FDS VERSUS EN-MODELS
Comparison between Heskestad model out of EN and CFD results

Tom Molkens [a]

[a] StuBeCo bvba, Engineering office, Overpelt, Belgium

Abstract

For a rather big hippodrome we made a whole FDS model to investigate the influence of a car fire on the structure in terms of smoke and temperature actions on the structure. As fire action we proposed a one or triple car fire. Smoke evacuation is done by natural ventilation; open windows in the roof and doors at ground floor automatically coupled on the detection system. In this particular case we could deliver a report with the guarantee of a smoke free evacuation layer during the required time and no protection is needed for the structure. A guide for the use of the hall was delivered with all the restrictions for a safe use of the construction.
At this moment it seems to be useful, for featuring projects, to investigate if there is a difference with the localized fire scenarios from annex C out of EN 1991-1-2. This is off course only valid for the structural impact of the fire load.

Keywords: local fire, flame height, temperature, heat flux

INTRODUCTION

It would be interesting if we could make a comparison between the results of a localised fire following annex C of the EN and the results of the CFD calculation done with the widely known FDS software from NIST. There is a huge time difference to solve both problems, where the EN takes about 5 minutes, the CFD takes sometimes weeks. In the following we like to point out the boundary conditions of room and fire, followed by a discussion of the main parameters such as; flame height $L_{f(z,t)}$, temperature $\Theta_{(z,t)}$ in the plume, heat flux to the structure h_{r+c} and at least and most important the steel temperature.

1 BOUNDARY CONDITIONS

1.1 Room geometry

The hippodrome is a long rectangular building with an insulated double pitch roof, in the sections (Fig. 2 and 3) you'll see some tribune elements which are also a separation or compartment boundary between the hall and secondary rooms like bars, shops and so on. Most important dimensions and materials are listed below:

- Maximum length of compartment = 114,6 m & maximum width = 100,5 m
- Minimum/maximum height of competition hall = 11,4/18,9 m
- Minimum/maximum height of exercise hall = 10,5/12,9 m
- Columns= concrete, steel truss beam for the roof
- Floor, tribunes and walls till about 4,2 m height in concrete, above steel cladding with insulation layer (only insulation in the model).
- Vertical window openings of 6x2,1 m² aerologic surface coupled on smoke detection system, ACME smoke detector I2 (α_e=1,8, β_e=-1,1, α_c=1 and β_c=-0,8).

The model is discretized in 335x382x67 cubes of 0,3x0,3x0,3 m³. The size is coming from the smallest dimension of the concrete columns.

Tab. 1 Materials and properties

Material	location	Conductivity (W/mK)	Specific heat (J/(kg.K))	Density (kg/m³)	Thickness (m)
Concrete	Floor, walls and columns	1,60	900	2300	0,300
Glass	Wall	0,80	840	2600	0,006
Steel	Beams	50	500	7800	0,020
Insulation	Walls and roof	0,05	1030	40	0,100

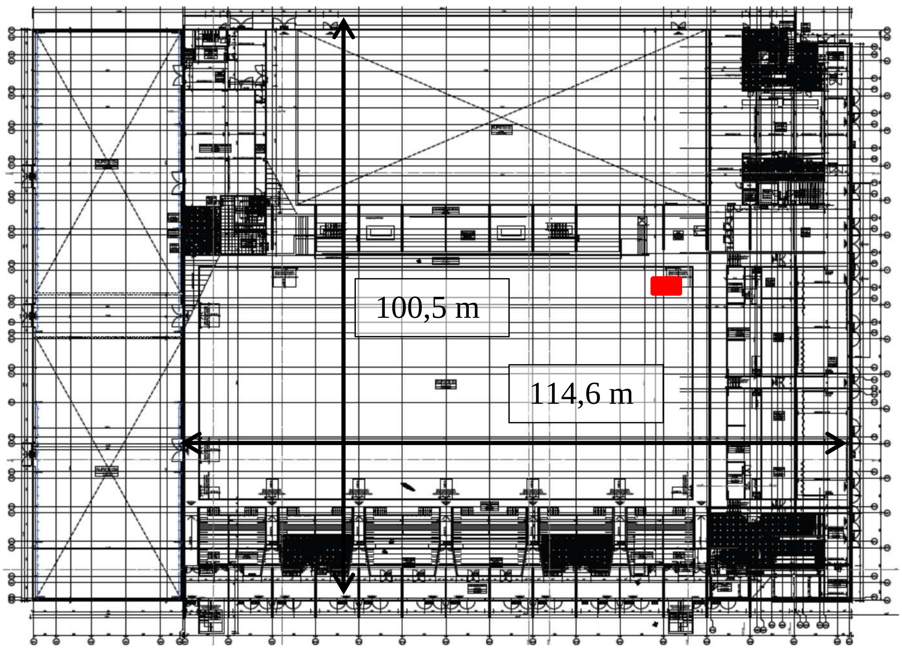

Fig. 1 Floor drawing

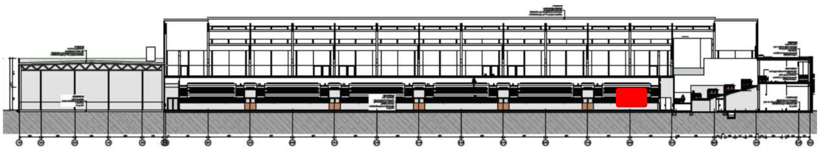

Fig. 2 Longitudinal section

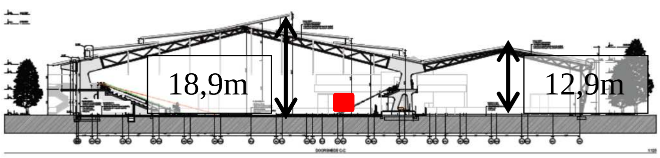

Fig. 3 Cross section

1.2 Fire geometry

Neither you investigate a so called Heskestad (flame height bellow ceiling) or Hasemi (flame against ceiling) fire, both of those given formulas in the EN are developed for a circular pool fire. The implantation of the car is determined by the most negative smoke spread which could be obtained out of several simulations.
A conversion must be made between the car fire into an equivalent pool fire. The car was simply modelled as a block with L = 4,2 m length by W = 1,8 m width and H = 1,5 height.

- First we made a FDS calculation where all energy dissipation will be done by the top surface of one car so $D_{eq,top} = \sqrt{[4/\pi.L.W]} = 3,1$ m and $RHR_{max} = 1098$ kW/m² .

- Secondly all energy dissipation will be done by the top and vertical surfaces of one car so $D_{eq,top+sides} = \sqrt{[4/\pi.(L.W+2.(L+W).H)]}$=5,7 m (surf x 3,4) and RHR_{max}=385 kW/m².
- In a third estimation all energy dissipation will be done by the top surface of three cars so $D_{eq,top,3} = \sqrt{[3.4/\pi.(L.W)]}$ = 5,4 m and not three times $D_{eq,top}$ of 1 car.
- In a fourth estimation all energy dissipation will be done by the top and vertical surfaces of three cars so $D_{eq,top+sides,3} = \sqrt{[3.4/\pi.(L.W+2.(L+W).H)]}$ = 9,9 m.
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Fig. 4 Real car fire

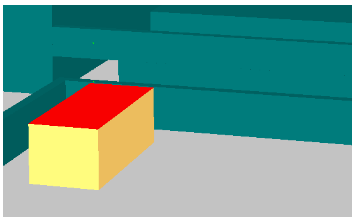

Fig. 5 Only top surface (1car)

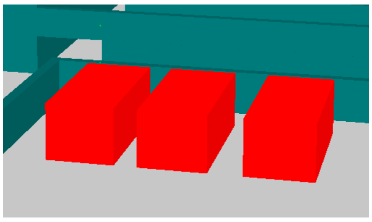

Fig. 6 Top + sides (3 cars)

1.2 Fire load

The in our case study applied fire is the one of a medium car, by Joyeux et al. a so called category 3 car of 9500 MJ with a combustion rate of about 71% like can be deduced for new cars. The rate of heat release of one till three cars are presented in the Fig. 7 and Tab. 2 below.

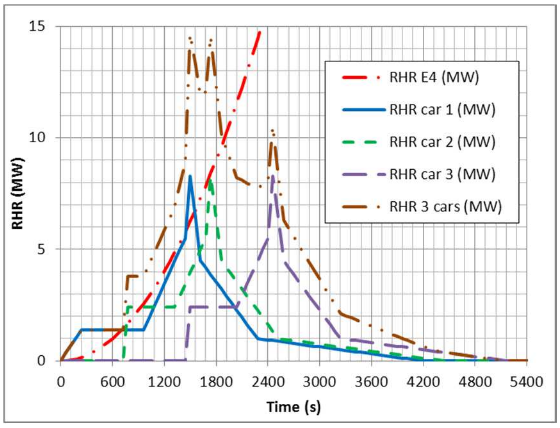

Fig. 7 RHR, Joyeux et al.

Tab. 2 RHR for 1 till 3 cars

time (s)	car 1 (MW)	time (s)	car 2 (MW)	time (s)	car 3 (MW)
0	0	720	0	1440	0
240	1,4	780	2,4	1500	2,4
960	780	1320	2,4	2040	2,4
1440	780	1680	5,5	2400	5,5
1500	780	1740	8,3	2460	8,3
1620	780	1860	4,5	2580	4,5
2280	780	2520	1	3240	1
4200	0	4440	0	5160	0

In Fig. 7. We added also the rate of heat release according to table E.4. from the EN 1991-1-2 for a slow fire in a public space. The grow rate seems to be more or less the same till the peak value for a 1 car fire.

For the description of the fire in the FDS software we used following parameters, we proposed a wood based fire as an approximation: C=3.4,H=6.2,O=2.5; SOOT_YIELD=0.08 and HEAT_OF_COMBUSTION=17000 kJ/kg. For smoke particles this can be expected as save sided.

2 FLAME HEIGHT

First criteria what must be checked will be the flame height, the choice between an Heskestad fire (flame don't reach the ceiling) or an Hasemi one has an influence on the formulas which must be applied to define the temperature in the Plume and heat flux. In this way this is of an extremely importance.

$$L_f = -1{,}02.D_{eq} + 0{,}0148.Q^{2/5} > 0 \qquad (1)$$

where D_{eq} Diameter of an equivalent pool, deducted from car surface.

Q Rate of heat release in W following Joyeux et al.

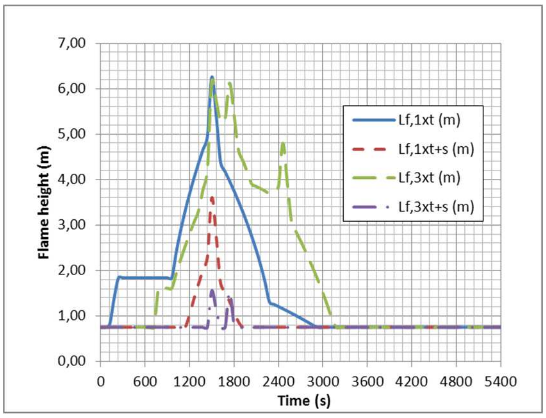

Fig. 8 Flame height following EN

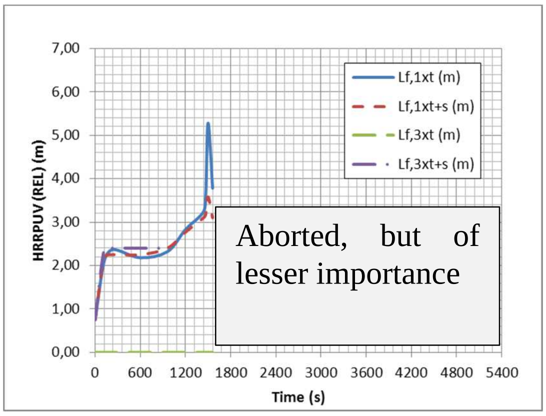

Fig. 9 Flame height following FDS

Following the flame length model included in the EN 1991-1-2, flames will never reach the ceiling, therefore the Heskestad seems to be valid. Because of limited computer capacity we did FDS only simulations for 1 car with energy dissipation on top (t), on top + sides (T+s) and with 3 cars on top + sides.

Maximum flame height following EN is reached with 1 car which is almost the same as for 3 cars and this with energy dissipation only at the top. Results of simulations with also the sides involved lead to very reduced flame height.

To obtain results of the FDS model about the flame height we used a graphical way, by the aid of the HRRPUV (REL) > 66 kW/m³ results. Accuracy is for this reason not famous and in the neighbourhood of 0,20 m. Simulations are done just somewhat further as 1500 s for a one car fire and just till about 1000 s for the 3 cars fire (due to time and computer limitation).

3 TEMPERATURE

Where flame height is important to determine the model, it is the temperature which will result in a heat flux on our structural components. The temperature in de plume can be calculated as follows

$$\Theta_{(z)} = 20 + 0{,}25.Q_c^{2/3}.(z - z_0)^{-5/3} < 900°C \quad (2) \qquad\qquad z_0 = -1{,}02.D + 0{,}00524.Q^{2/5} \quad (3)$$

where Q_c Conductive part of the rate of heat release in W, taken as 0,8.Q, look (1).

z level in m along the centre of the plume from mass centre.

z_0 imaginary centre point of the flame in m, if < 0 above mass centre.

At the location of our car the ceiling height is at 14,1 m, we present the calculated results with steps of 2 m just till 2,1 (or 0,6 m above the car) and that in function of time. Because the lower levels of the steel structure are situated at 13,8 m and 11,7 m also measurements this levels are involved. In the FDS software there are simple devices incorporated.

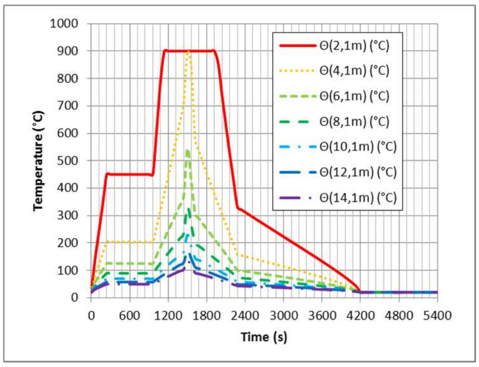

Fig. 10 Temperature for 1 car (t) EN

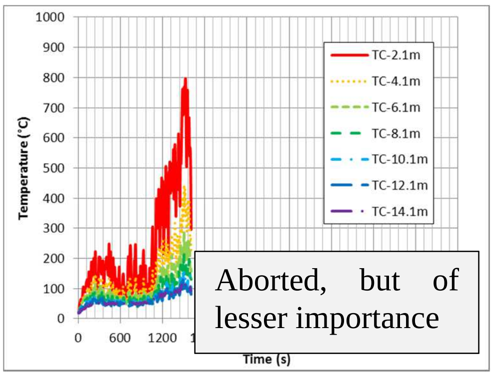

Fig. 11 Temperature for 1 car (t) FDS

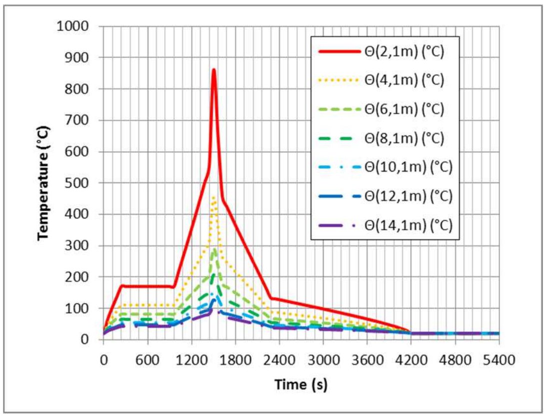

Fig. 12 Temperature for 1 car (t+s) EN

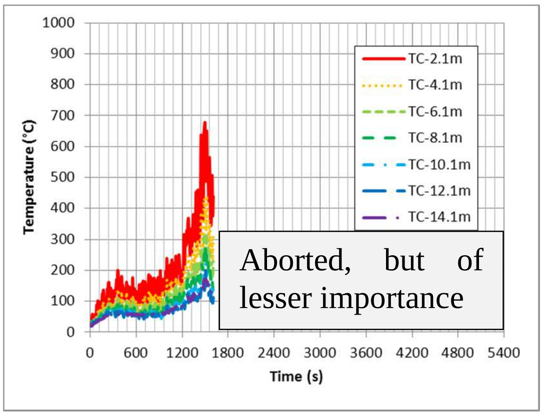

Fig. 13 Temperature for 1 car (t+s) FDS

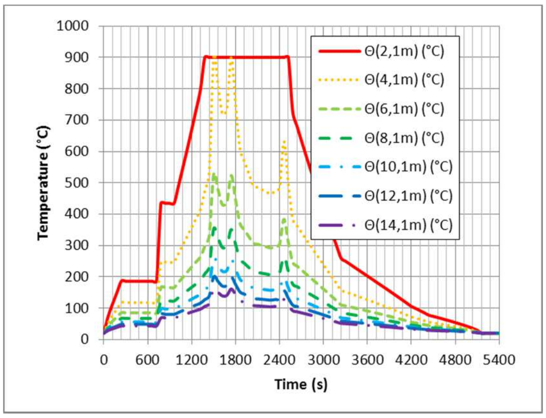

Fig. 14 Temperature for 3 cars (t) EN

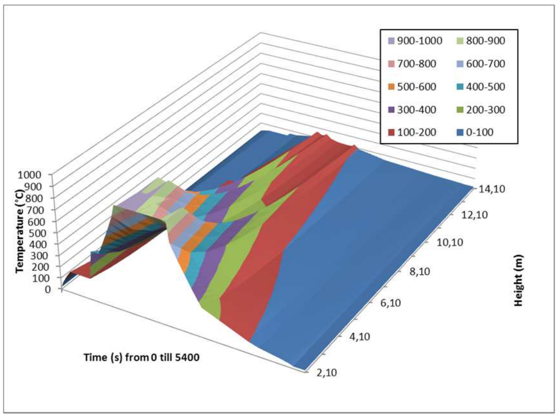

Fig. 15 Temp. for 3 cars (t) EN, 3D impression

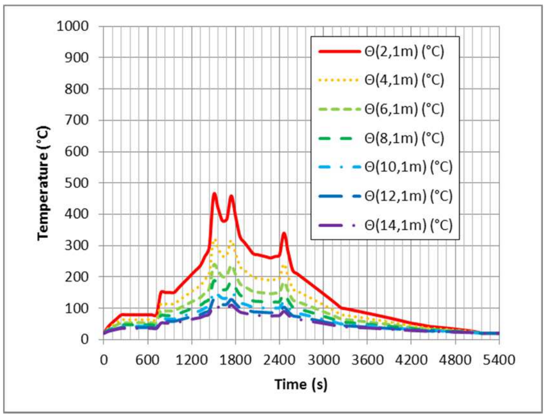

Fig. 16 Temperature for 3 cars (t+s) EN

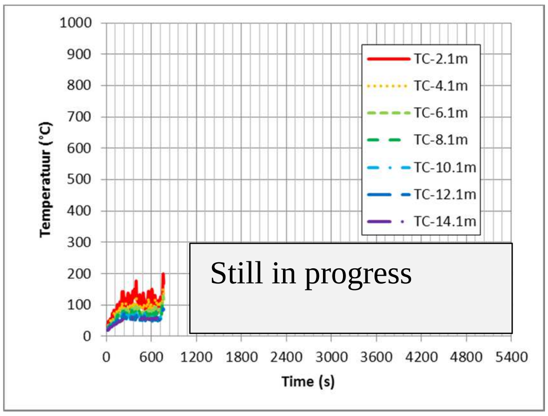

Fig. 17 Temperature for 3 car (t+s) FDS

Out of the wide range of figures (8 till 14) it becomes clear that our scope of interest can be reduced to what happens at 1500 s. We listed all reading in one table for EN and FDS.

Tab. 3 Temperatures in °C after 1500 s, values in italic are on steel members

Level	2,1 m	4,1 m	6,1 m	8,1 m	10,1 m	12,1 m	14,1 m	*11,7 m*	*13,8 m*
1 car t / EN	900	900	544	331	229	172	136	*181*	*141*
1 car t / FDS	767	445	289	213	157	125	123	*33/111**	*30/84**
1 car t+s / EN	861	454	290	207	158	127	106	*133*	*109*
1 car t+s / FDS	**677**	**391**	**317**	**270**	**225**	**200**	**171**	***39/133****	***32/100****
3 car t+s / EN	461	319	238	187	153	129	111	*133*	*113*
3 car t+s / FDS	?	?	?	?	?	?	?	*?*	*?*

* = Adiabatic surface temperature / Bold values are probably best match to reality

4 HEAT FLUX TO STEEL AND SURFACE TEMPERATURE

Finally we're most interested in the reaction of our structural component, perhaps errors in flame height and temperature are of lesser importance because the influence on the heat flux is limited. On base of the EN we calculate in the HEA 180 steel truss members a temperature at 11,7 m of 93/72 °C and at 13,8 m of 75/61 °C based on respectively the t/t+s schema for the fire load, look also last two columns of Tab 3.

Tab. 4 Heat flux to the steel in W/m² at 1500 s

Level	$h_{r+c,11,7}$	$h_{c,11,7}$	$h_{r,11,7}$	$h_{r+c,13,8}$	$h_{c,13,8}$	$h_{r,13,8}$
1 car t / EN	3507	2456	1052	2449	1822	627
1 car t / FDS	670	117	554	2240	1720	516
1 car t+s / EN	2255	1698	558	1710	1329	380
1 car t+s / FDS	948	159	789	3390	2670	726
3 car t+s / EN	2315	1745	570	1849	1431	418
3 car t+s / FDS	?	?	?	?	?	?

The differences in heat flux (Tab. 4) can be explained by differences in viewing factor, width of the flame (Tondini et al.), radiation from ceiling and smoke flow due to natural ventilation.

5 CONCLUSIONS

It seems that there is a very good agreement between EN and FDS results when comparing the flame height for a car with energy dissipation on the top + side surface (t+s). When we involve only the top surface of the car (t), the EN regulations seems to give an overestimation of the flame height.
On base of the figures, for the temperature the best approach is again achieved with 1 car and t+s burning surface. But with the listed values of Tab. 3 it seems that at higher levels (starting form 6,1 m) this t+s approximation is unsafe sided. Till about 10,1 m the best + save sided approach is obtained by the t system, at higher levels this becomes also an unsafe underestimation. The Horizontal plateaus like obtained by EN are not found.
Regarding the obtained surface temperatures on the structure, again the EN t+s schema fits very well if applied as adiabatic temperature on the steel. It is already shown (Wickström et al.) that this is the best single parameter interface between structural and structural models.
Calculations for a 3 car fire are still in progress, so conclusion can only be made for a local fire with 1 car at this time. Sensibility analyses are on the way to verify influence of material and reaction parameters.

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