignitability , the rate of surface flame spread. Nor flammable materials in the type M3 vehicles (buses) are tested for toxicity of combustion products [3]. Car parking in the urban area, close to residential buildings, garages and in columns may represent a potential hazard.

The most objective assessment of the fire hazard of the motor vehicle type is a full-scale fire test simulating a fire under defined conditions and connected with measuring the heat release rate, the heat fluxes, the temperature field, the amount of smoke released and the concentration of pollutants contained therein / toxicants incl. rate of spread of fire until a flash-over rise. There is already a number of published results of the tests carried out with the aim of their use in the construction of motor vehicles and the creation/specification of standards and regulations specifying technical vehicles´ parameters and their testing [1] - [6].

This paper briefly describes:

1 / fires and motor vehicles´ accidents in the Czech Republic,

2 / the devastating effects of fire on the occupants of vehicles and the surroundings,

3 / results of full - scale fire tests of a passenger car (next the fire test - FT) realized on 8th October 2014 in the area UCEEB - Czech Technical University, Buštěhrad.

Students of the Faculty of Transport and Civil Engineering Faculty participated as well as the staff of the Fire Technical Institute in Prague.

The aim of the FT was in a passenger car (PC) (sample non-approved vehicle) as a teaching aid):

a/ measuring in the open air, under defined conditions, thermal effects of fire (temperature field, heat flux density) emissions from smoke fire sampled for chemical analysis for the content of selected toxicants/pollutants (CO, CO_2, SO_2, NO_x, HCN, HX (hydrogen halides)) and the meteo-situation (speed and direction of air flow, temperature and barometric air pressure) in the vicinity of the vehicle before and after FT, the optical smoke density and the heat release rate,

b / documenting FT course photographically with the video and the thermal imaging cameras,

c / simulating FT with the computer and comparing the calculated data with the measured ones.

1. STATISTICS OF FIRES OF PASSENGER MOTOR VEHICLES (PMV) IN THE CR

Danger of the PMV´ fires and accidents in the Czech Republic can be documented by the data in Fig. 1 - 5.

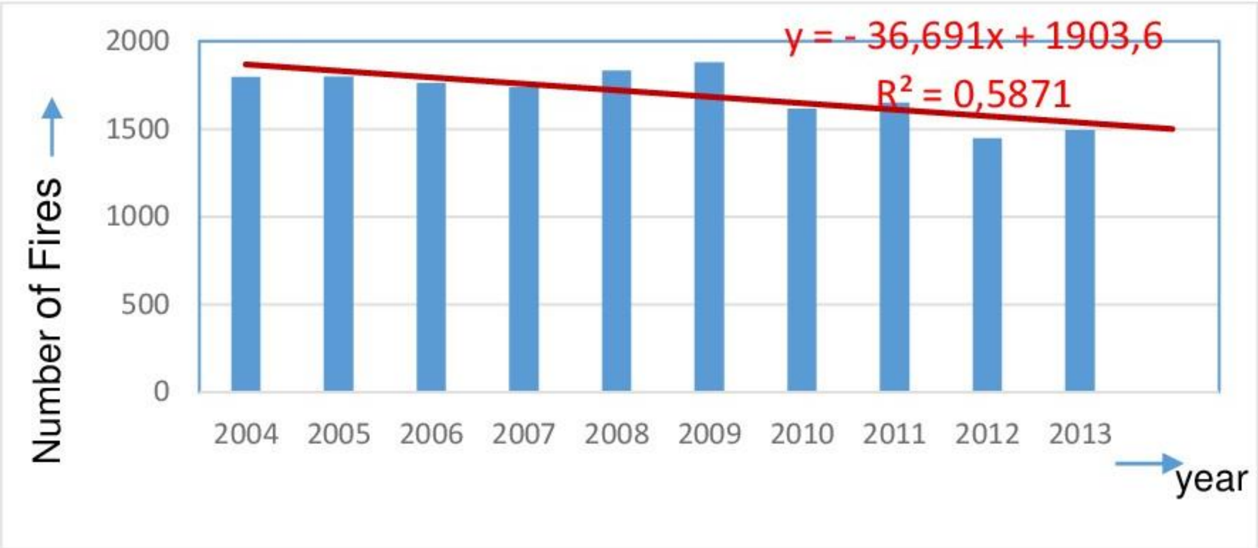

Fig. 1. Total annual counting rate of PMV´ fires in the Czech Republic in the period of 2004-2013 [7]

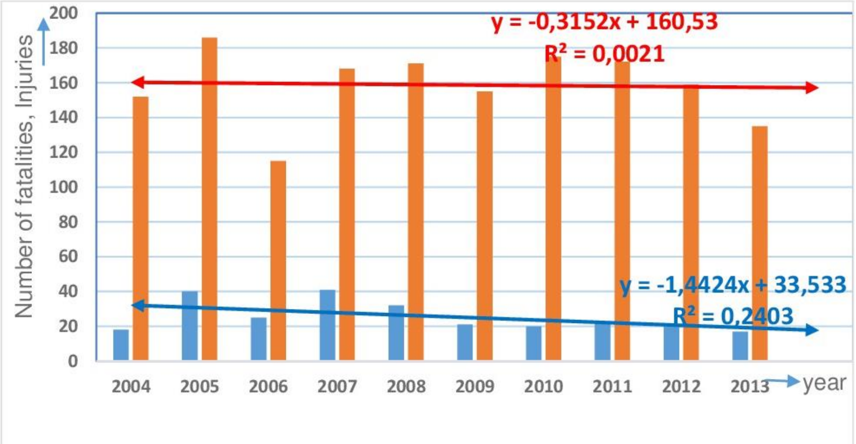

Fig. 2. Total annual counting rate of civilian fire deaths (D) and injuries (I) caused by PMV´ fires in the Czech Republic for the period of 004-2013 [7]

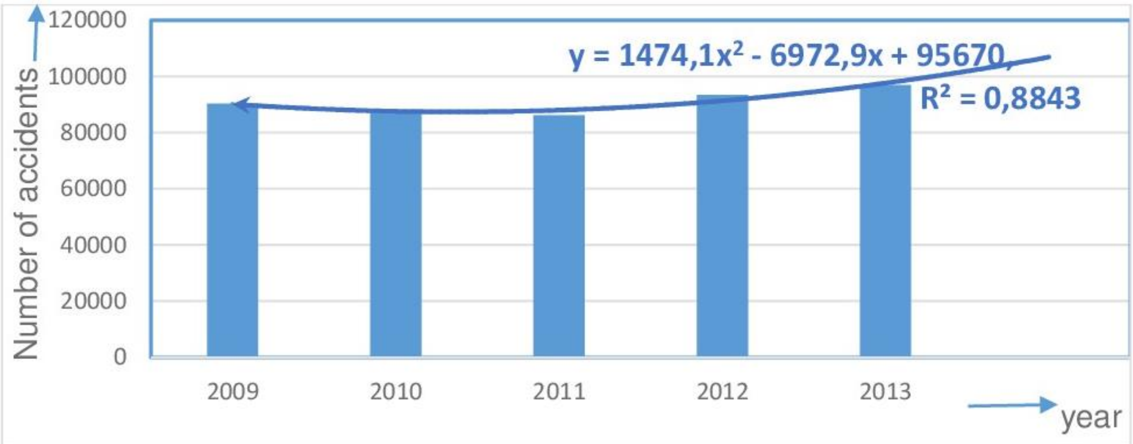

Fig. 3. Annual overall rate of counts of accidents of PMV´ without a trailer and with a trailer (total) in the Czech Republic in the period of 2009-2013 investigated by the Police of the Czech republic [8]

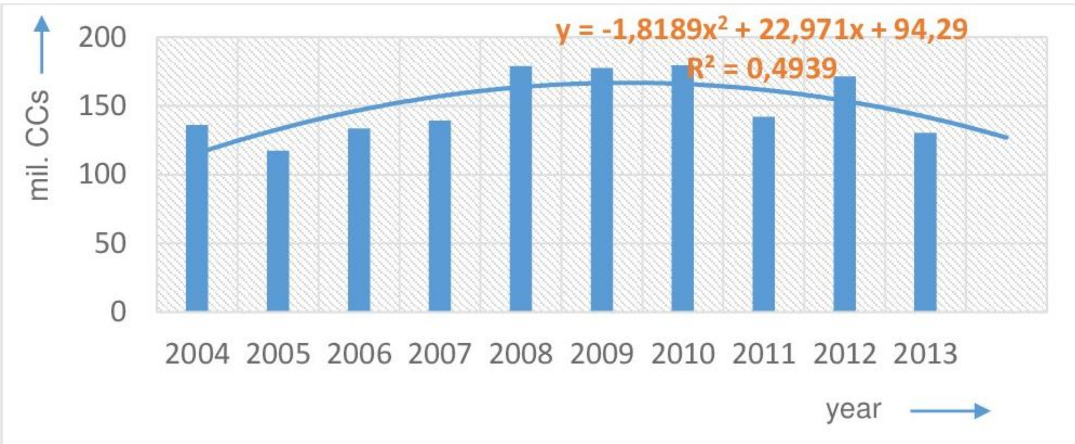

Fig. 4. Direct damage caused by PMV´ fires in the Czech Republic in the period of 2004-2013 [7]

According to the EU data the share of domestic passenger transit increased from 73.8% in the year 2002 to 74.8% in the year 2012 in units pkm (passenger – kilometres) [8] In the Czech Republic.

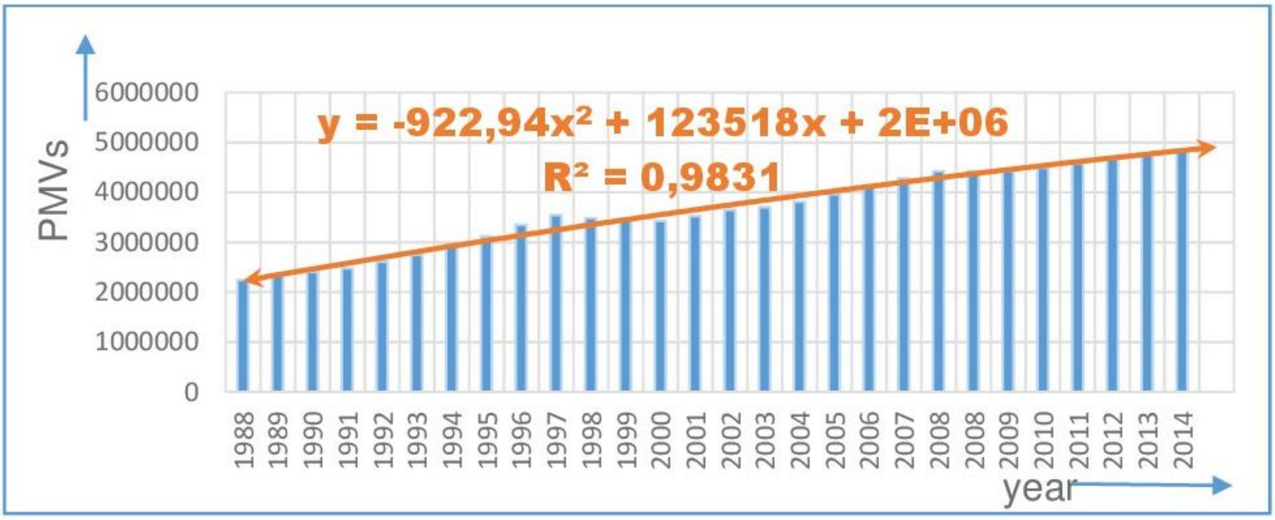

Fig. 5. Number of PMVs registered in the Czech Republic from 1998 to 6/2014 [8]

2. THE DEVASTING EFFECTS OF FIRES ON THE VEHICLE´S OCCUPANTS AND SURROUNDINGS

Potential disruptive effects of PMV´ fires on their crew and surrounding area can be divided into the following factors a/ to f /:

a / intoxication by fire effluents

The harmful health effects of substances occurring in fire effluents are characterized in the Tab. 1.

Tab. 1. PEL and STEL Limit values of selected gases and vapours [10]

Substance	**PEL** (mg/m^3)	**STEL** (mg/m^3)
CO	30	150
CO_2	9 000	45 000
NO_x	10	20
SO_2	5	10
HCl, HF	8, 1.5	15, 2.5
HCN	3	10
HCHO (formaldehyde)	0.5	1
CH_3CHO (acetaldehyde)	50	100
CH_3CHCN (acrylonitrile)	2	6
C_2H_{12} (benzo(a)pyrene)	0.005	0.025

Explanations: PEL = Permissible Exposure Limit, STEL = Short Term Exposure Limit

DOI 10.14311/CEJ.2015.02.0008

b/ heat and open flames and hot smoke effects

Tab. 2. Physiopathological effects of irradiance Q by radiation on human skin [9]

Q (kW/m^2)	**Effects**
1	As with sun radiation in the tropical zone
2.5	30 min tolerability
5	Blisters in 30 s
8	The onset of spontaneous ignition of wood
9.5	Achieving the pain threshold in 6 s
90	Immediate destruction of the skin

c / visibility loss after smoke´s filling the interior of vehicle cabin

The visibility in smoke is expressed in meters (m), the smoke extinction coefficient (optical density per meter) in (m^{-1}).

The smoke opacity (O) means the rate of extinction of the light beam passed through a layer of smoke.

The optical density of the smoke (D) means a common logarithm of opacity.

In a smoke-filled space with D = 0.5 the rate of escape decreases to about 0.3 m/s.

d/ suffocation due to lack of the oxygen in the affected cabin

Potential devastating effects in terms of lower oxygen content in the air are illustrated in Tab. 3.

Tab. 3. Physiopathological effect of the lower oxygen content in the air [11]

[O_2](% v/v)	**Effect**
17	Reduction of the night vision, acceleration of the breathing and the heart rate
16	Dizziness
15	Loss of the judgement and the attention
12	Loss of the coordination, loss of the consciousness, irreversible brain damage
10	Loss of mobility, vomiting
6	Irregular breathing, convulsive movements, death in (5-8) min.

3. FIRE TEST

FT was implemented in the passenger car as a sample non-approved vehicle - teaching aid (hereafter it is referred to as "car") with dimensions as shown in Fig. 6 with technical specifications mentioned below.

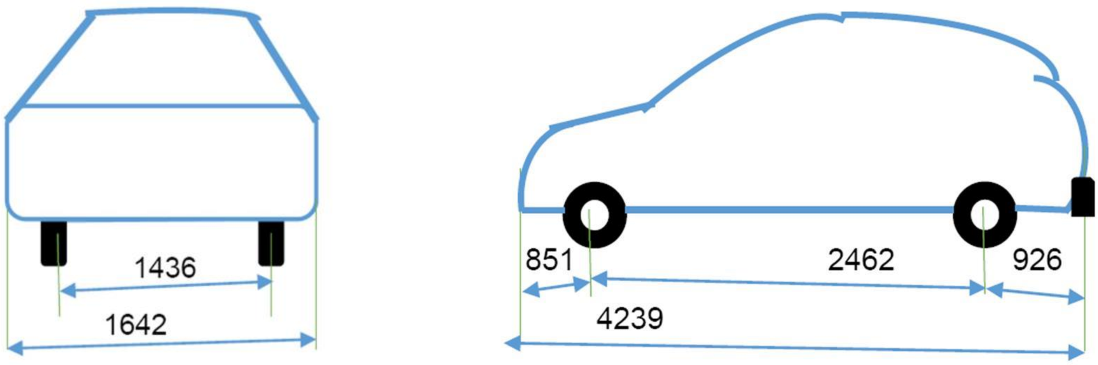

Fig. 6. External car dimensions [1]

Technical specifications: - Type of automobile body: COMBI, five-door, - Engine location: Front, - Engine type: diesel TDI (direct injection), - Engine capacity: 1199 cm^3, - Engine power: 55 kW, - Number of cylinders: 3, - Drive axle: front, - Transmission: five-speed with manual transmission, - Curb weight: 1095 kg.

The scene of the fire was located in the vicinity of the UCEEB campus with two L-shaped screens to protect from the prevailing SW wind and away from a local road and the closest buildings, see Fig. 5. The automobile was placed in a catch basin to prevent fuel penetration into reinforced ground using a crane on 3 pillars (steel pipes) with bilateral end plates; pillars were interconnected with steel angles.

The fire of the automobile was simulated by a fuel leakage from the fuel tank and ignition of vapours from the exhaust under the car as follows:
- 15 l spilled AP fuel (Automobile petrol) was placed in an iron tray (90 x 90 x 15) cm under the vehicle before the rear wheels,
- AP in the tray was ignited with a flaming torch by a fireman in the protective clothing.

The UCEEB meteo - station measured before and during the test:
- temperature at heights of 5 cm (grey triangular points) and 2 m (blue plus points) above the ground and humidity of air (blue connector) with positions relative to the scene of the fire according to Fig. 7 and with the results in the Fig. 8,
- wind speed and direction near the fire place with the results in the Fig. 9.

DOI 10.14311/CEJ.2015.02.0008

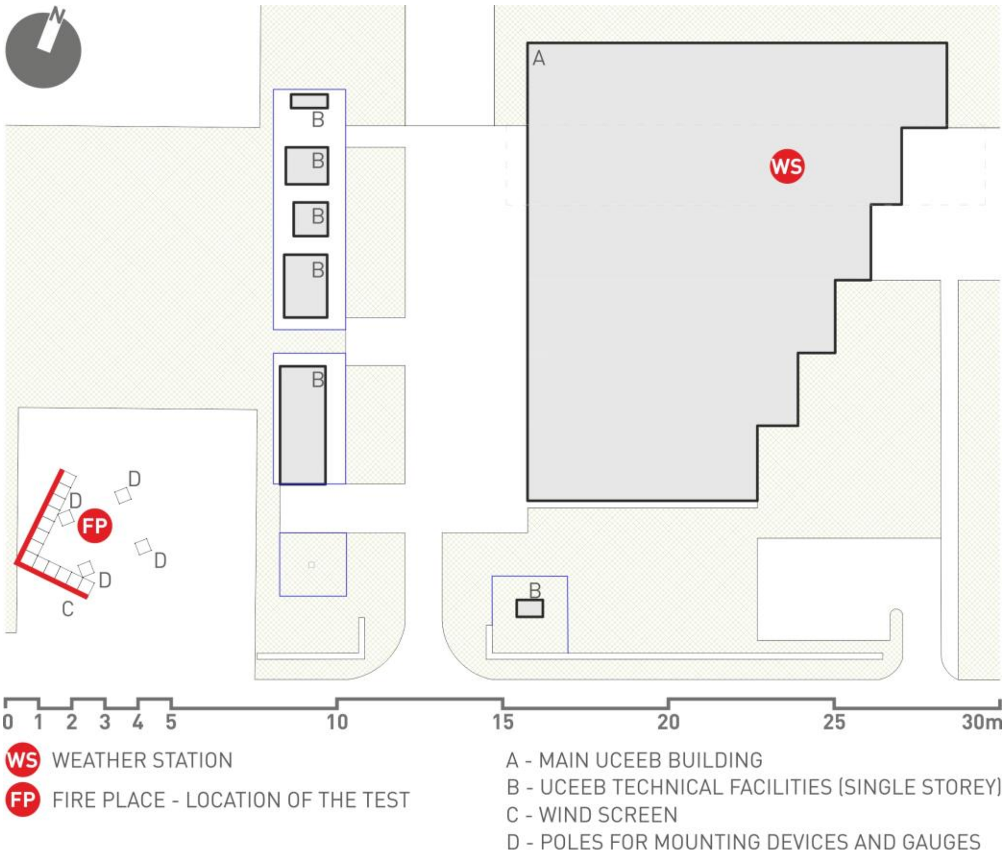

Fig. 7. Sketch map showing positions of the Weather Station and the PMV during the fire test [1]

Weather Station, Fire place - location of the test, the Main UCEEB building, UCEEB technical background (single), wind screen, poles for mounting devices and gauges

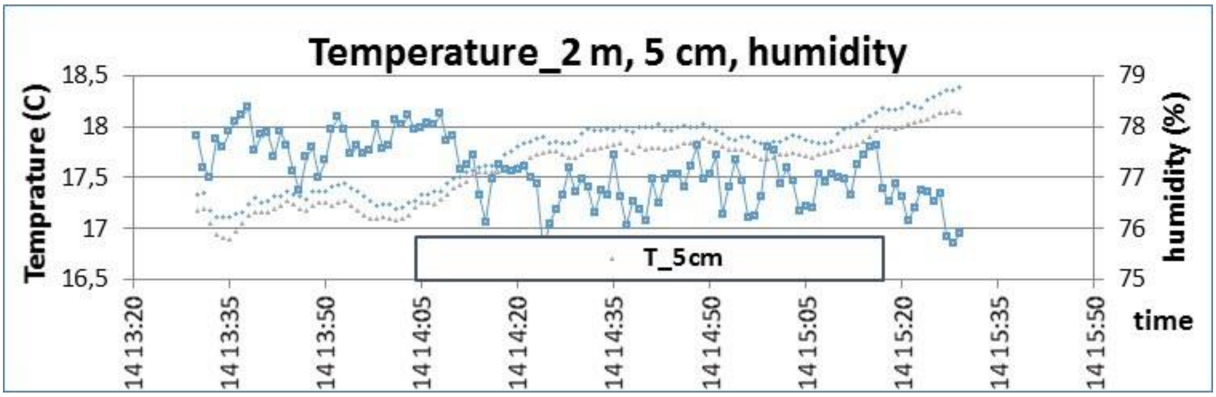

Fig. 8. Graph of temperature and humidity in the air during FT[1]

DOI 10.14311/CEJ.2015.02.0008

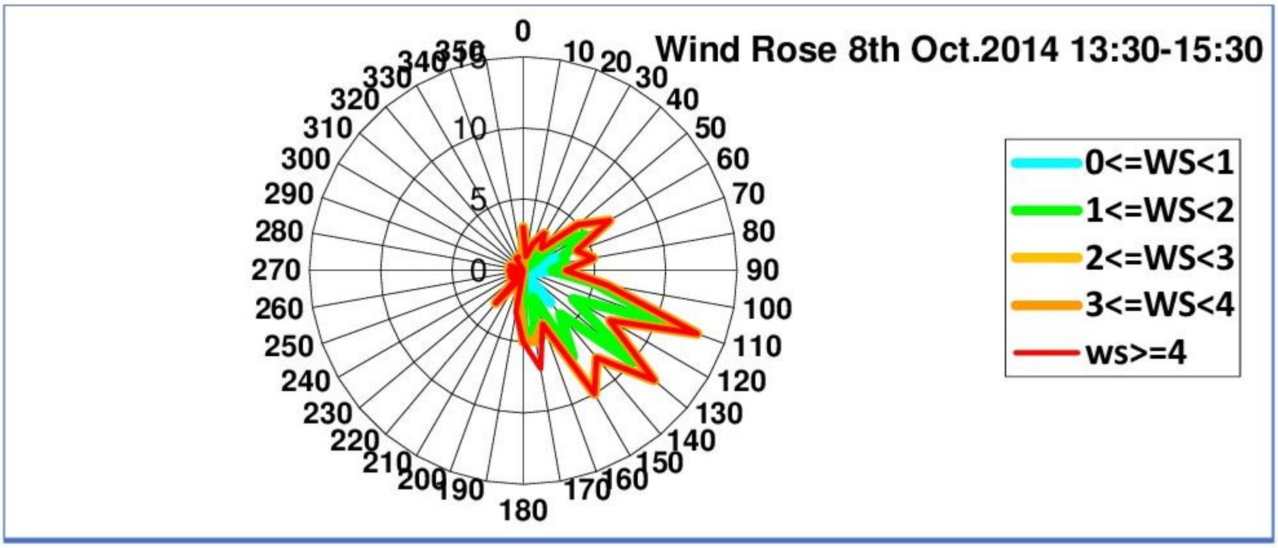

Fig. 9. Graph of the progress of the wind speed and its direction during FT [1]

The results of the wind speed measuring during the test with the anemometer EVA 935 - TH5 in the position of about 1 m from the inside corner of the L- leeward wall toward the car and at a height of approximately 1.5 m above the ground: v = <0.01 to 1.00> m / s.

3.1 Measuring the temperature field and the irradiance

The temperature field was measured inside and outside the car interior during the fire test, the irradiance outside the car only, in both cases at defined positions (x, y, z).

The temperature was measured in 20 positions outside the vehicle and the irradiance in the following four positions according to the Fig. 10. Temperatures (° C) were read using the K type thermocouples (TCs) in the positions indicated by symbols T1 to T20, from which:

- - 8 items were at the height of 2 m (positions T1 to T8)
- - 8 items were at the height of 3 m (T11 to T18 positions)
- - 4 items were placed directly above the automobile

Thermocouples (TCs) were fixed with their hot ends on cords stretched between the towers in the desired positions. By means of compensating cables they have been connected with the PC and the logger that were placed behind the screen. **Irradiances** in kW/m2 were scanned with 4 radiometers of the type SBG 01-100 Heat Flux Sensor in positions R1 to R4 and at heights of 1.5 m, see Fig. 10. The bodies of radiometers (inlets and outlets of cooling water, electricity conductors) were placed on iron racks and directed with measuring dots to the car. Data radiometers lines were pulled behind a screen to the logger ALMEMO 5690-2 and PC.

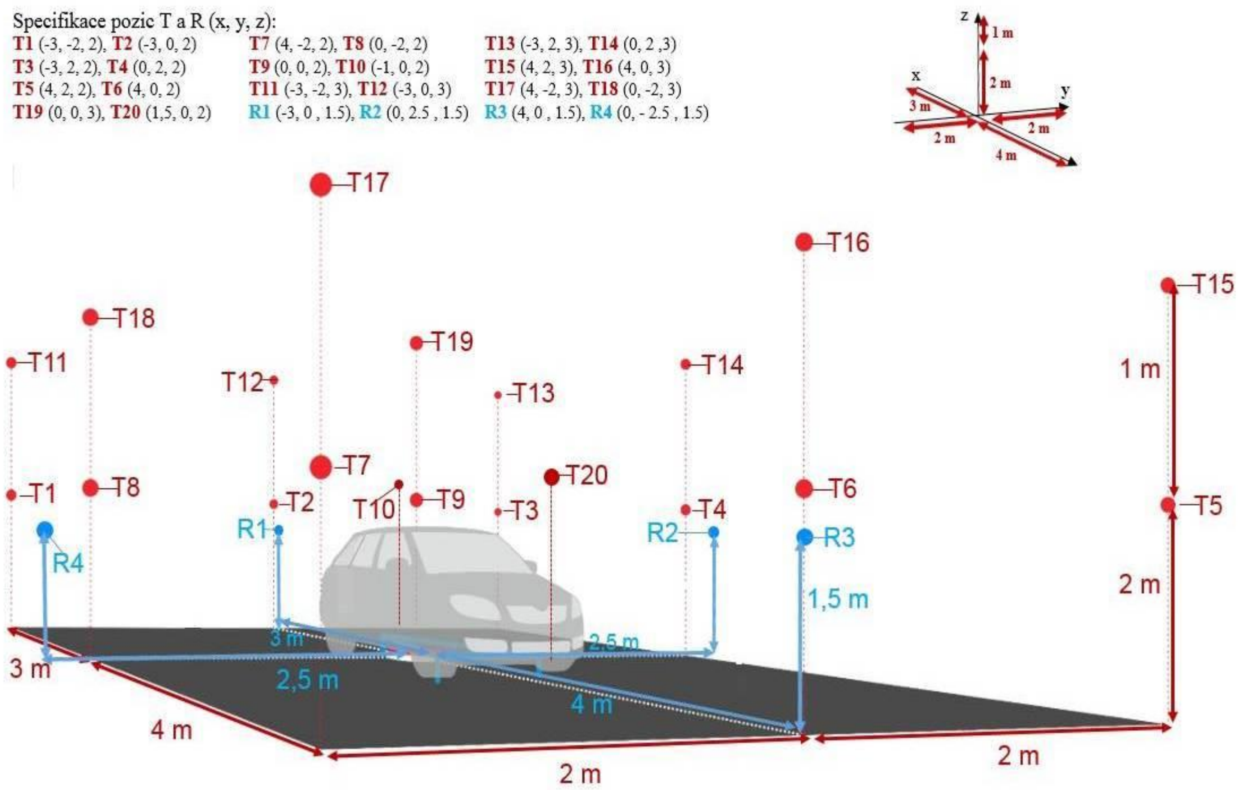

Fig. 10. The perspective view of the positions of thermocouples (T1 – T20) and radiometers (R1 - R4) and their coordinates (x, y, z) outside the test vehicle during FT. [1]

Graphs are developed from the results of temperature and flux density measurements during the time assay [1]. For this article the maximum measured values are evaluated and listed in the following Tab. 4 and 5 with the estimation of their expanded uncertainty U (k = 2) = ± 1.8°C

Tab. 4. The maximum measured temperature values T_{max} outside the burning automobile with the times τ of their achievement [1]

Sensor / quantity	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
T_{max} (°C)	58,6	370,2	292,6	1066,7	91,7	61,5	44,0	468,3	582,1	883,8
τ (s)	1314	618	609	225	378	426	429	102	675	717
Sensor (TC)	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
T_{max} (°C)	56,8	237,4	203,2	664,6	83,1	60,6	37,0	271,9	580,0	934,3
τ (s)	513	621	438	222	372	426	429	99	480	540

The temperature field (° C) was measured in 8 positions inside the vehicle interior and were scanned using a type K thermocouples (TCs) in the positions indicated by the symbols T1 to T8 and with the position specifications (x, y, z) in Fig. 11.

Tab. 5. The maximum measured irradiances Q_{max} outside the automobile at the time τ of their achievement and with the estimated expanded uncertainty U_Q (k=2) [1]

Sensor / quantity	R_1	R_2	R_3	R_4
Q_{max} (kW/m^2)	30,14	85,83	11,61	67,53
U_Q (kW/m^2)	± 1,96	± 5,58	± 0,75	± 4,39
τ (s)	183	156	186	117

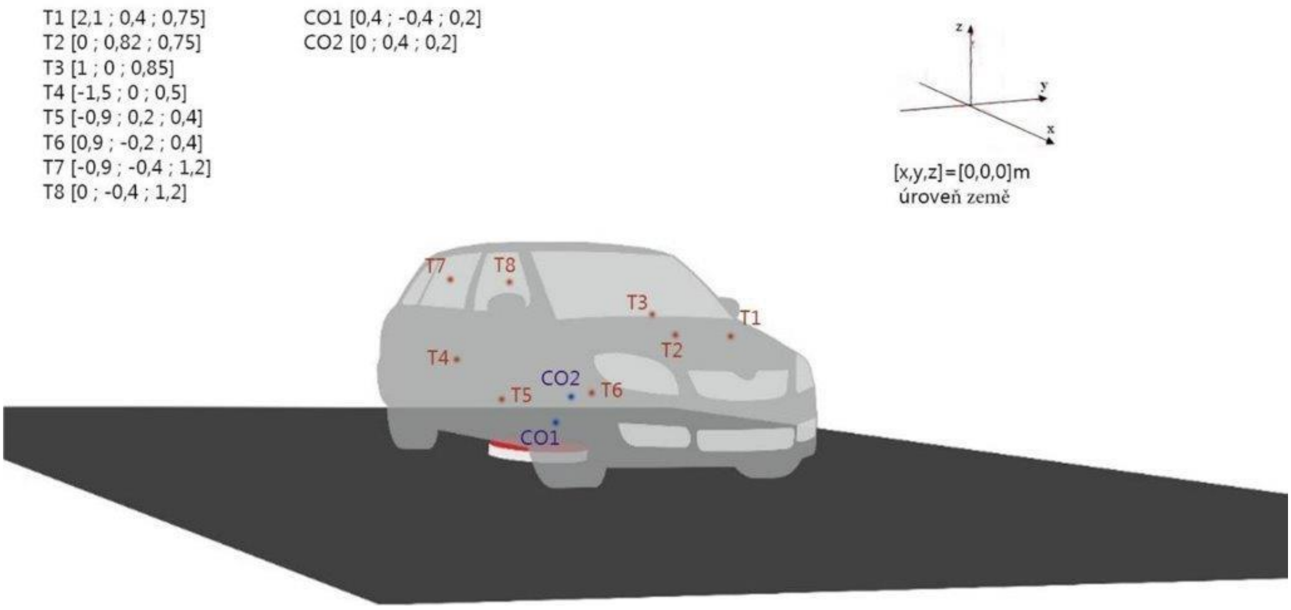

Fig. 11. The perspective view of the thermocouples positions (T1 - T8) and the CO detectors (CO1, CO2) and their coordinates (x, y, z) inside the test vehicle during the FT [1]

Description of TCs location:

T1 – on the air filter in the engine compartment,
T2 – on the outside door handle of the front left door,
T3 – on the inside of the windscreen,
T4 – on the reserves cover in the luggage compartment,
T5 – on the upper side of the tank,
T6 – nn the motor bulkhead in the cabin,
T7 – before the right rear headrest,
T8 – before the left front headrest,

CO1 – on the floor in the left front seat,
CO2 – on the floor behind the right front seat, see Fig. 11.
The beginning of the coordinates x = 0, y = 0, z = 0 is at the intersection of the perpendicular from the geometrical centre of the automobile to the ground.

Graphs are also prepared from the results of temperature measurements at the test time [1]. The maximum measured values are evaluated for this article, see Tab. 6 with the estimation of their expanded uncertainty U (k = 2) = ± 3.25 °C.

Tab. 6. The maximum measured temperature values Tmax on thermocouples (TCs) inside a burning automobile with times of their achievement τ_{Tmax} [1]

TČ	T_{max} (°C)	τ_{Tmax} (s)
T1	1104.8	700
T2	1264.2	690
T3	930.4	960
T4	915.1	980
T5	968.3	1050
T6	880.6	930
T7	896.9	960
T8	981.4	1060

3.2. Sampling and chemical analysis of samples taken for the content of pollutants inside the burning automobile

The fire effluents in the automobile interior were sampled using the metal probes No. 1 and No. 2 inserted through a small window of the right rear door. Compensating lines from the CO detectors were kept in a protective tube through a small window of the left rear door.
Both tubes 1 and 2 rattled in front of the rear right seat headrest. At their opposite end, at the distance of about 2 meters from the automobile, there was attached silicone tubing, about 10 m long, kept behind a protective wall and here at the measuring station they were connected: through filters and a refrigeration unit to the analyser Testo 350 L (1) with sensors measuring CO, CO2, O_2, NO, NO_2, SO_2, through the mass flowmeter GFM17 / Air (Aalborg), the needle valve, the variable-area flowmeter to sampling Supelco - ORBO tubes (2). Data collection includes the notebook with the SW "Testo Emission Easy v. 2.0".

Graphs are also prepared from the measurement results of the CO, CO_2, O_2, NO, NO_2 and SO_2 gases concentrations during the test [1]. The maximum measured values are evaluated for this article, see Tab. 7 with the estimation of their expanded uncertainty U can be seen in Tab. 8.

Tab. 7. Measured maximum concentration values of the CO, CO_2, NO, NO_2, SO_2 and O_2 gases concentrations with times τ achieved from the start of testing [1]

[O_2] (vol. %) τ (s)	[CO] (ppm) τ (s)	[NO] (ppm) τ (s)	[SO_2] (ppm) τ (s)	[NO_2] (ppm) τ (s)
0.21 365	84898 355	134 455	2150 370	0

Tab. 8. The expanded uncertainty U (k = 2) of the gas concentrations measured with the Testo 350 L analyzer [1]

Serial No.	Concentration	U = ±
1	O_2 (% v/v)	0.2 (vol. %)
2	CO (ppm)	30 (ppm)
3	CO_2 (vol. %)	0.2 (vol. %)
4	NO (ppm)	15 (ppm)
5	SO_2 (ppm)	10 (ppm)
6	NO_2(ppm)	10 (ppm)

The highest concentrations of the **CO** measured with the insulated electrochemical sensor TGS 5042 (+ data logger Compact RIO M Cro-9025, module type NI9213 and compensating cables, GG-JK-24S) in the position CO1 amounting to 5331.68 ppm at 490 s and in the CO2 position amounting to 2742,6 ppm also at 490 s have the indicative value (with respect to their specification of use).
Chromatograms were developed from the chemical analyses of fire effluents inside the vehicle interior for the content of the VOCs and the PAHs from ORBO 1, 2 and 3 tubes [1]. The found VOCs and the PAHs are listed for this article, see Tab. 9 indicating values specifying individual substances. The proportional representation of individual analyses in the smoke can be concluded from the peak areas.

Tab. 9: Overall table of main identificated VOCs a PAHs components

Substance:	RT [s]	char. weight	ORBO 1 [% area]	ORBO 2 [% area]	ORBO 3 [% area]	ORBO 4 [% area]
			5-7 (min)	**8-11** (min)	**15-18** (min)	**21-25.5** (min)
			3 l	**3 l**	**3 l**	**4.5 l**
Toluene (C_7H_8)	315	91	18.0	15.1	11.2	8.3
Ethyl Benzene (C_8H_{10})	408	106	7.1	2.4	2.7	3.6
m, p, Xylene (C_8H_{10})	416	106	1.8	6.9	1.9	4.9
Phenyl Ethine (C_8H_6)	424	102	29.4	5.5	25.3	4.8

o-Xylene (C_8H_{10})	442	106	3.1	1.2	0.8	1.1
Styrene (C_8H_8)	444	104	0.3	0.8	3.1	22.6
Benzaldehyde (C_7H_6O)	509	106	-	1.5	0.6	0.
cis-□-Methyl Styrene (C_9H_{10})	529	118	4,2	2,8	0.7	-
Benzonitrile (C_7H_5N)	533	103	0,2	11.0	19.6	6.4
Group tri alkyl Benzenes	-	120	6	2	0.3	1.4
Indane (C_9H_{10})	524	118	1.1	0.9	0.2	0.1
1-Propynyl Benzene (C_9H_8)	592	116	4.9	8.0	9.5	7.2
Indene (C9H8)	606	116	0.3	0.5	0.1	0.1
Acetophenon (C_8H_8O)	612	120	1.2	5.7	6.6	0.5
Naftalene ($C_{10}H_8$)	724	128	3.5	5.9	6.6	19.3
Methyl Naphtalenes ($C_{11}H_{10}$)	818, 832	142	0.7	2.1	2.6	2.0
Biphenyl ($C_{12}H_{10}$)	885	154	0.3	0.7	1.2	0.7

3.3 Measurement of the burning automobile weight loss to computational estimation of the heat release rate (HRR)

For the weighing need of a automobile weight loss during a fire test due to burning off flammable materials in a vehicle design CTI -CF developed and installed fireproof scales with this technical specifications:

- Weighing in 3 points - stands resting on three strain gauges (hereinafter referred to as SG) Ø = 150 mm and v = 35 mm, max. weighing capacity = 20 kN (2,000 kg) and a resolution of 100 g, - SG data cables were connected with the data logger located at the right corner of the protective screen, - SG and data cables protection from high temperatures: tiling with a mineral insulation.
Weighing began at 2:14:53 p.m and was finished with the still functional scales in 702.7 seconds with a final weight loss of 1.79 kN, ie. 179.67 kg. Acceleration in weight loss was observed after a period of about 400 s. About 111,87 kg other combustible materials in the construction and inside the vehicle burned after deducting the known quantity of the diesel fuel (DF) in the tank (about 32.8 kg) and 5 pieces of tires (about 35 kg). Information about these kinds of flammable materials, their quantity and FTCh however, failed to get from the vehicle manufacturer, therefore the calculation of HRR and the total amount of heat released was not implemented.
The expanded uncertainty U (k = 2) of the measured data with weighing is estimated in the Tab. 10.

Tab. 10. Expanded uncertainty (U) of the TS LUKAS S-35 [1]

Sensor / Range	U = ± (kN)			
	p. n. 610	p. n. 611	p. n. 612	Set of all sensors
10 kN	0,199	0,104	0,059	0,073

S. Komárníková estimated the total amount of released heat in her dissertation [10] on the basis of the estimation of flammable materials sorts and their quantities in the tested automobile.

4. PHOTO RECORDS OF THE FIRE TEST (FT) COURSE

The course of the automobile fire was captured by two video cameras and thermocameras placed against the forehead and right side of the vehicle. Records were evaluated in a table with the following data: real-time, time from ignition, event description, and the corresponding video and thermo records.

Tab. 11. Evaluation of major phenomena surrounding the automobile fire during a FT [1]

Real time	Time from ignition	Event description	Video- record No1	Video- record No2
0:00	- 5:00	Start of the experiment	00_00	00_00
5:00	0:00	Fire initiation	05_00	05_00
5:30	0:30		05_30	05_30
6:00	1:00		06_00	06_00
6:25	1:25	Burnout of rear bumper	06_25	06_25
6:30	1:30		06_30	06_30
6:48	1:48	left rear tire explosion	06_48	06_48
7:00	2:00		07_00	07_00
7:02	2:02	fuel tank burning through	07_02	07_02
7:30	2:30		07_30	07_30
7:33	2:33	broken left rear window	07_33	07_33
7:47	2:47	Right side airbag explosion	07_47	07_47
8:00	3:00		08_00	08_00
8:02	3:02	left front tire explosion	08_02	08_02
8:09	3:09	left rear shock explosion	08_09	08_09
9:54	4:54	explosion of left front shock absorber	09_54	09_54
10:00	5:00		10_00	10_00

10:20	5:20	oil tank burning through	10_20	10_20
10:30	5:30		1_30	10_30
10:35	5:35	falling out of the rear window	10_35	10_35
11:00	6:00		11_00	11_00
11:20	6:20	right rear tire explosion	11_20	11_20
11:28	6:28	right rear shock absorber explosion	11_28	11_28
11:47	6:47	left side airbag explosion	11_47	11_47
12:25	7:25	airgbags Pyro-cartridge explosion	12_25	12_25
14:14	9:14	right front tire explosion	14_14	14_14
14:30	9:30		14_30	14_30
14:40	9:40	right front airbag explosion	14_40	14_40
16:12	11:12	right front shock absorbers explosion	16_12	16_12
16:16	11:16	powerful explosion	16_16	16_16
17:59	12:59	left front air bag explosion	17_59	17_59

For illustration the 6 video - recordings of the burning vehicle are shown in the Annex 1.

5. A COMPUTER SIMULATION OF THE FT USING SW FDS

The FT was numerically simulated by computer using the SW FDS 6.1.1/Pyrosim 2014.2.0807 with the graphical output using Smokeview January 6.1.11 SW with generating the automobile geometry and basic computing network, see Tab. 12. The total modelling time was 2100 seconds, the same as the real fire test lasted.

Tab. 12: Parameters of the numerical network [1]

Network title	**X_{min}-X_{max}** [m]	**Y_{min}-Y_{max}** [m]	**Z_{min}-Z_{max}** [m]	**Cell size** [m^3]	**Cell number**
Mesh01	0-2	0-1,8	0 -1,5	$(0,025)^3$	345600
Mesh02	2-4,5	0-1,8	0-1,5	$(0,025)^3$	432000
Mesh03	-1 – 6,2	1,8 – 3,1	0 – 3,1	$(0,05)^3$	232128
Mesh04	-1 – 6,2	0 – 1,8	1,5 – 3,1	$(0,05)^3$	165888
Mesh05	-1 – 0	0 – 1,8	0 – 1,5	$(0,05)^3$	21600
Mesh06	-1 – 6,2	-1,3 – 0	0 – 3,1	$(0,05)^3$	232128
Mesh07	4,5 – 6,2	0 - 1,8	0 – 1,5	$(0,05)^3$	36720
Celkem	-1 – 6,2	-1,3 – 3,1	0 – 3,1	$(0,05)^3$ a $(0,025)^3$	1466064

The chemical reaction of burning was applied as a source of combustion for the combustion calculation using the data from Tab. 13. This model was selected in order to be possible to computational predicting the field concentrations of the CO, O_2 and CO_2 gases in time and space. The concentration of toxicants was estimated according to the chemical reaction of the PUR foam combustion in the seat upholstery. The initial and boundary conditions, the flow model, the simulation model, the radiation model and the simulation length were set to correspond as closely as possible the conditions during the test fire. Calculations of temperatures, irradiances and concentrations of selected toxicants inside the automobile 10 were carried out at measuring points according to the Fig. 10 and 11.

Tab. 13. Material characteristics - Input data for the FDS [1]

Material	T_{ign} [°C]	ΔH_v [kJ/kg]	**HRR** [kW/m^2]	ρ[kg/m^3]
Plastics	440	4000	300	930
Upholstery	365	3600	250	80
Steel	-	-	-	7850
BQA	220	43700	2130	770

The result of modelling [1] is processed in:

a/ graphs of the time histories calculated values of:

- temperature T (°C)
- irradiance q (kW/m^2)
- and CO, O_2, NO, NO_2 and SO_2 concentrations (mol/mol)

b/ tablets, see Tab. 14 - 16

c/ comparing records of thermo-camera and visual model sections of temperature fields during a fire in the 30th, 60th, 120th, 240th and 360th s, see 2nd Annex.

DOI 10.14311/CEJ.2015.02.0008

Tab. 14. Comparison of the maximum temperature Tmax measured with computed ones by modelling $T_{max,mod}$ in time τ [1].

sensor / quantity	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
T_{max} (°C)	58.6	370.2	292.6	1 066.7	91.7	61.5	44.0	468.3	582.1	883.8
τ (s)	1314	618	609	225	378	426	429	102	675	717
$T_{max,,mod}$ (°C)	32.6	50	32.3	44.3	27.4	28.7	26.4	42.7	629.1	692.4
τ (s)	96.6	94.6	90.3	134.4	310,8	403.2	256.2	86.	69.3	81.9
sensor	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
T_{max} (°C)	56.8	237.4	203.2	664.6	83.1	60.6	37.0	271.9	580.0	934.3
τ (s)	513	621	438	222	372	426	429	99	480	540
$T_{max,,mod}$ (°C)	28.6	37.4	29.3	34.9	24.2	26.7	23.1	53.5	399.0	71.2
τ (s)	96.6	90.3	111.3	86.1	153.3	386.4	153.3	220.5	138.6	153.3

Tab. 15. Comparison of the maximum irradiances Q_{max} measured by the Radiometers R with the ones calculated with modelling $Q_{max,mod}$ in time τ [1]

sensor / quantity	R_1	R_2	R_3	R_4
Q_{max} (kW/m^2)	30.14	85.83	11.61	67.53
U_Q (kW/m^2)	± 1.96	± 5.58	± 0.75	± 4.39
τ (s)	183	156	186	117
$Q_{max,mod}$ (kW/m^2)	18.2	15.9	3.3	14.8
τ (s)	88.2	132.3	249.9	102.9

Tab. 16. The maximum calculated concentrations $C_{max,mod}$ of gases measured inside the automobile in the surveyed positions in time τ [1]

Sensor / concentrations	CO1 [ppm]	CO2 [ppm]	Testo CO-2 [vol. %]	Testo CO-1 [vol. %]	Testo O_2 [vol. %]	Testo NO [vol. %]	Testo NO_2 [vol. %]	Testo SO_2 [vol. %]
$C_{max,mod}$	4016	4168	8.8	0.4	20.8	0	0	0
τ (s)	323.4	63	63	63	6.3	0	0	0

Legend: CO1 and CO2 are concentrations measured in the positions according to the Fig. 11.

Differences in values can be explained as follows:

- the computational model is heating up faster and thus burn out sooner,
- calculated measured values are lower than on location,
- the modelling software is not able to display the detailed automobile geometry,
- ignorance of the accurate input flammable materials parameters in the automobile ,
- a certain imprecision of gauges´ positions,
- measured values were heavily influenced with a wind that changed direction and speed during the test.

CONCLUSION

The risk of a vehicle fire for its crew and surroundings is evident by comparing e.g. the measured values of temperatures, irradiances and the concentrations of toxic substances generated during FT (see chapter 3) with their devastating effects characterized in the Chap. 2 of this report. Total toxic potential can be predicted computationally from the measured concentrations of toxicants using the mathematical model of N- gases.

It is obvious that the large - scale fire tests of newly developed vehicles and their computer models have still an irreplaceable role for the assessment of their fire risk and taking the necessary fire safety measures.

ACKNOWLEDGEMENTS

Authors would like to thanks to the promotion of the European Union project, OP RDI no. CZ1.05 / 2 Jan. 00 / 03.0091 - "University Center of energy-efficient buildings", staff the Research and development department of the Fire Technical Institute in Prague (Bursíková P., Karl J., Růžička M., Suchý O., Ševčík L.) for cooperation in the measurement and evaluation of measured and computer-modelled results [1] and the CTU -FT and BF students for assistance in the preparation and implementation of a test fire.

REFERENCES

[1] DVOŘÁK, O. a kol. *Zpráva o výsledcích velkorozměrové požární zkoušky s automobilem ŠKODA – FÁBIA Combi 1,2 TDI* (vzorek nehomologovaného vozidla zajištěného Fakultou dopravní ČVUT jako učební pomůcka). Praha: ČVUT- FD a FSv, leden 2015, 72 s.

[2] vyhl. MDaS č. 341/2002 Sb., *o schvalování technické způsobilosti a technických podmínkách provozu vozidel na pozemních komunikacích*.

[3] Směrnice Evropského parlamentu a rady č. 95/28/ES z 24. října 1995 *o hořlavosti materiálů používaných v konstrukci interiéru určitých kategorií motorových vozidel*

[4] www.mvfri.org/index.html

[5] POLEDŇÁK, P., Experimentálne overenie požiarov osobných motorových vozidiel. In: *Zborník zo 4. medzinárodnej konferencie Ochrana pred požiarmi a záchranné služby*. FŠI ŽU v Žiline. 2. - 3. 6. 2010. ISBN 978-80-554-0208-6.

[6] I. SOJKOVÁ, *Výzkumné zprávy č. Z-6/86, č. Z-64/86, č. Z-64/88*. Praha: Ústav pro výzkum motorových vozidel.

[7] *Podklad z DB MV – GŘ HZS ČR*, pplk. Ing. V. Vonásek, 2014.

[8] *Podklad z DB MV – Policejního prezídia PČR*, pplk. Ing. P. Sobotka, 2014

[9] O. Dvořák, Působení požáru na lidský organismus. *Odborný časopis požární ochrany 112,* ročník XVII, č.

12/2013, s. 8 – 11.
[10] *Nařízení vlády č. 361/2007 Sb*.,
[11] C. CRAME, Human Tolerance Limit to Elevated Temperatures. *Report No. ACC- 114-78-2,1978*.
[12] S. Komárníková, *Diplomová práca „Rýchlosť uvolňovania tepla při požiaroch osobných automobilov.* Praha: ČVUT-FSt, 2014, 77 s.