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Uncertainty of Smoke Filling Calculations in Large Enclosures through Comparison to Experimental Results

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Presentation

- Background
- Objectives
- Experimental Analysis
- Numerical Analysis
- Results
- Conclusions and future works

Background

Engineers have a number of options available for evaluating the performance of a smoke management system and, depending on the country where he/she is based, different design guides are used.

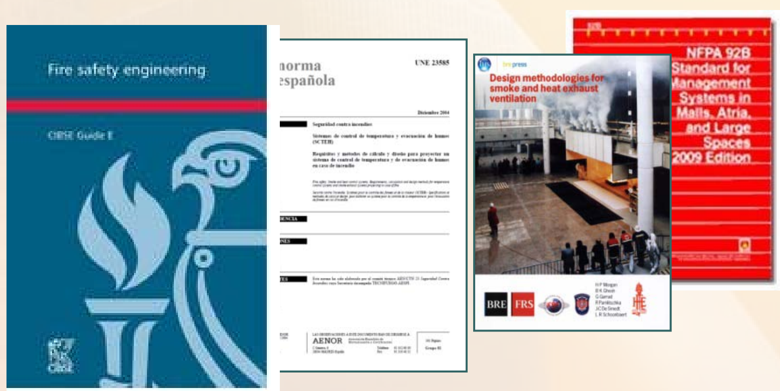
Often national guides are considered the only one valid in a given country, no matter if the approach used is out-of-date or simply wrong.

NFPA 92, PD 7974, BRE 368, CIBSE E, TM 19, UNE 23585, UNE 12101, NBN S21 208, …etc.

Background

It may happen that the same designer needs make similar calculation in different countries encountering a non-homogenous approach to the smoke modelling.

Instead of using international best practice on the latest research *(e.g. Harrison et all)* engineers often rely on national codes and prescribed/given methods.



NFPA 92, PD 7974, BRE 368, CIBSE E, TM 19, UNE 23585, UNE 12101, NBN S21 208, …etc.

Objectives

- A thorough understanding of the smoke filling techniques, from the more basics to the more sophisticated.
- This is necessary to prevent a misuse of them and in that way guarantee a certain level safety in the design of buildings and infrastructure.
- This has been possible by Experimental research

Experimental analysis

We had the chance to get experimental data from fire tests performed in a fairly large enclosure. We used different air entrainment correlations to predict the smoke layer interface and comparing the results to the data obtained by the tests

This research work has been divided in 2 main areas:

- Experimental research and data acquisition
- Comparison with the most diffused plume entrainment correlations

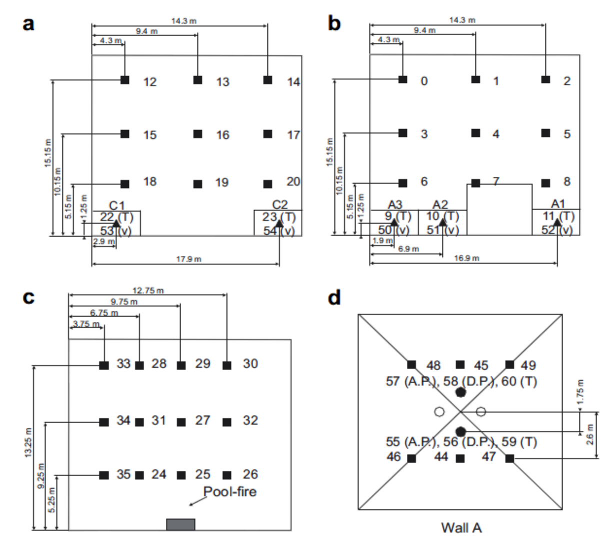
The Murcia Fire Atrium

In January 2013 researchers from the University of Jaén, The University Comillas (ICAI) with the collaboration of the Imperial College of London, MAPFRE and the fire consultancy JVVA Fire and Risk have undertaken several full scale fire tests in the Fire Atrium test facility in Murcia (Spain).

The Murcia Fire Atrium

The Murcia Fire Atrium

- The Murcia Fire Atrium is a full-scale facility consisting of a prismatic structure of 19.5 m x 19.5 m x 17.5 m and a pyramidal roof raised 2.5 m at the centre.
- The walls and roof are made of 6 mm thick steel sheets whilst the floor is made of concrete.
- The atrium is provided with four exhaust fans (with two velocity, provided by Sodeca) installed on the roof, each with a nominal flow rate of 9.2m3/s approximately.
- As per make up air, there are eight grilled vents arranged at the lower parts of the walls.



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The Murcia Fire Atrium

- The burning fuel was heptane contained in circular steel pans placed at the centre of the atrium floor for an approximate HRR of 2MW and 4MW.
- The atrium has been equipped with temperature, pressure and velocity sensors, in order to study the thermal and flow fields induced by the fire. Load cells have been installed top estimate the burning rate and consequently the HRR. Up to 60 sensors have been installed.
- Measurements of walls and roof metal temperature, and air temperature at several locations (next to the walls, at a central section, through the exhaust fans and through the inlet vents) have been recorded. Differential and absolute pressure sensors at the exhaust fans have been also installed to check, from the fan performance curves, the mass and volume flow rate evacuated.
- The smoke layer interface was measured by an aspiration detection system installed at different heights in the atrium (detection system provided by Xtralis).

Test data

- The data measured from the latest tests in January need to be processed and analyzed

- This presentation will focus on tests carried on between 2003 and 2008 by researcher from the University of Jaén (Prof. Cándido Gutiérrez-Montes)

5 test cases

	MFA1	MFA2	MFA3	MFA4	MFA5
Date	17/11/03	28/06/05	01/07/05	03/04/08	04/04/08
Pool diameter (m)	0.92	0.92	0.92	0.92	0.92
Fuel volume (l)	44	52	52	52	52
Burning time (s)	837	883	1094	909	1010
Extract rate (m^3/s)	15.2	15.2	15.2	7.6	7.6
Temperature (ºC)	16.7	28.9	27.5	26.5	13.0
Pressure (mbar)	1018	1008	1007	1011	1014
Weather	Cloudy	Clear	Clear	Clear	Cloudy
Wind speed (m/s)	-	-	-	2.00	Null
Calculated average HRR (MW)	1.58	1.77	1.43	1.72	1.55

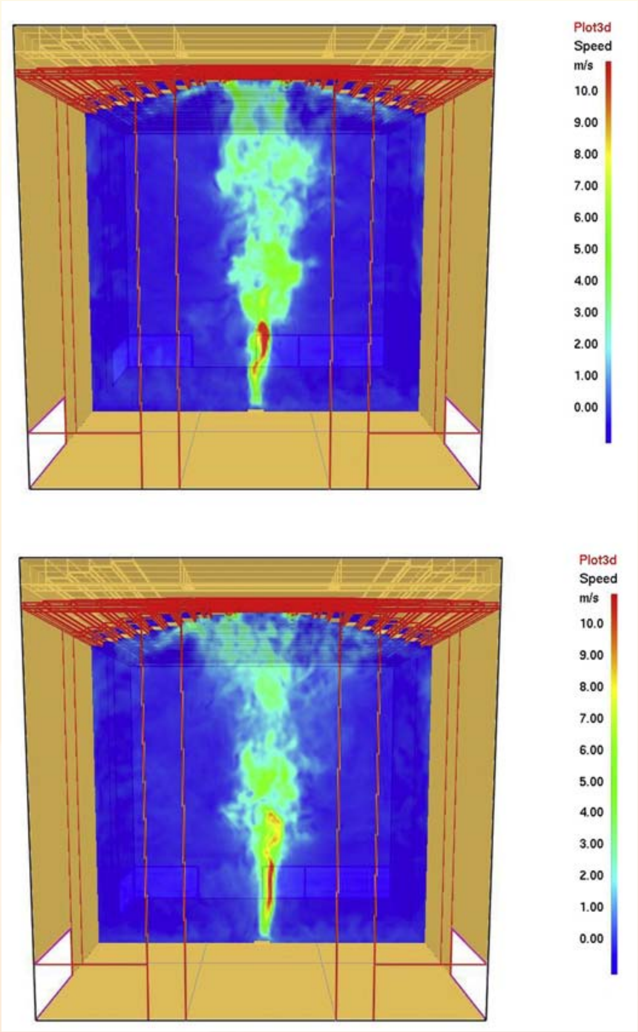
NUMERICAL MODELS

Approaches used

Several analysis using CFD codes have been made in the last few years and new ones are coming using the new fire data together with new CFD code.

For this analysis we only concentrate to 2 approaches

- Algebraic models (through empirical plume entrainment correlations)
- Zone models (CFAST, OZone and Branzfire)



Algebraic models

Zukoski

$$\dot{m}_p = 0.21 \left(\frac{\rho_\infty^2 g}{c_p T_\infty}\right)^{1/3} Q_c^{1/3} z^{5/3}.$$

Heskestad

$$\dot{m}_p = 0.071\, \dot{Q}_c^{1/3}(z - z_0)^{5/3} + 1.92\, 10^{-3}\dot{Q}_c \qquad z_0 = 0.083\, \dot{Q}_c^{2/5} - 1.02D$$

$$L_{fl} = 0.235\, \dot{Q}^{2/5} - 1.02D$$

$$\dot{m}_p = 0.0056\, \dot{Q}_c \left(\frac{z}{L_{fl}}\right). \qquad L_{fl} = 0.235\, \dot{Q}^{2/5} - 1.02D$$

Thomas

$$\dot{m}_p = 0.59\, D\, z^{3/2}.$$

McCaffrey

$$\dot{m}_p = 0.011\, Q \left(\frac{z}{Q^{0.4}}\right)^{0.566} \qquad 0 < \frac{z}{Q^{0.4}} < 0.08$$

$$\dot{m}_p = 0.026\, Q \left(\frac{z}{Q^{0.4}}\right)^{0.909} \qquad 0 < \frac{z}{Q^{0.4}} < 0.08$$

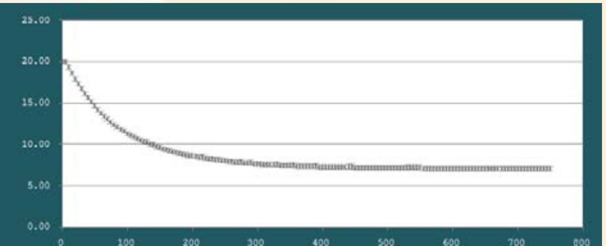
$$\dot{m}_p = 0.124\, Q \left(\frac{z}{Q^{0.4}}\right)^{1.895} \qquad 0.20 < \frac{z}{Q^{0.4}}$$

Plume entrainment correlations

In order to estimate the transient behaviour of the smoke in filling the atrium, a simple transient model has been developed, with a time step of 5 s, that considers the volume of the smoke produced by the fire, the smoke exhausting and the smoke filling into the atrium.

Heat transfers though the walls have been intentionally not considered since it's commonly not taken into account when using basic correlations.

Minimum Layer Height (m) z_{min}		
7.09		
Dt	5	s
R	287	J/kg-K
c_p	1.0006	J-kg-K
pressure	101325	
conv	0.6	
tamb	289.859	
hc	20	m
S	400	m²



	Heat release rate	Smoke layer height	Mass of smoke layer	Volume of smoke layer	Temperature of smoke layer	Density of smoke layer	Mid-step	Convective heat release rate	Mass flow of plume below smoke layer	Plume temperature	Volume extracted by ventilation	Mass extracted by ventilation	Fire diameter	Fire perimeter
Time [s]	Q [kW]	z(n) [m]	M(n) [kg]	V(n) [m3]	'(s,n) [oK]	s,n) [kg/m	ime_Mid [s	Q_c [kW]	ı(p) [kg/s	T(p) [oK]	V(e) [m3]	m(e) [kg]	d_f [m]	p [m]
										293.15				
0	0.00	20.00	0.00	0.00	289.86	1.22	2.5	0.00	0.00	293.15	15.00	18.27	0.92	2.89
5	1000.00	20.00	0.00	0.00	289.86	1.22	7.5	600.00	88.25	296.65	15.00	18.27	0.92	2.89
10	1070.00	19.28	349.88	287.25	289.86	1.22	12.5	642.00	84.92	297.41	15.00	18.27	0.92	2.89
15	1140.00	18.60	683.13	560.87	289.86	1.22	17.5	684.00	81.67	298.23	15.00	18.27	0.92	2.89
20	1210.00	17.95	1000.12	821.12	289.86	1.22	22.5	726.00	78.51	299.10	15.00	18.27	0.92	2.89
25	1280.00	17.33	1301.30	1068.39	289.86	1.22	27.5	768.00	75.45	300.03	15.00	18.27	0.92	2.89
30	1350.00	16.74	1587.21	1303.12	289.86	1.22	32.5	810.00	72.52	301.02	15.00	18.27	0.92	2.89
35	1420.00	16.19	1858.44	1525.81	289.86	1.22	37.5	852.00	69.71	302.07	15.00	18.27	0.92	2.89
40	1490.00	15.66	2115.63	1736.97	289.86	1.22	42.5	894.00	67.03	303.19	15.00	18.27	0.92	2.89

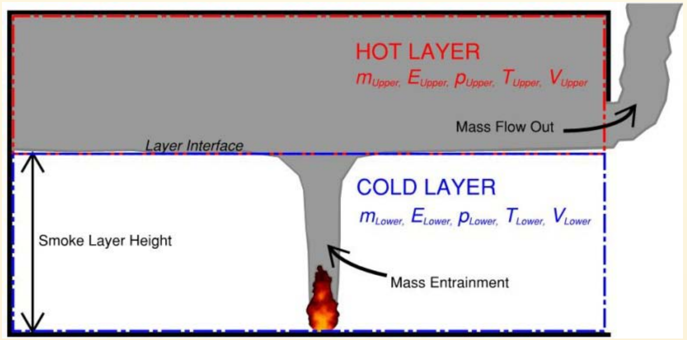
Zone models

- Zone models are simple computer models that divide the considered fire compartments into separate zones, where the condition in each zone is assumed to be uniform.

- The theoretical background of zone models is the conservation of mass and energy in fire compartments.

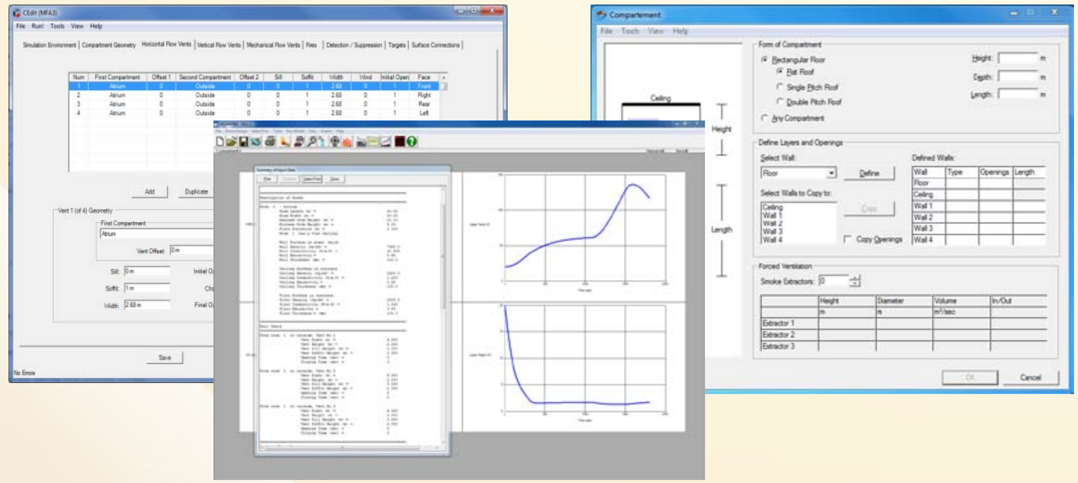
- Basically, the models take into account of rate of heat release of combustible materials, fire plume, mass flow, smoke movement and gas temperatures.

- They rely on some assumptions concerning the physics of fire behaviour and smoke movement suggested by experimental observation of real fires in compartments.



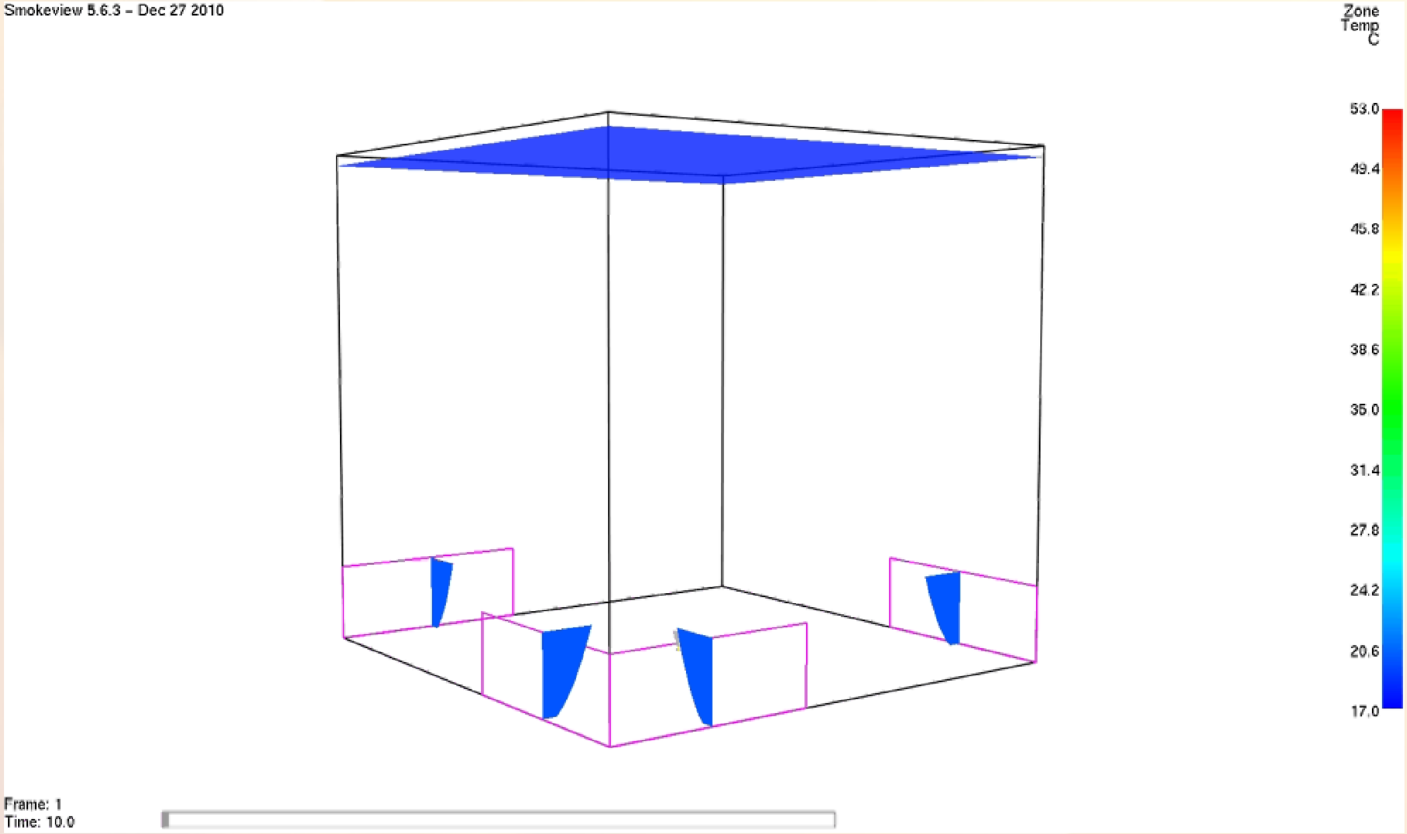
Zone models

CFAST
OZone
BRANZFIRE



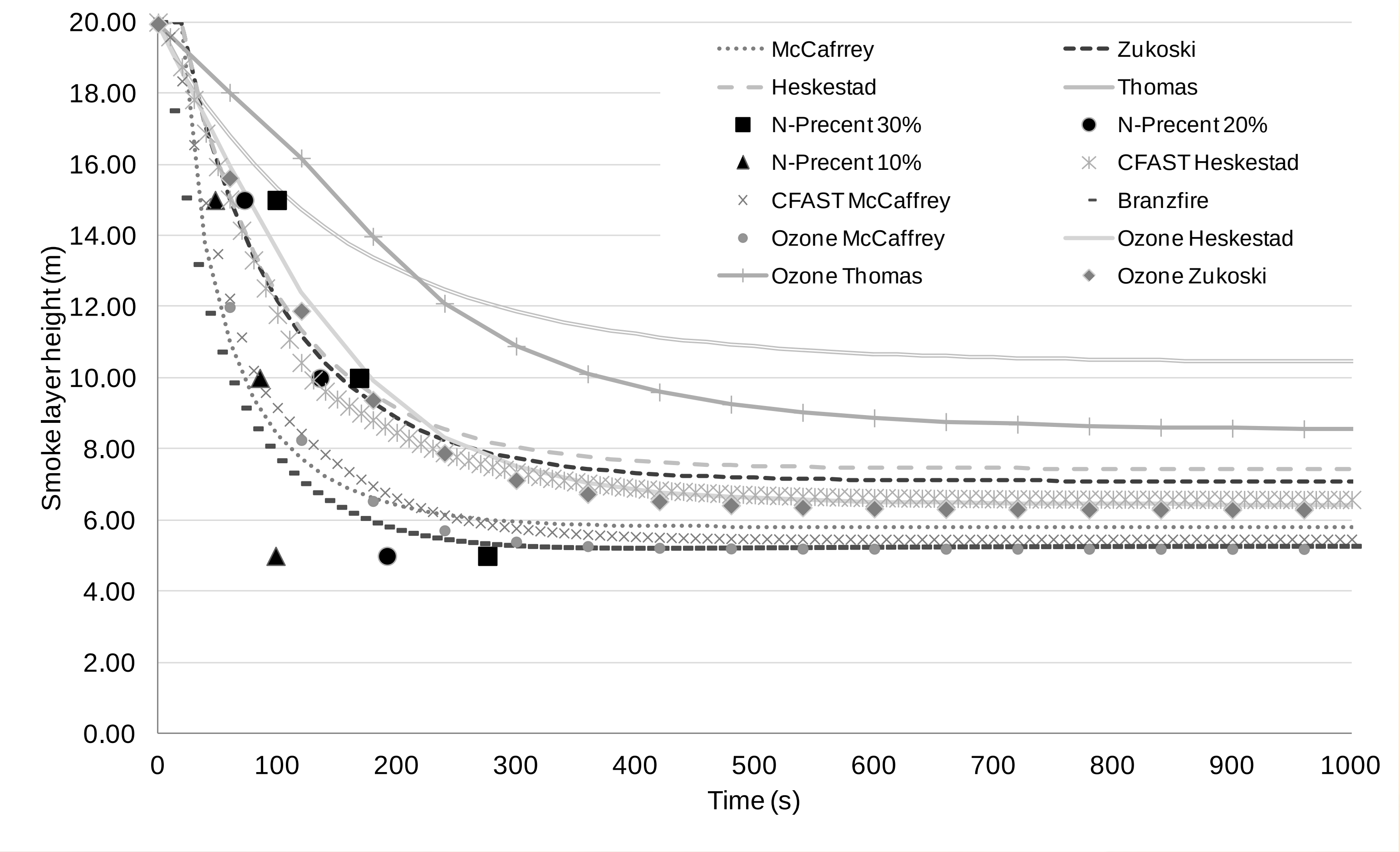
Model	Author	Country	Plume entrainment correlations
CFAST	NIST	USA	Heskestad McCaffrey
OZONE	University of Liège	Belgium	Heskestad McCaffrey Thomas Zukoski
BRANZFIRE	Canterbury University	New Zealand	McCaffrey Delichatsios

Zone models


Smokeview 5.6.3 – Dec 27 2010
Zone
Temp
C
53.0
49.4
45.8
42.2
38.6
35.0
31.4
27.8
24.2
20.6
17.0
Frame: 1
Time: 10.0

Results

MFA1



Results

Test	HRR (kW)	Total extraction (m^3/s)	Time required to reach 15m (s)									
			Test data			OZone				BRANZ FIRE	CFAST	
			Test data N-30%	Test data N-20%	Test data N-10%	Zukoski	Heskestad	Thomas (Hinkley)	McCaffrey	McCaffrey	Heskestad	McCaffrey
MFA1	1580	15.2	99.5	72.3	47.8	68	75	152	35	20	60	40
MFA2	1770	15.2	164.3	107.5	78	65	72	150	35	20	60	35
MFA3	1430	15.2	164.9	118	79.3	70	65	162	35	20	75	55
MFA4	1720	7.6	173.2	117.3	76.5	58	62	120	32	20	75	55
MFA5	1550	7.6	101.6	75.6	54.6	42	45	78	28	20	75	55

Because of the assumption of the smoke filling calculations that the smoke reaches instantaneously the ceiling, it is not easy to rely on the results in the first period of the fire (i.e. when smoke reaches 15m).

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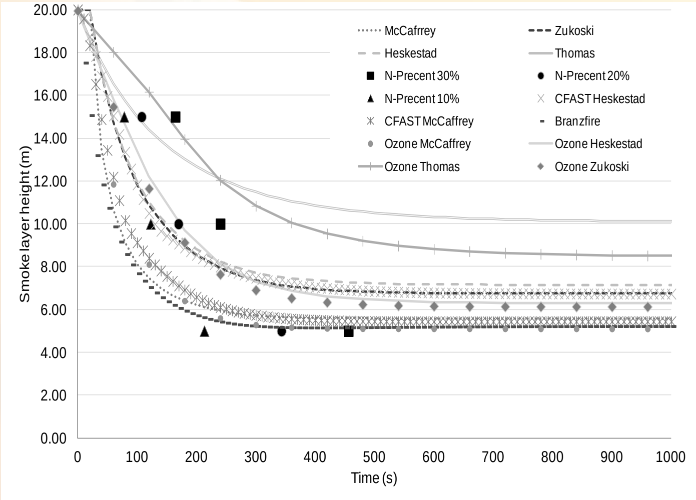
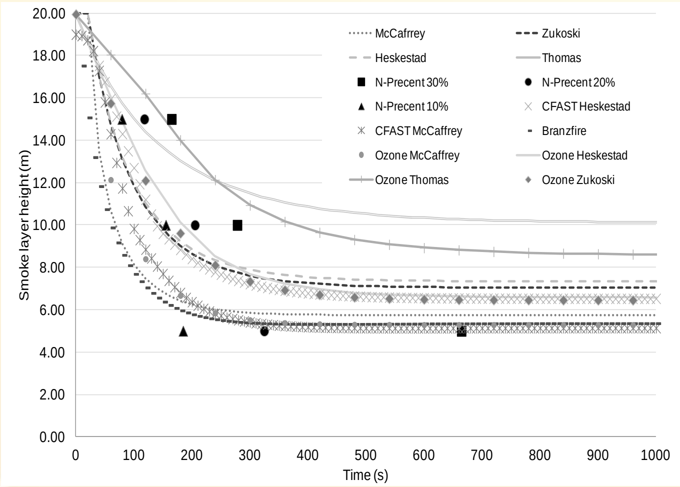
Results

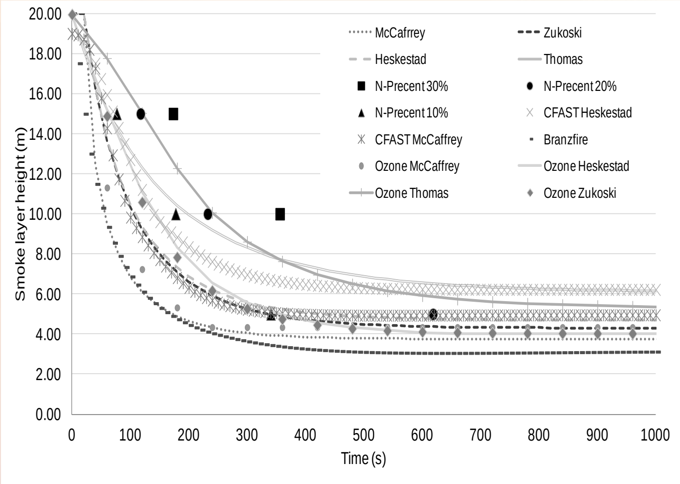
MFA2



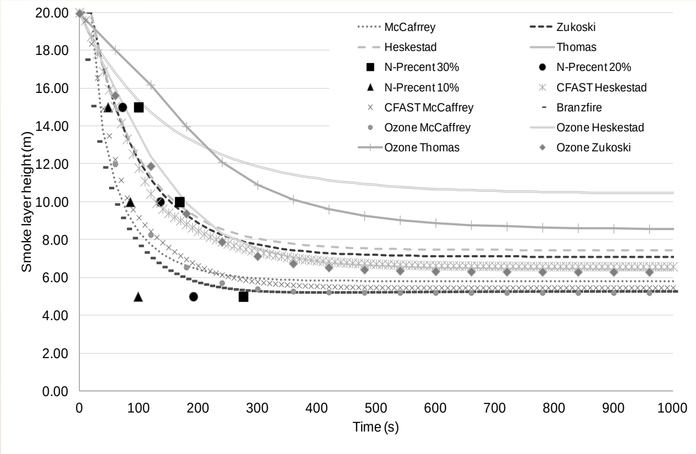
MFA3



MFA4



MFA5



Summary

The Murcia facility has been used to perform large scale fire tests in order to obtain data to compare with numerical models.

In this work two different types of numerical models have been used for the analysis:

- Algebraic models
- Zone models

Conclusions

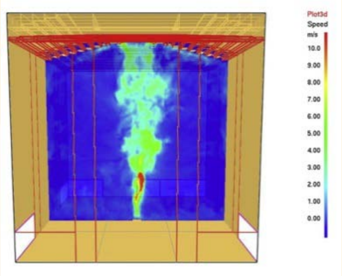
- The analysis has shown a significant variability in the smoke layer height using different approaches.
- The average range of uncertainty is about 35% with peak of almost 100% (Thomas, MFA1).
- Most of the results are not conservative, i.e. the predicted smoke layer is higher than the measure one.
- The use of basic numerical models in the design of smoke control system in large enclosures need to be carefully considered before use.

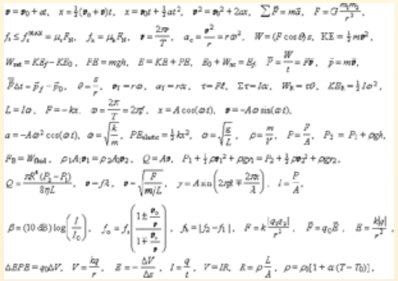
Future work

- When we presented this work in the SFPE conference in Hong Kong we promised to perform new tests (done!)
- Now we have a fairly wide range of data and we need to process them
- Once we have the data processed → Compare the new data with algebraic model, zone model and CFD model

Inverse Modelling

- If the CFD models perform well, use them as **reverse modelling** to get more data to compare with simple model (smoke layer interface for example)





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Thanks for your attention

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