LOCAFI+

Temperature assessment of a vertical member subjected to LOCAlised FIre
Dissemination

1. State-of-the-art and reason for the project

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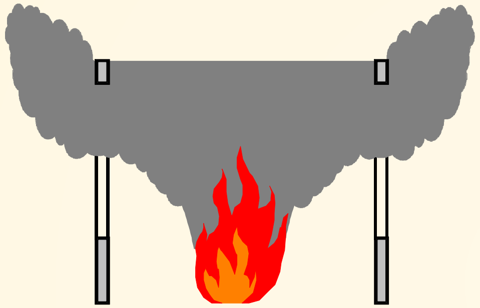
1. State-of-the-art and reason for the project

State-of-the-art : Performance-based fire

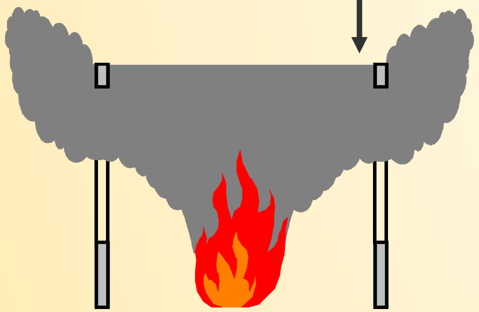
LOCALISED FIRE



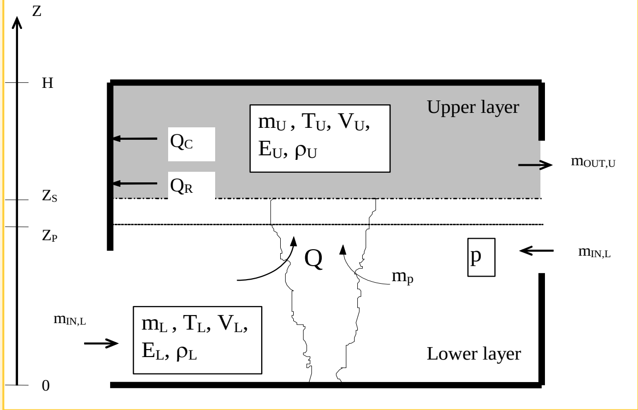
No flashover occurs

Flashover occurs

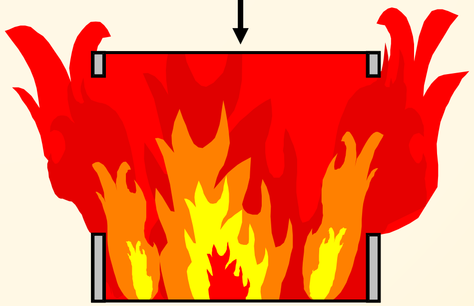
The Fire stays localised



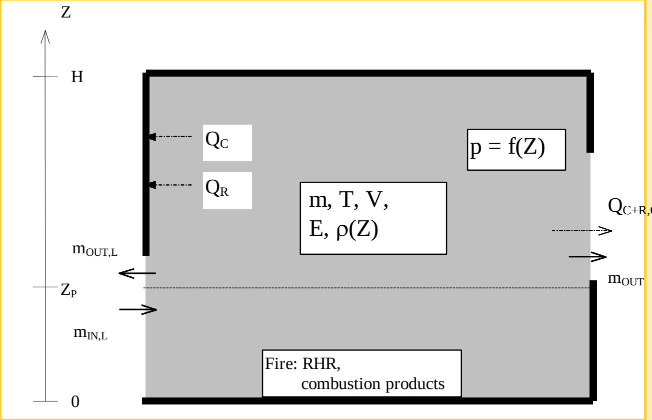
LOCALISED FIRE



The Fire switch to a fully engulfed fire



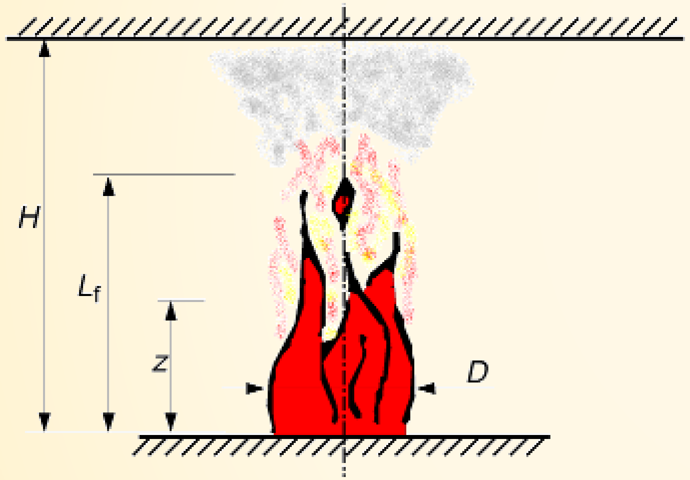
FULLY ENGULFED COMPARTMENT



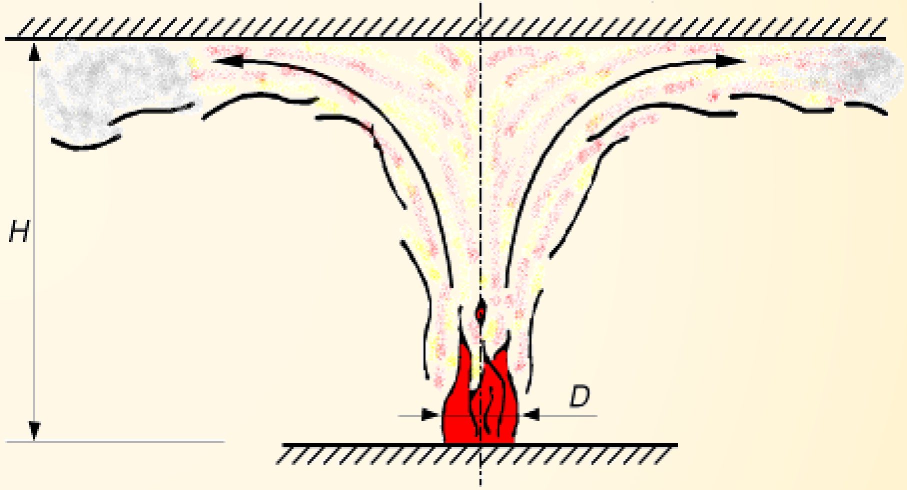
1. State-of-the-art and reason for the project

State-of-the-art : Localised fire

Currently two models are available in the EN1991-1-2 Annex C to describe the effects of localised fire to the structure:



Heskestad model
for fire not impacting the ceiling



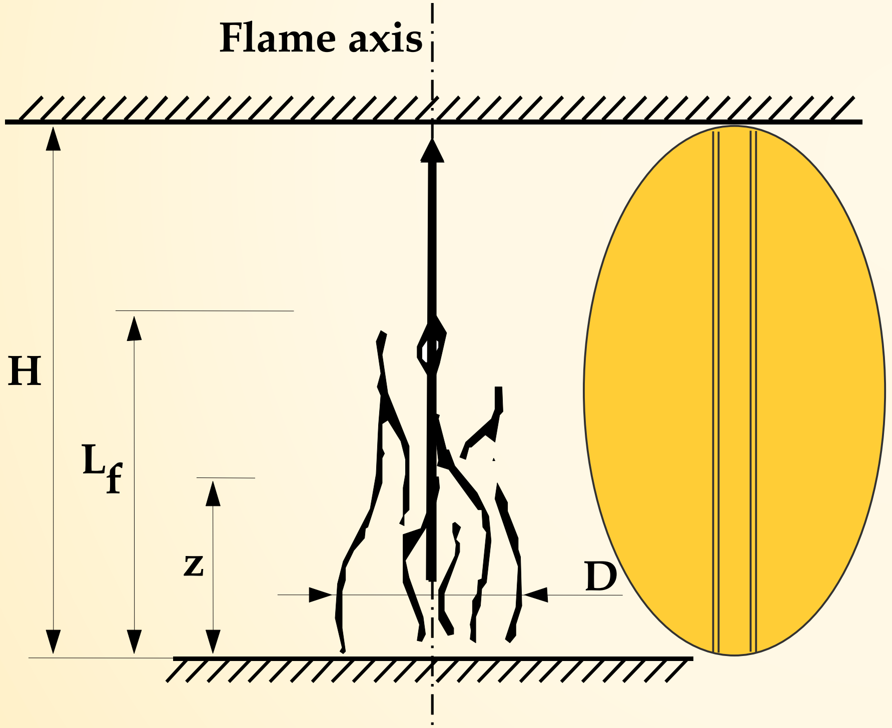
Hasemi model
for fire impacting the ceiling

For car parks structures, several experimental campaigns have been used to validate the ***Hasemi model*** as design tool able to reproduce with sufficient safety margin the temperature field in horizontal structural elements caused by burning cars.

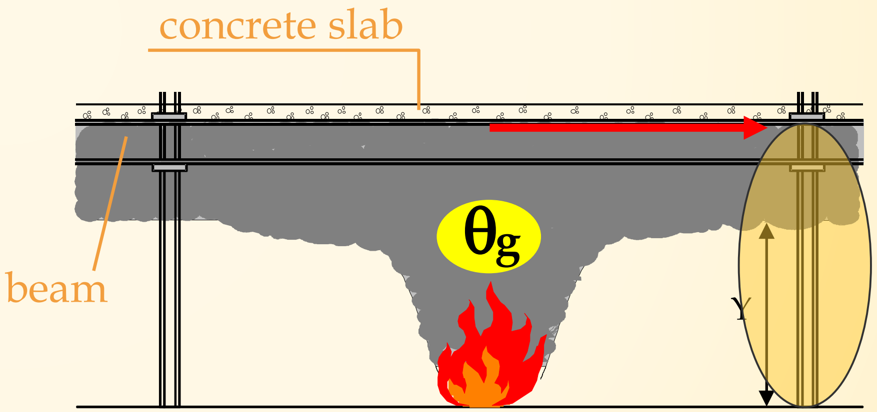
1. State-of-the-art and reason for the project

Reason for the project

Annex C of EN 1991-1-2:
Flame not impacting the ceiling



Annex C of EN 1991-1-2:
Flame impacting the ceiling



Y = Height of the free zone

In this situation, column temperature is mainly governed by radiative fluxes. But how to tackle this ?

1. State-of-the-art and reason for the project

Objectives of LOCAFI Project

- Providing scientific evidence about the thermal attack imposed on a steel column surrounded by a local fire or attacked by a local fire at a distance from the column (including verification of equations providing temperature along centreline of the source) ;
- Providing design equations that allow reproducing this thermal attack as well as temperatures induced in the column, publication of these equations and implementation in existing software (OZone, SAFIR,…) ;
- Providing rules that form the basis of the design equations in order to have them implemented in Eurocodes, which will make the models automatically accepted without any discussion by the authorities of the different Member States.

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2. Experimental tests and CFD calibration

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2. Experimental tests and CFD calibration

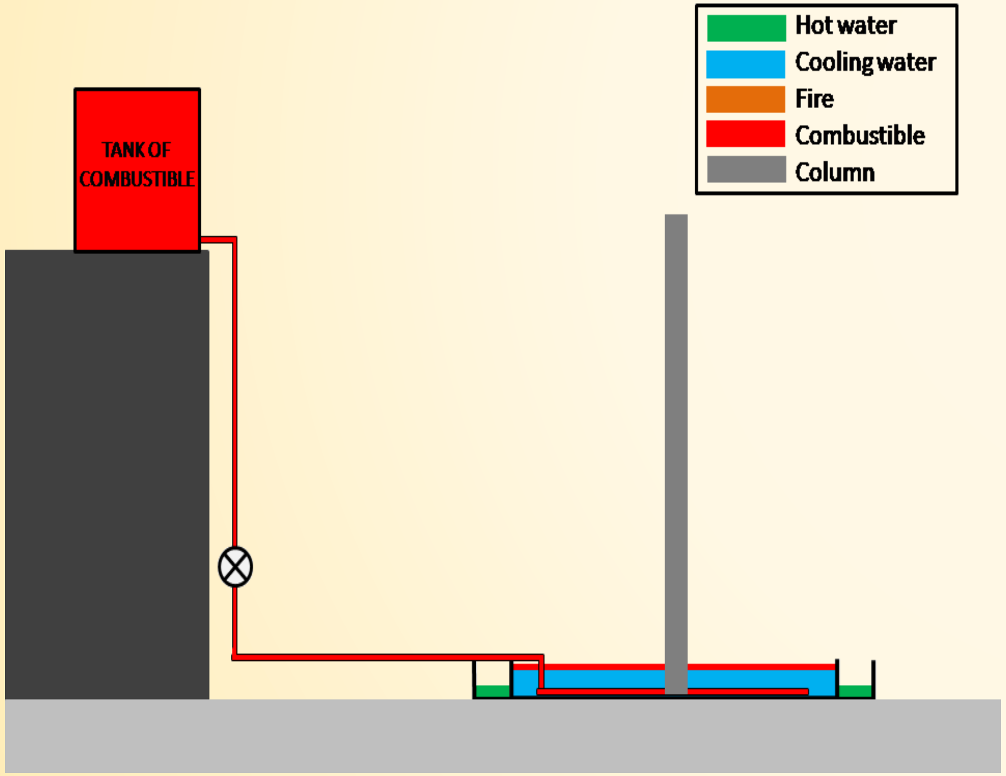
Tests performed by the University of Liège

Characterisation of heat fluxes received by elements engulfed into the fire

- 24 tests have been performed by the University of Liège varying:
  - The diameter of the fire (*5 diameters : 0.6m, 1.0m, 1.4m, 1.8m and 2.2m*)
  - The type of combustible (*2 different combustible liquids (diesel and N-heptane) + 1 cellulosic fire load*)
  - The presence of a column engulfed into the fire
- For each diameter and for the two combustible liquids:
  - One test without column into the fire
  - One test with a column at the centre of the fire source

Tests performed by the University of Liège

General test set-up

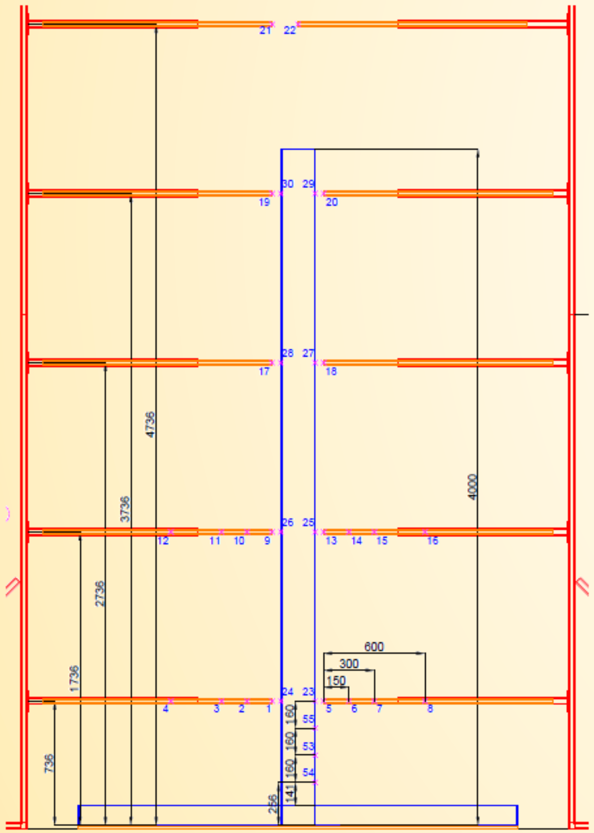


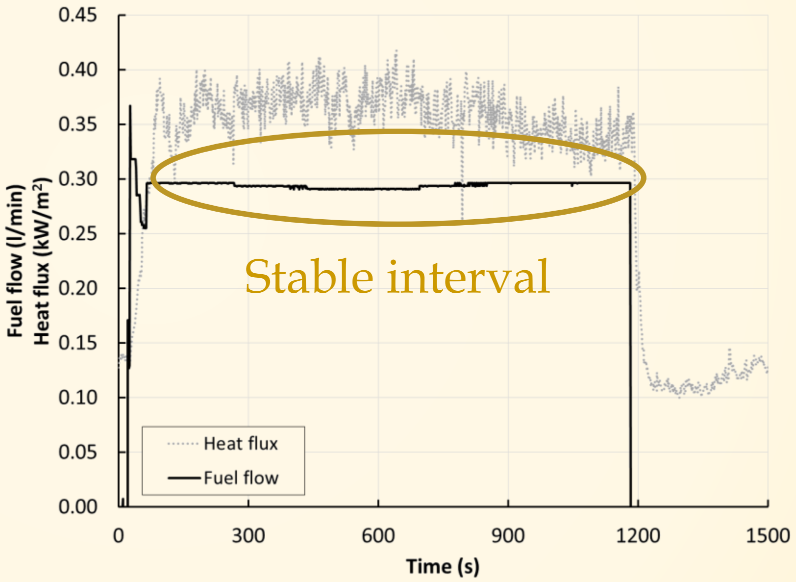
- Two tanks filled of heptane and diesel were placed at higher height than the floor to allow the fuel to flow by gravity ;
- The Rate of Heat Release of the pool fire was controlled by adjusting the flow of injected combustible by a simple manual valve ;
- The basin was continuously fed with cold water in order to cool down the layer underneath the burning fuel and, thus to provide a more stable steady burning regime by avoiding water ebullition.

2. Experimental tests and CFD calibration

Tests performed by the University of Liège

Experimental measurements : temperature and fluxes



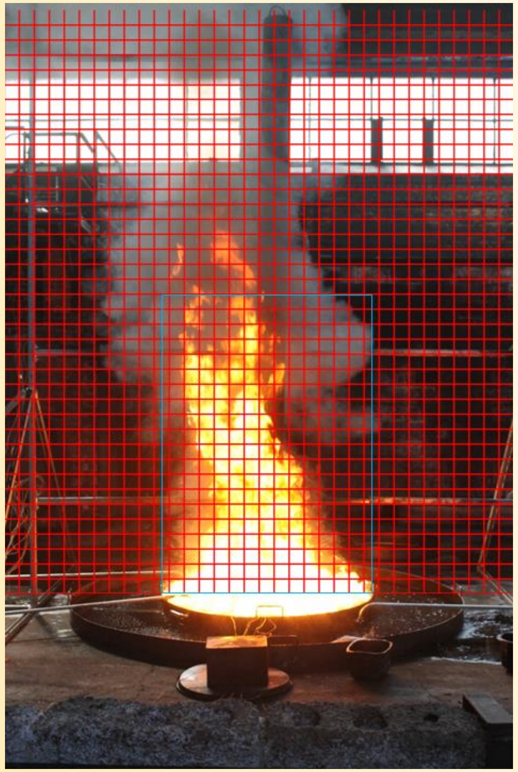


- Tests are performed until a steady-state configuration is reached (measurements of gas temperature and radiative heat flux are stabilised) ;
- In configuration with steel columns, thermocouples also provide evolution of steel temperature.

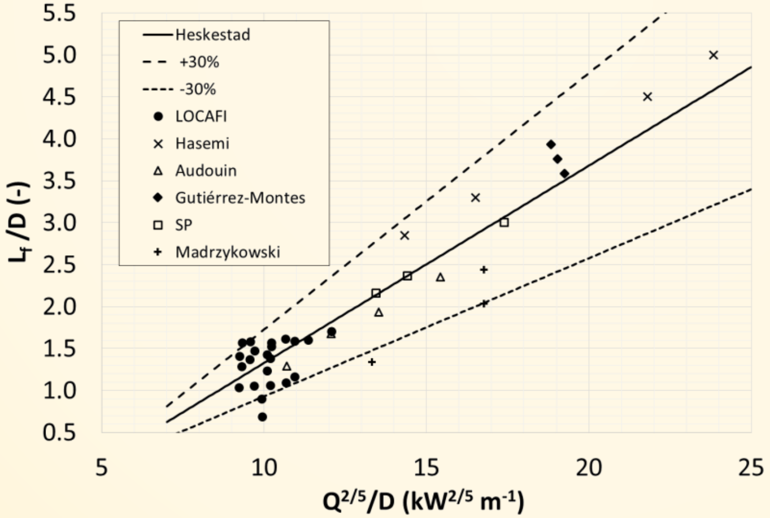
2. Experimental tests and CFD calibration

Tests performed by the University of Liège

Experimental measurements : flame length



The mean flame length L is the distance above the fire source where the intermittency has declined to 0.5, where intermittency I(z) is defined as the fraction of time the flame lies above the fire source. This assessment was made using digital image analysis.



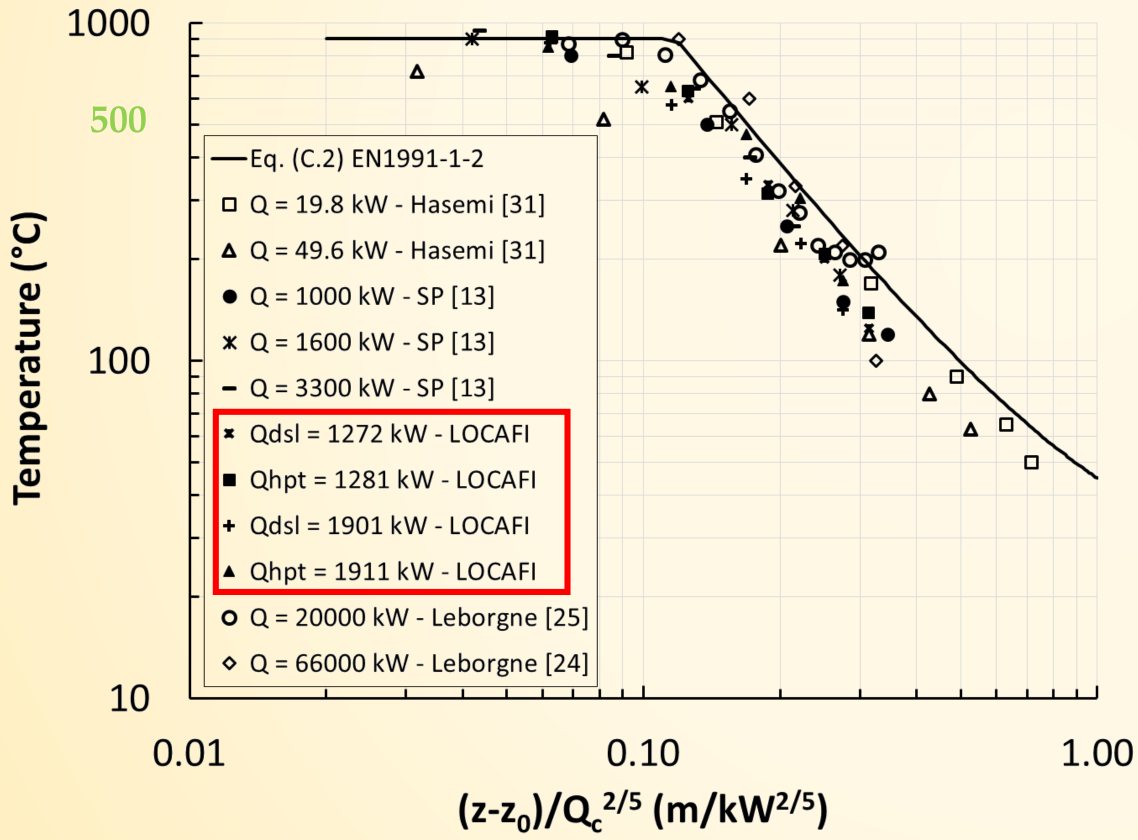
The difference between the experimental flame length and the flame length predicted by Heskestad is between +30% and -30% but this is in line with other pool fire investigations and mainly due to uncertainty about combustion efficiency and fuel density.

N. Tondini, J.M. Franssen, "Analysis of experimental hydrocarbon localised fires with and without engulfed steel members", Fire Safety Journal 92 (2017), 9-22

2. Experimental tests and CFD calibration

Tests performed by the University of Liège

Experimental measurements : temperature and fluxes



EN 1991-1-2 correlation provides a good assessment of temperatures both in the flame ($\theta_g \geq 500°C$) and the plume ($\theta_g < 500°C$).

2. Experimental tests and CFD calibration

Tests performed at the University of Ulster

Characterisation of heat fluxes received by elements outside the fire



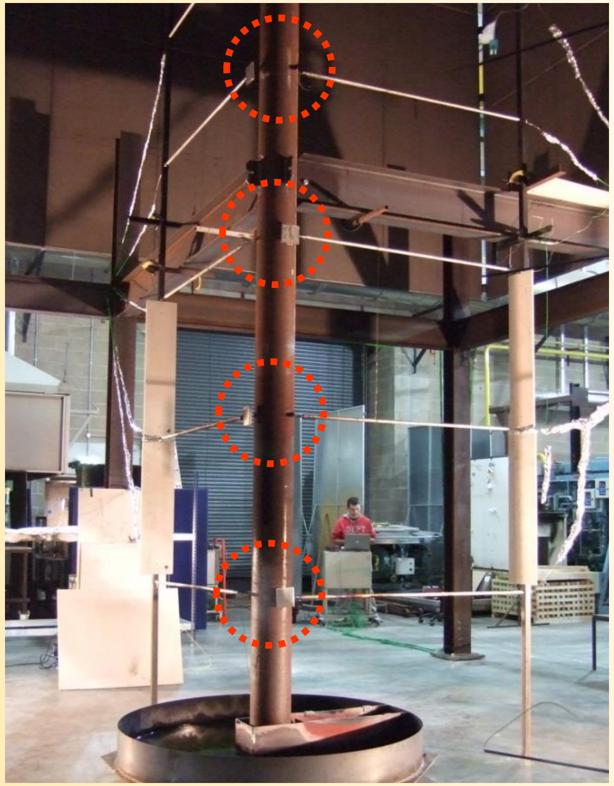


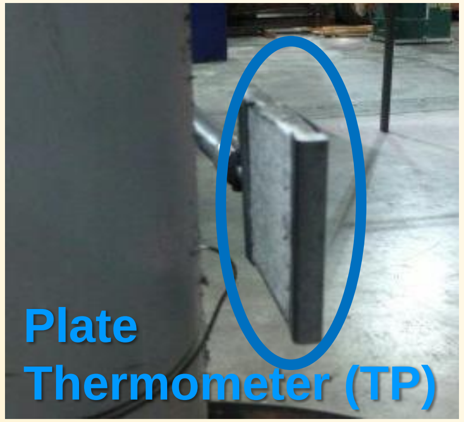
- 58 tests have been performed by the University of Ulster varying:
  - The presence or not of a ceiling (37 tests without / 21 tests with)
  - The number of pool fires (*from 1 to 4*) and diameter of these pools (*2 diameters : 0.7m and 1.6m*)
  - The type of combustible (*2 different combustible liquids (diesel and kerosene) + 1 cellulosic fire load*)
- The 9mx9m structure is composed of three types of columns (*I-section, H-section and O-section*)
- The HRR varied with time (not controlled) and was measured by a calorimeter hood
- Flame length is assessed by video analysis and on the basis of the flame presence probability

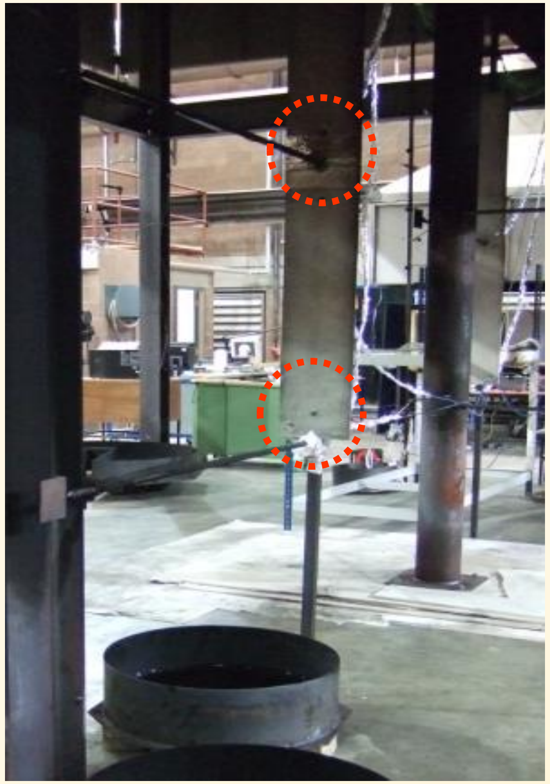
2. Experimental tests and CFD calibration

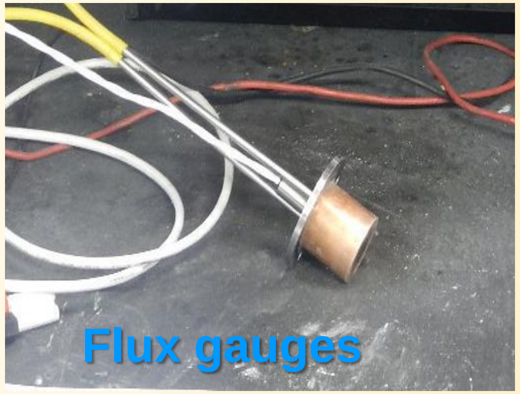
Tests performed at the University of Ulster

Experimental measurements : temperature and fluxes outside the fire







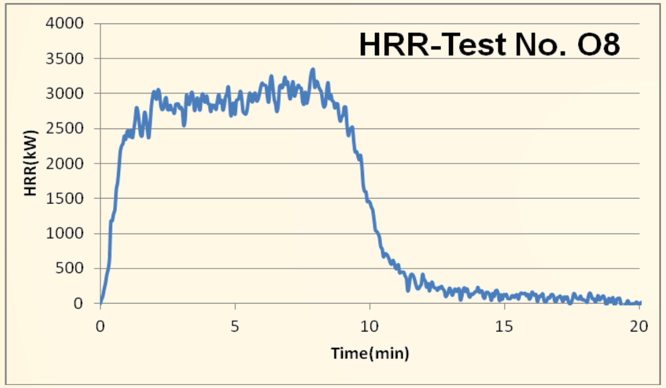


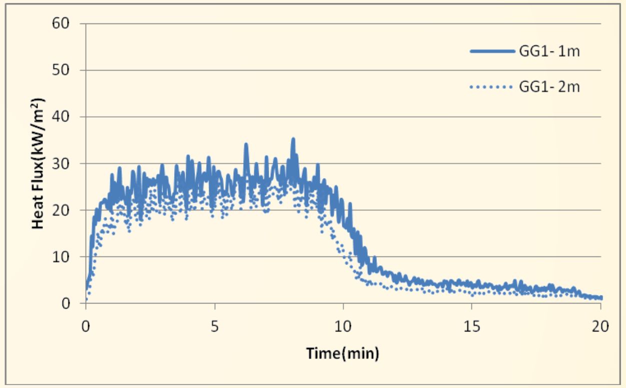
2. Experimental tests and CFD calibration

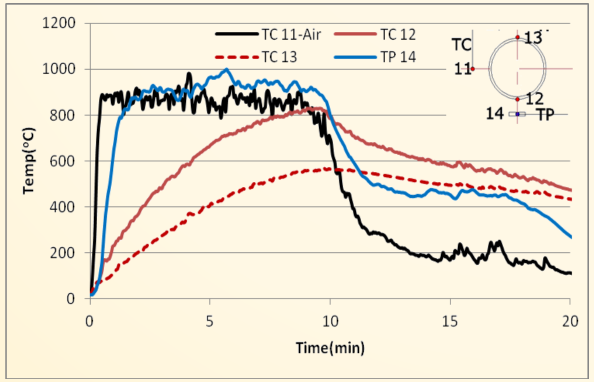
Tests performed at the University of Ulster

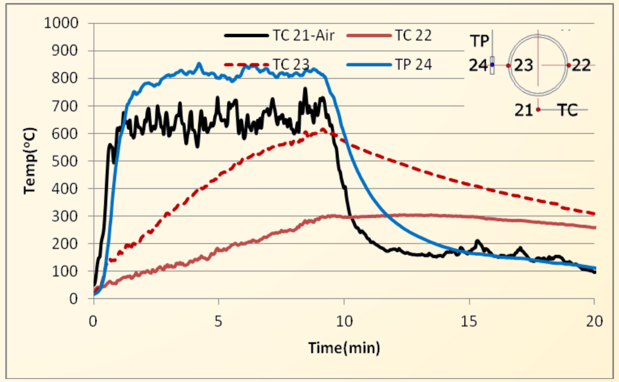
Experimental measurements : results obtained from O8 test

- Number of Pan(s) : 1
- Diameter of the pan : 1.6 m
- Fuel type : Kerosene
- Fuel quantity : 60 L
- Pool-column distance : 0 m
- Gauges-column distance : 1.5m
- No ceiling









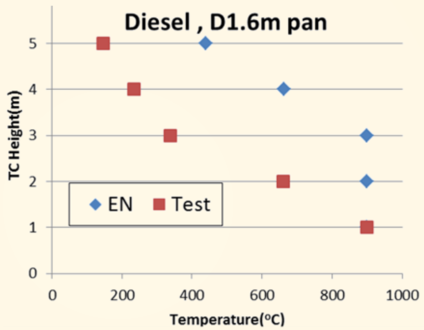
2. Experimental tests and CFD calibration

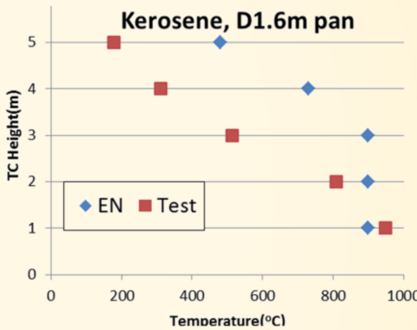
Tests performed at the University of Ulster

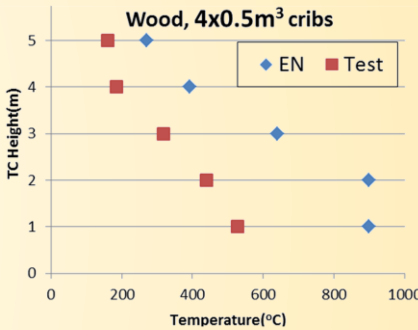
Experimental measurements : flame temperature

HEIGHT	TESTS O8, I9 (KEROSENE, D1.6M)		TEST O10 (DIESEL, D1.6M)		TESTS O1,O2 (KEROSENE, D0.7M)		TESTS O3,O4 (DIESEL, D0.7M)		TEST O14 (WOOD CRIBS)	
	EN	TEST	EN	TEST	EN	TEST	EN	TEST	EN	TEST
1M	900	949	900	899	900	686	900	652	900	527
2M	900	810	900	660	845	223	697	208	900	440
3M	900	515	900	339	381	90	325	89	640	317
4M	730	312	663	235	228	-	198	-	391	185
5M	479	179	440	146	157	-	139	-	271	159

These tests confirm that Heskestad correlation (EN 1991-1-2) over-estimates temperatures in the flame ($\theta_g \geq 500°C$) and the plume ($\theta_g < 500°C$) domains.







2. Experimental tests and CFD calibration

Calibration of a CFD model using FDS software

Objectives

- The number of tests is limited and the measurements made during these tests are limited too.

- Due to the dimensions of the building/lab where the experimental tests have been undertaken, it was not possible to cover the full range of localised fires (Annex C of EN 1991-1-2 applies until D = 10 m and Q = 50 MW)

→ After validation of the model(s), CFD modelling is a cost-effective and powerful tool able to provide a very large set of results for further validation of analytical calculation methods

- FDS software is a free software, developed by NIST, and widely-used by the community of fire engineers

Calibration of FDS models was processes by reproducing a selection of 5 tests chosen on the basis of the following criteria

- Tests performed under constant and controlled conditions (Liège) and free conditions (Ulster)
- Tests exhibiting long stable and steady-state results
- Different types of fuels, small and large pool diameters, with and without ceiling,…

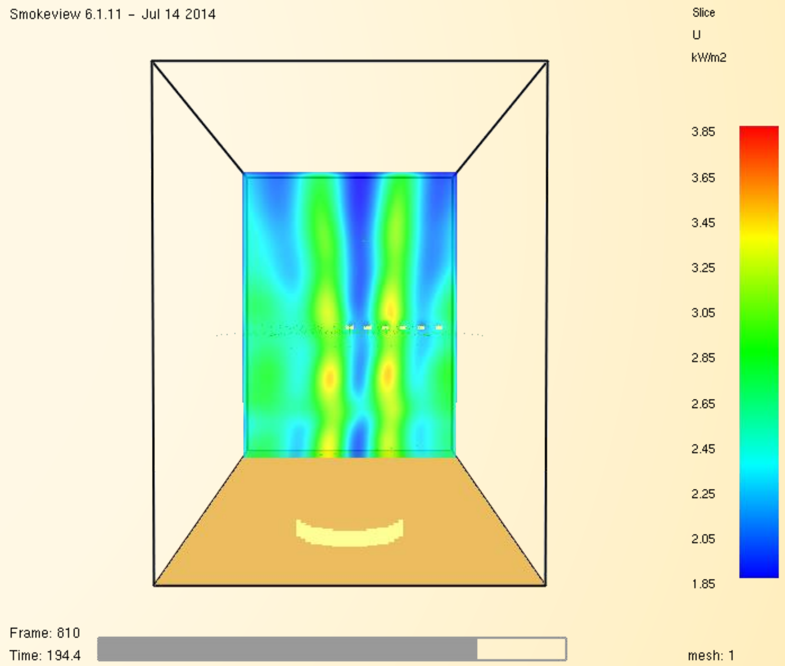
2. Experimental tests and CFD calibration

Calibration of a CFD model using FDS software

Calibration parameters

The most influencing parameters adjusted during the calibration process are :

- Turbulence model (Smagorinski, $C_s = 0.1$)
- Fuel properties, including soot yield, taken from literature (overventilated conditions)
- Number of Radiation Angles (200)
- Radiative loss fraction (range of 0.2-0.5, mainly depending on fuel type and fire diameter)
- Wind effects (based on measurements)
- Mesh grid dimensions (based on characteristic length and measure of turbulence resolution)



Example of flux variations due to an insufficient number of Radiation Angles

2. Experimental tests and CFD calibration

Calibration of a CFD model using FDS software

Test ULG 06 (D = 1m, Heptane, no column)

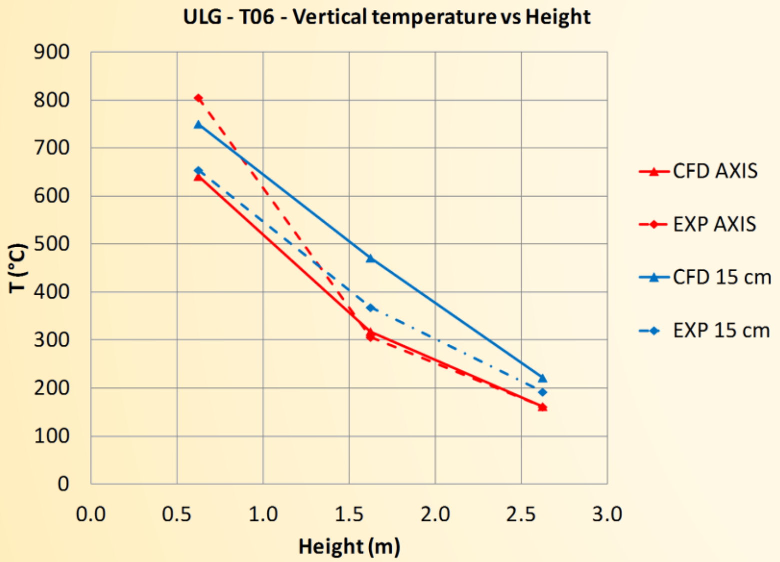
Average fuel flow q_{fuel}	0.98 l/min
Fuel density ρ	675 kg/m^3
Soot yield y_{soot}	0.037
Ideal heat of combustion $\Delta H_{c,ideal}$	44600 kJ/kg
Heat of combustion ΔH_c	41200 kJ/kg
RHR computed with $\Delta H_{c,ideal}$	491.7 kW (626.1 kW/m^2)

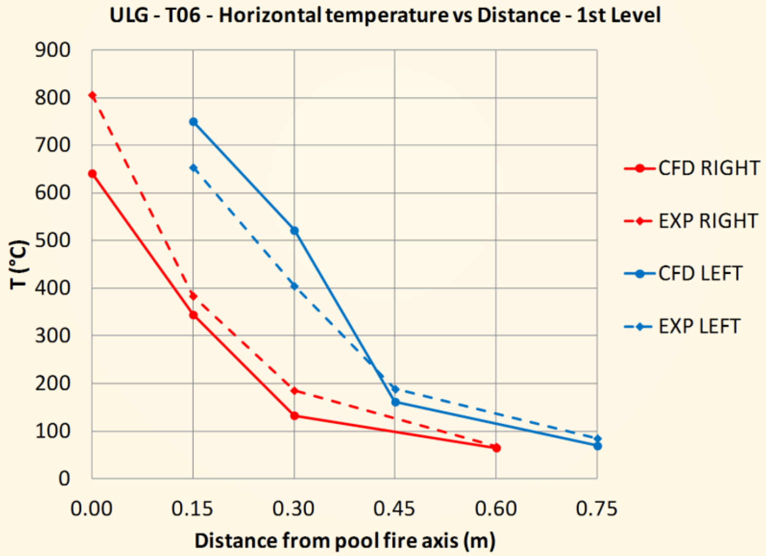
- Dimension of the CFD domain : 5.75m x 3m x 4m
- Grid size : 5cm x 5 cm x 5 cm
- Wind speed : 0.22 m/s
- Radiative loss fraction : 0.45 (SFPE)

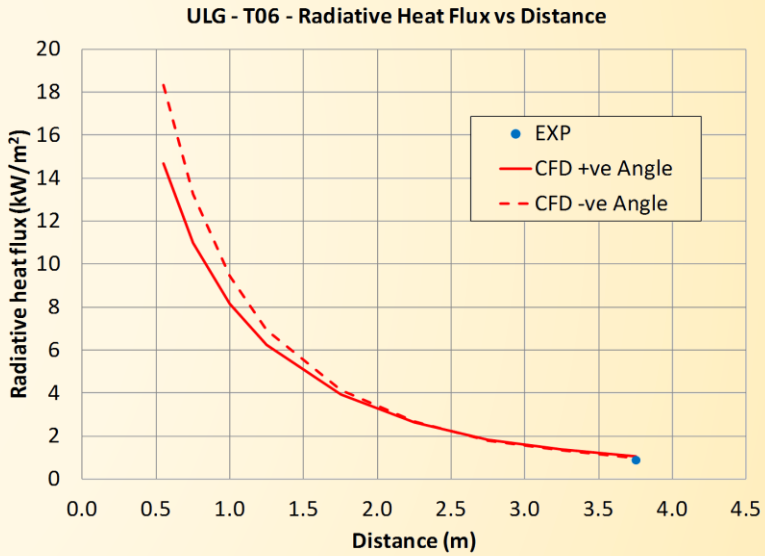
2. Experimental tests and CFD calibration

Calibration of a CFD model using FDS software

Test ULG 06 (D = 1m, Heptane, no column)







2. Experimental tests and CFD calibration

Calibration of a CFD model using FDS software

Test Ulster O29 (D = 0.7m, Diesel, with ceiling at 3.5m)

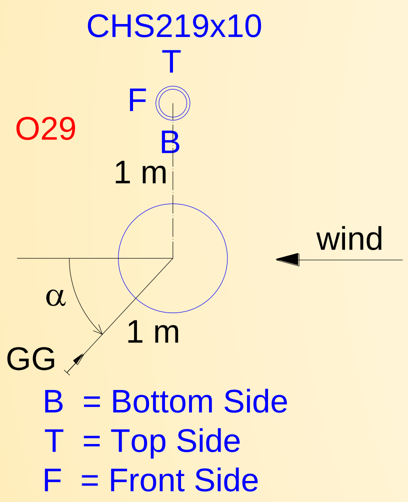
Fuel density ρ	**823 kg/m^3**
Soot yield y_{soot}	**0.10**
Ideal heat of combustion $\Delta H_{c,ideal}$	**44000 kJ/kg**
Heat of combustion ΔH_c	**41200 kJ/kg**
RHR computed with $\Delta H_{c,ideal}$	**491.5 kW (1277.1 kW/m^2)**

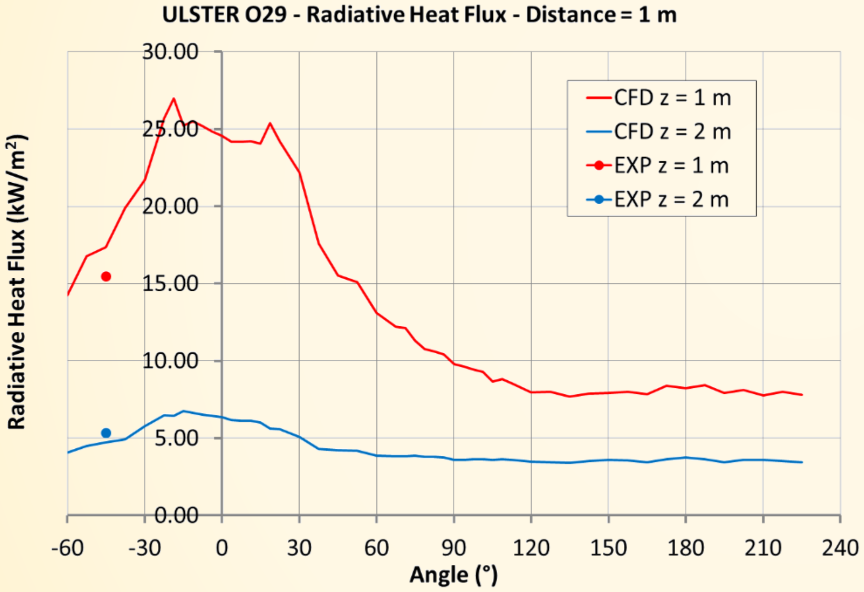
- Dimension of the CFD domain : 7m x 7m x 3.5m
- Grid size : 5cm x 5 cm x 5 cm
- Wind speed : 0.76 m/s
- Radiative loss fraction : 0.45 (SFPE)

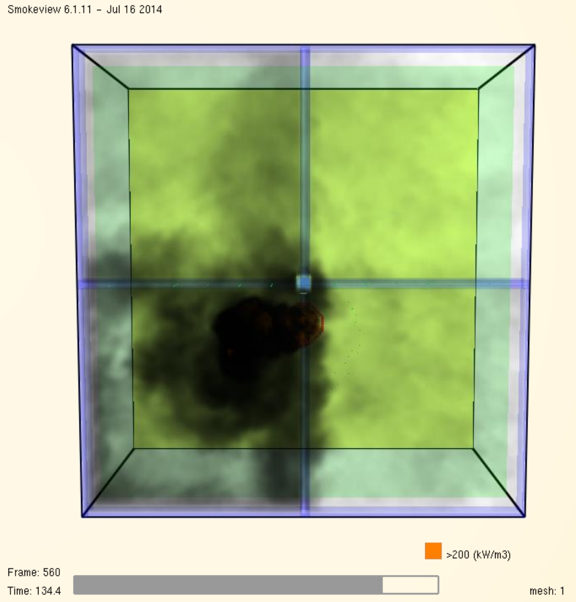
2. Experimental tests and CFD calibration

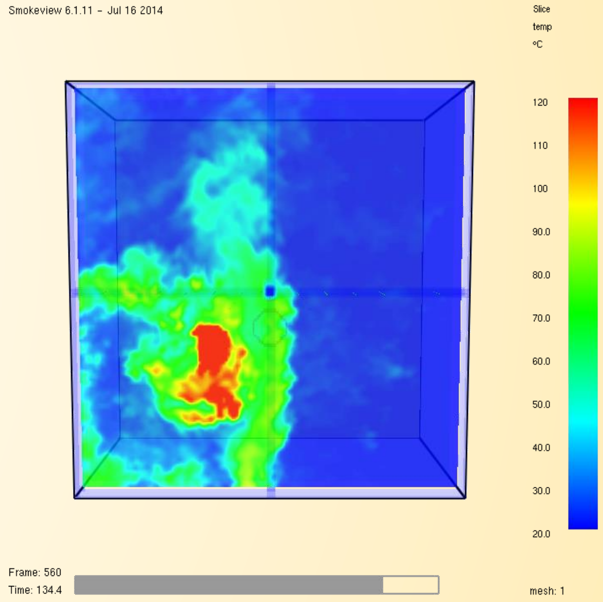
Calibration of a CFD model using FDS software

Test Ulster O29 (D = 0.7m, Diesel, with ceiling at 3.5m)









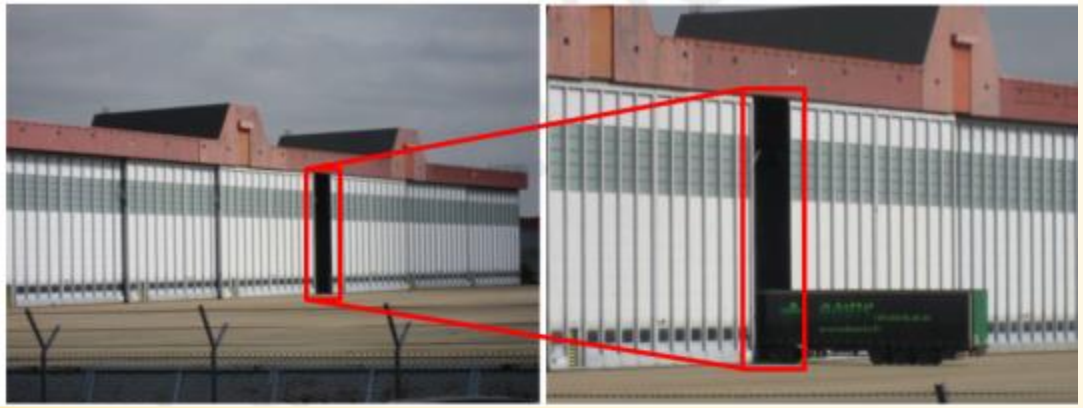
z (m)	CFD RHFG GG (kW/m²)	EXP GG (kW/m²)	Error (%)
1	17.35	15.45	12.3
2	4.71	5.32	-11.5

2. Experimental tests and CFD calibration

French tests (not in the scope of LOCAFI+)

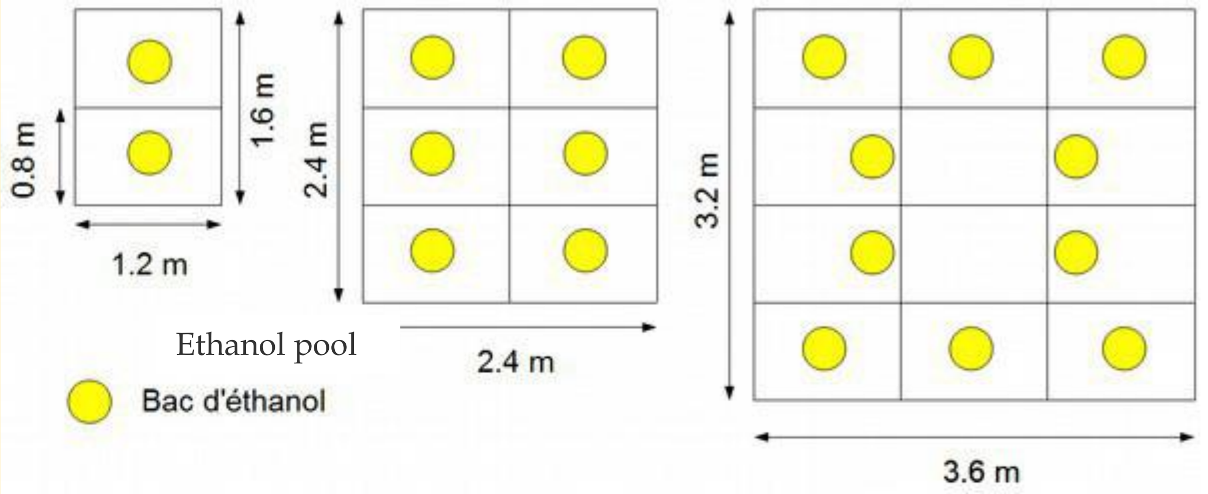
Tests initiated by LCPP in a large volume :

- Main hall : 300 m x 50 x 17 m
- 2 kinds of combustibles : wood pallet / kerosen
- Fire tests repeated
- Highly instrumented : thermocouples, gauge heat flux, videos (IR and normal)



2. Experimental tests and CFD calibration

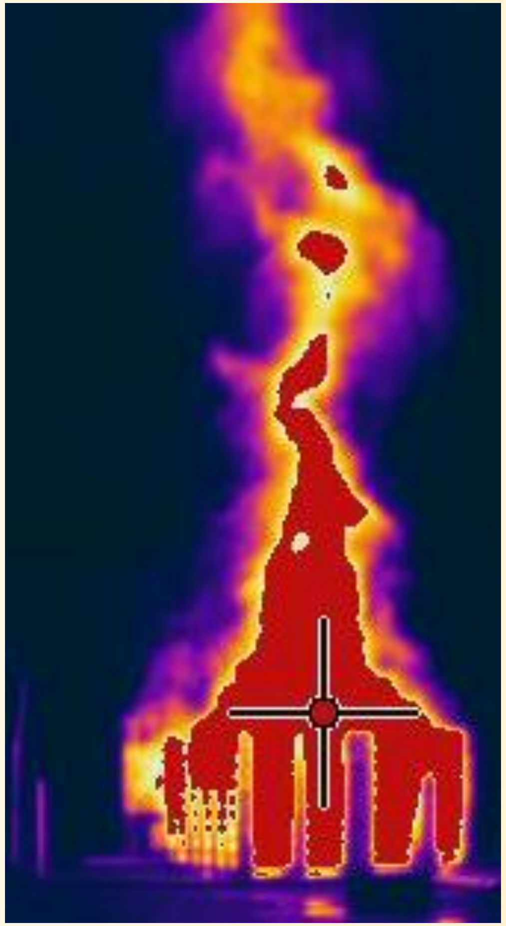
Small Medium Huge



Small test : ~ 20 palets
Medium test : ~ 60 palets
Huge test : ~ 110 palets

2. Experimental tests and CFD calibration

HRR ~ 30 MW



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3. Analytical method and validation

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3. Analytical method and validation

3.1. Concept of Virtual Solid Flame

Modelling of the flame

Step 1: The surface of the fire is transformed into an equivalent discus

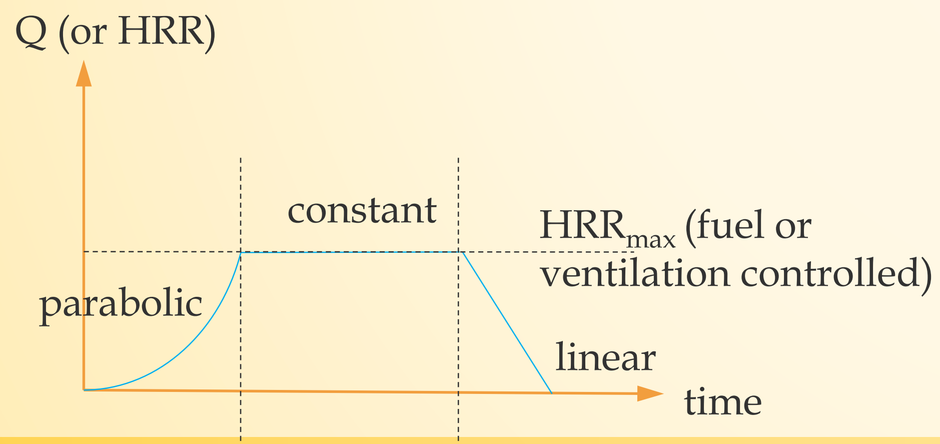
$$D_{fire} = \sqrt{\frac{4.S}{\pi}}$$

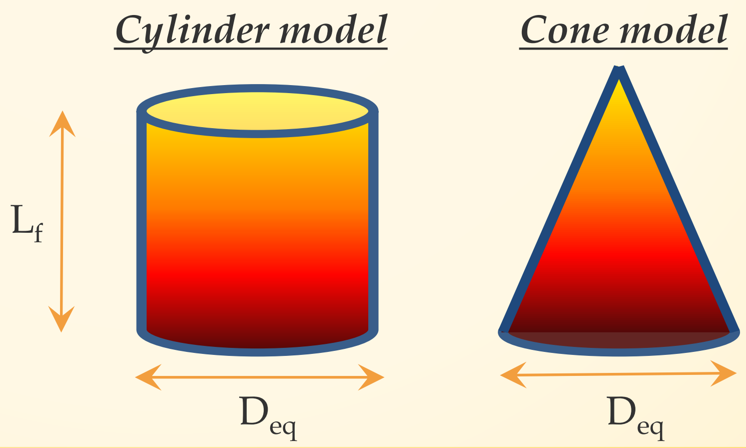
Step 2: The evolution of Heat Release Rate is calculated according to EN 1991-1-2 Annex E (growing phase, plateau, decaying phase)

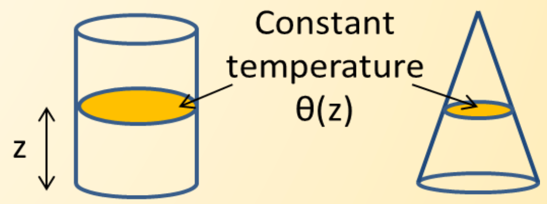
Step 3: The flame length L_f is calculated by application of EN 1991-1-2 Annex C

$$L_f(t) = -1.02\, D_{fire} + 0.0148\, Q(t)^{0.4}$$

Step 4: The action of the fire is represented by a virtual solid flame, conic or cylindric, defined by D_{eq} and L_f





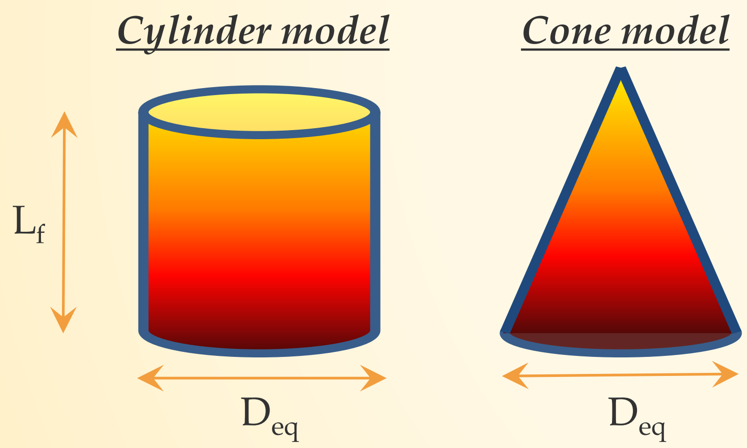


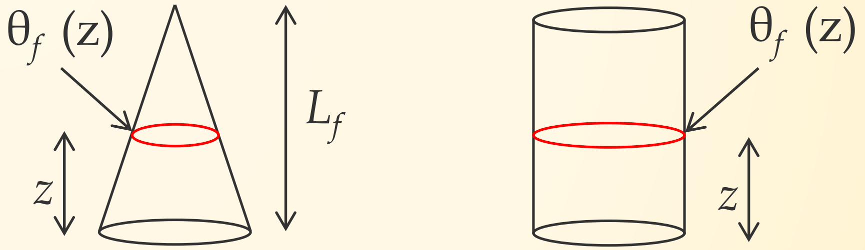
3. Analytical method and validation

3.1. Concept of Virtual Solid Flame

Modelling of the flame

If the flame does not impact the ceiling ($L_f < H_{ceiling}$ or no ceiling)





$$\theta_f(z) = \min\left(900; 20 + 0.25\left(0.8Q(t)\right)^{2/3}(z - z_0)^{-5/3}\right)$$

$$z_0 = -1.02D_{fire} + 0.00524\, Q(t)^{0.4}$$

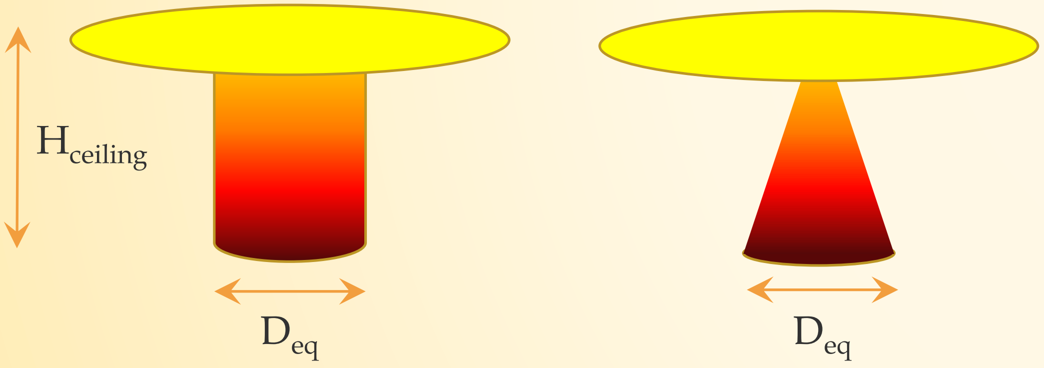
3. Analytical method and validation

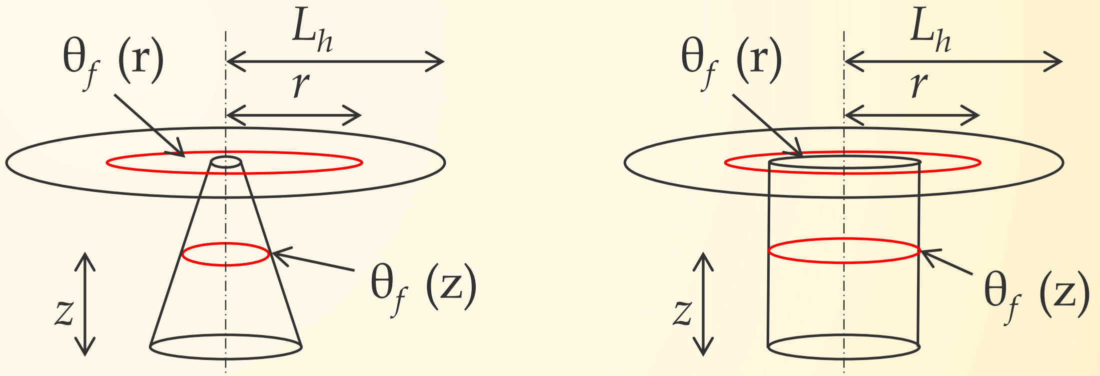
3.1. Concept of Virtual Solid Flame

Modelling of the flame

If the flame does impact the ceiling ($L_f > H_{ceiling}$)

Cylinder model ***Cone model***





$$\theta_f(z) = \min\left(900; 20 + 0.25\left(0.8Q(t)\right)^{2/3}(z - z_0)^{-5/3}\right)$$

$$z_0 = -1.02D_{fire} + 0.00524\,Q(t)^{0.4}$$

$$L_h(t) = H\left(2.9Q(t)_H^{0.33} - 1\right)$$

$\dot{h}(r)$ *calculated from Hasemi*

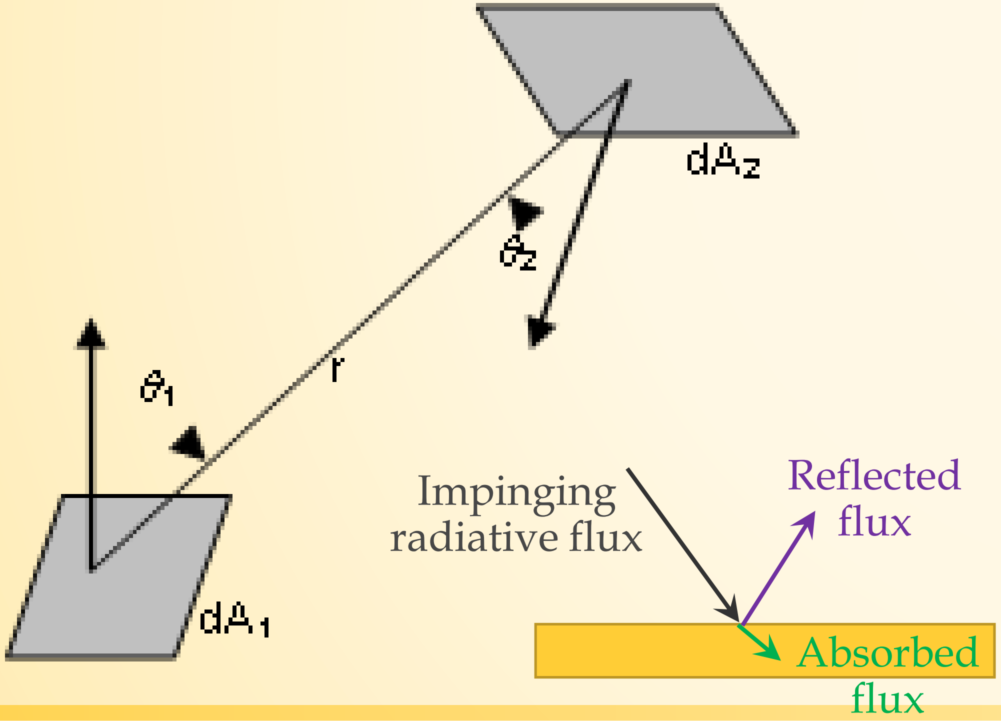
$\theta_f(r)$ *satisfies to* $\dot{h}(r) = \sigma\left(\left(\theta_f(r) + 273\right)^4 - 293^4\right) + 35\left(\theta_f(r) - 20\right)$

3. Analytical method and validation

3.2. Geometrical method for exchanged heat fluxes

Assessment of radiative heat fluxes

The radiative heat flux leaving a given radiating surface dA_1 and received by a surface dA_2 is :



$$\emptyset_{dA_1 \rightarrow dA_2} = \alpha_2 \varepsilon_1 \sigma . T^4 \frac{cos(\theta_1) cos(\theta_2) dA_1 dA_2}{\pi r^2}$$

- the emissivity ε_1 (of the emitting surface) is assumed equal to 1 for flames
- the absorptivity α_2 depends on the receiving surface properties
- Kirchoff Law : absorptivity (α) = emissivity (ε)
- For steel, $\varepsilon = \alpha = 0.7$

3. Analytical method and validation

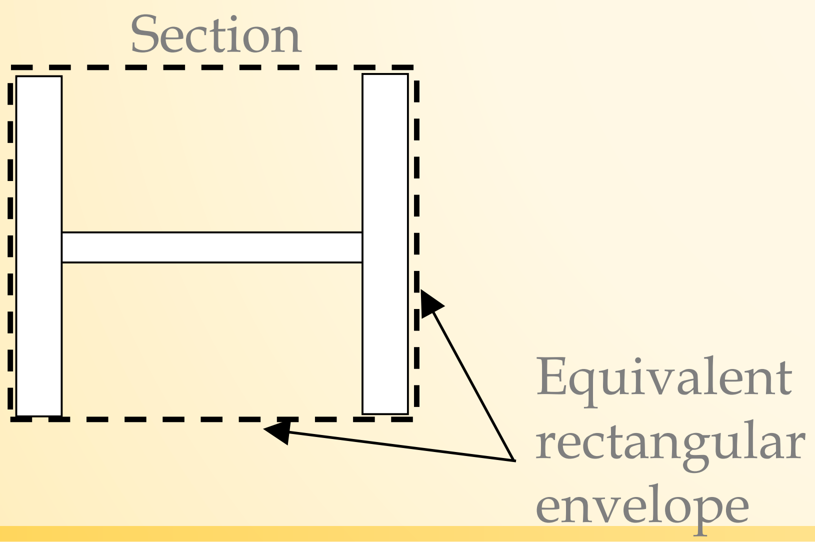
3.2. Geometrical method for exchanged heat fluxes

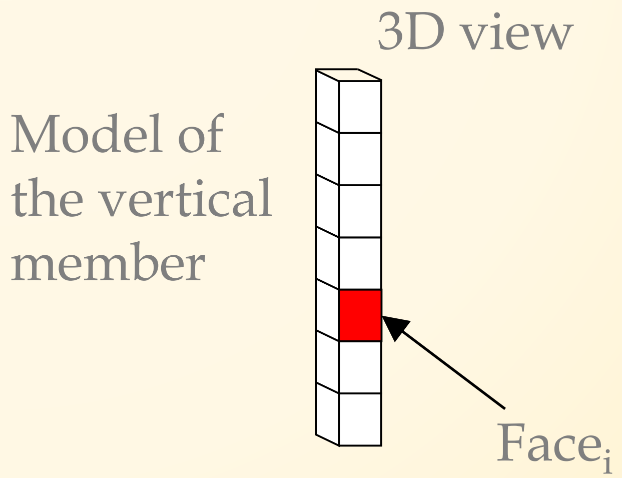
Modelling of the vertical member

Concave sections imply **shadow effect** → As a simplification, heat fluxes are calculated on a convex perimeter

For I- or H-sections, the structural member is transformed into a rectangular-shape tubular section (in line with EN 1991-1-2 Annex G)

Then, the perimeter surface is sub-divided into faces

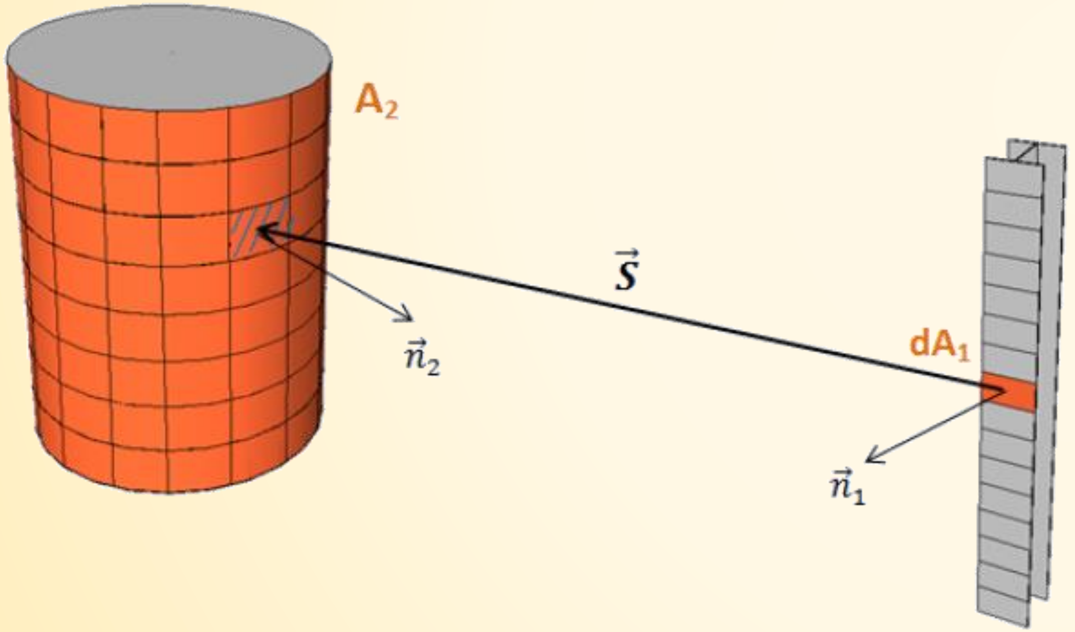




3. Analytical method and validation

3.2. Geometrical method for exchanged heat fluxes

Numerical integration

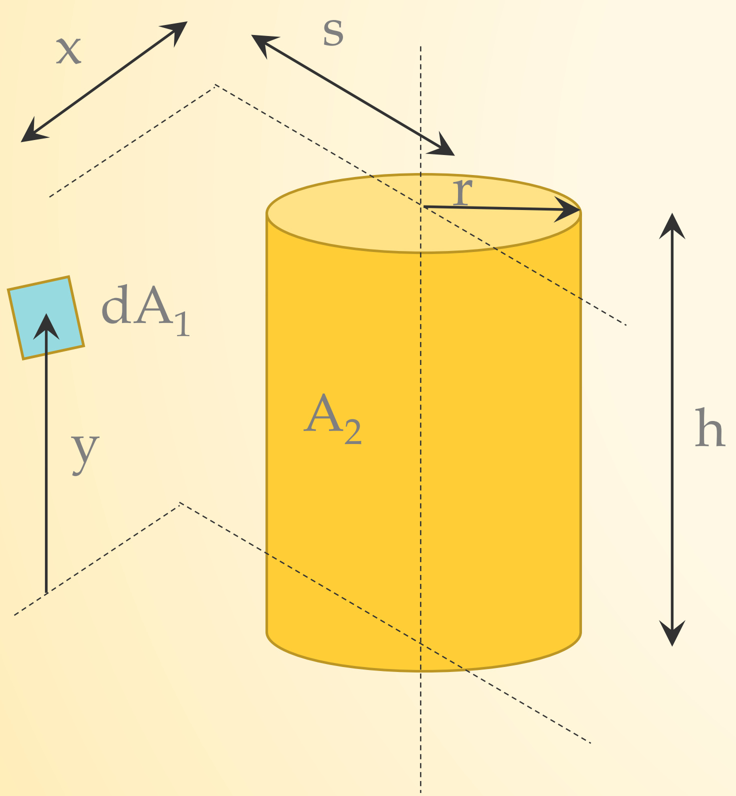


$$F_{d1-2} \simeq \frac{-1}{\pi} \sum_i \frac{(\vec{S}.\vec{n_1})(\vec{S}.\vec{n_2})}{S^4} \Delta A_i$$

- Each "individual" radiative exchange is calculated (at each time step).
- Requires a program for real applications.
- Allows applying non-uniform conditions (radiative fluxes) on the section perimeter.

3.3. Simplified model

Factor view between an infinitesimal surface and a cylinder



$$F_{dA_1 \to A_2} = \frac{S}{B} - \frac{S}{2B\pi} \left\{ \begin{array}{l} \cos^{-1}\left(\frac{Y^2 - B + 1}{A - 1}\right) + \cos^{-1}\left(\frac{C - B + 1}{C + B - 1}\right) \\ -Y\left[\frac{A + 1}{\sqrt{(A-1)^2 + 4Y^2}}\cos^{-1}\left(\frac{Y^2 - B + 1}{\sqrt{B}(A - 1)}\right)\right] \\ -\sqrt{C}\frac{C + B + 1}{\sqrt{(C + B - 1)^2 + 4C}}\cos^{-1}\left(\frac{C - B + 1}{\sqrt{B}(C + B - 1)}\right) \\ +H\cos^{-1}\left(\frac{1}{\sqrt{B}}\right) \end{array} \right\}$$

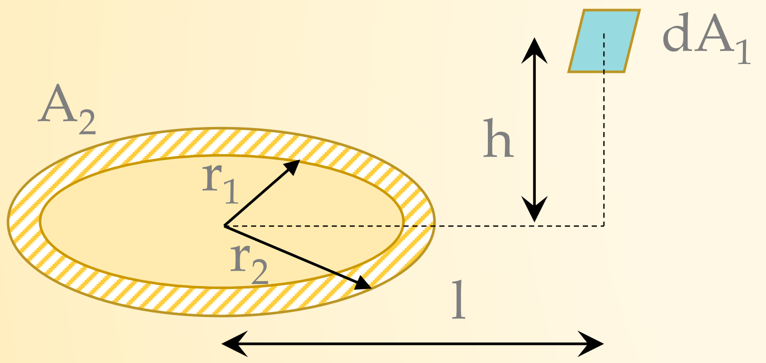
$$S = s/r$$
$$X = x/r$$
$$H = h/r$$
$$A = X^2 + Y^2 + S^2$$
$$B = S^2 + X^2$$
$$C = (H - Y)^2$$

Valid only if the plane defined by dA_1 does not intersect the cylinder !

3. Analytical method and validation

3.3. Simplified model

Factor view between an infinitesimal surface and a ring



$$F_{dA_1 \rightarrow A_2} = \frac{H}{2}\left(\frac{H^2 + R_2^2 + 1}{\sqrt{(H^2 + R_2^2 + 1)^2 - 4R_2^2}} - \frac{H^2 + R_1^2 + 1}{\sqrt{(H^2 + R_1^2 + 1)^2 - 4R_1^2}}\right)$$

$$H = h/l$$
$$R = r/l$$

Valid only if $l > r_2$!

3. Analytical method and validation

3.3. Simplified model

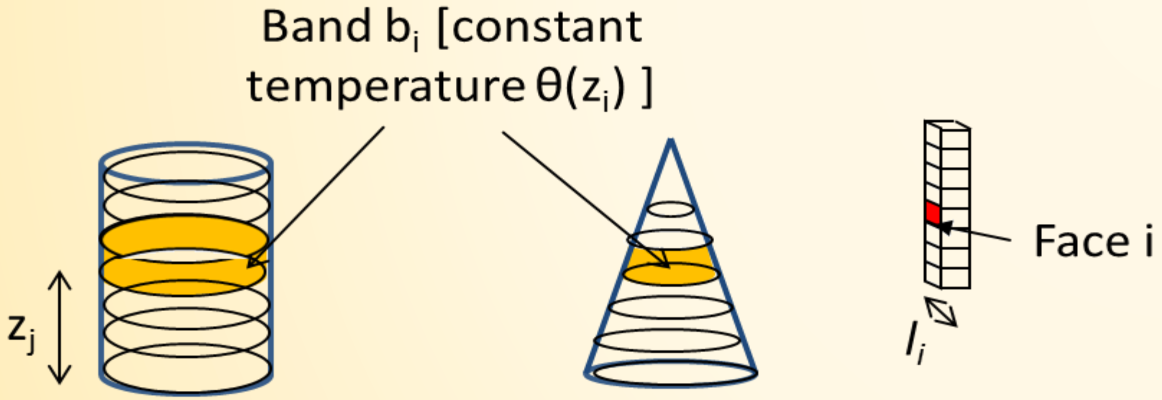
Sub-division of the flame into cylinders and rings

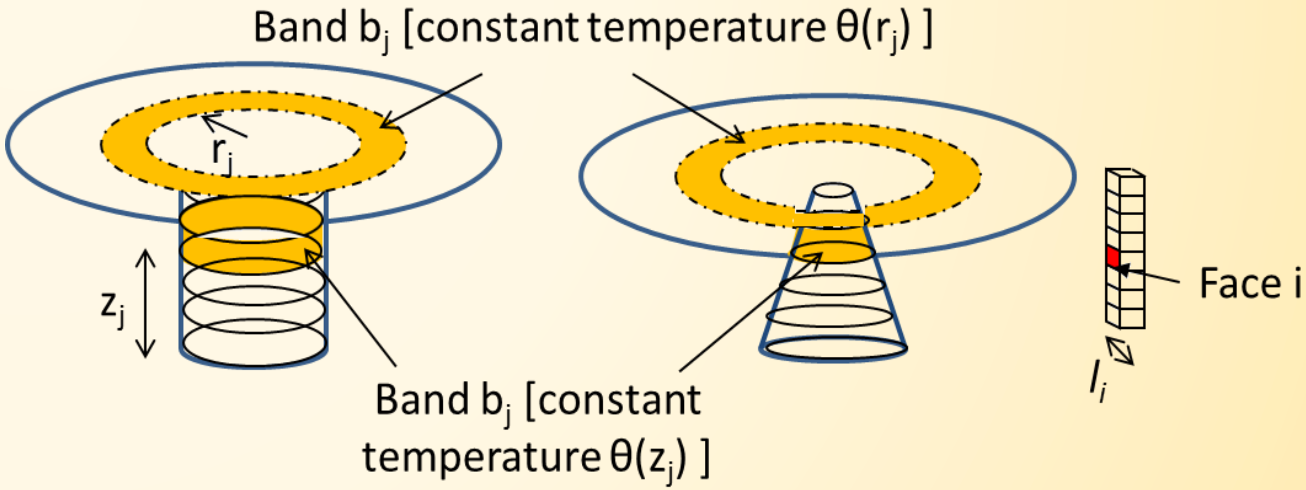
If the flame does not impact the ceiling

($L_f < H_{ceiling}$ or no ceiling)

If the flame does impact the ceiling

($L_f > H_{ceiling}$)



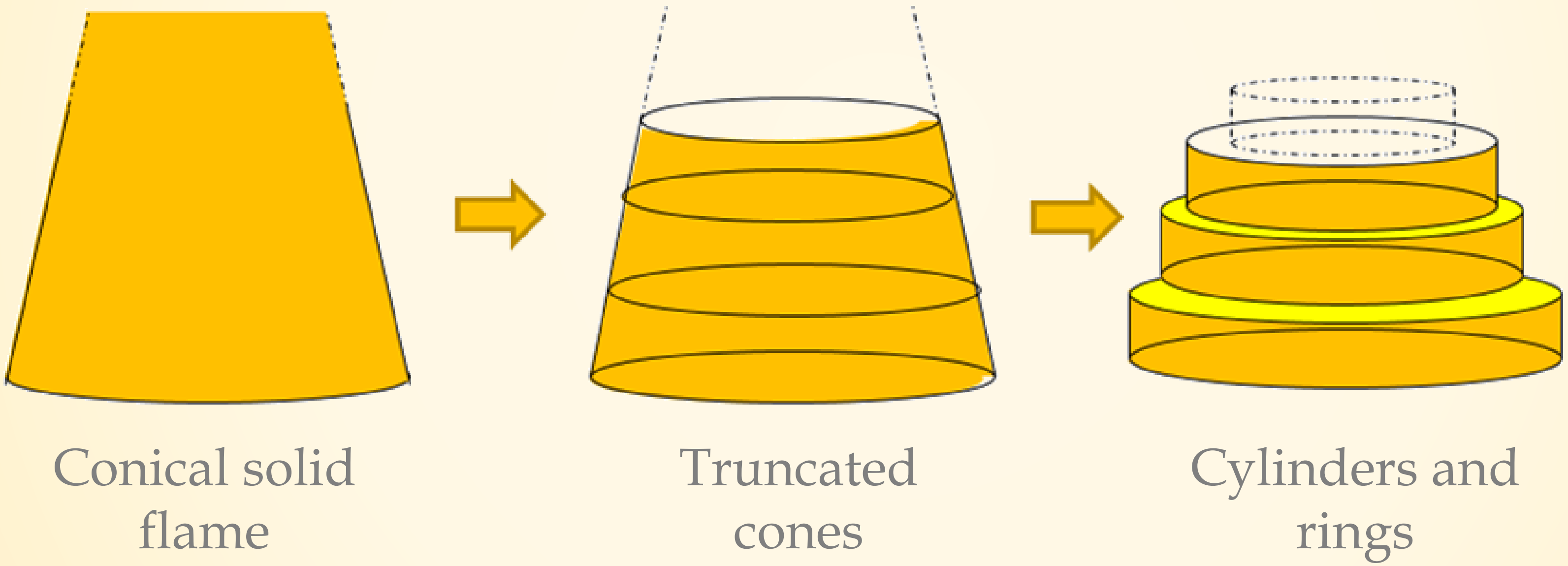


Note : the contribution of the ring is really low, except if the member is situated in the ring

3. Analytical method and validation

3.3. Simplified model

Sub-division of the flame into cylinders and rings (Adaptation 1)

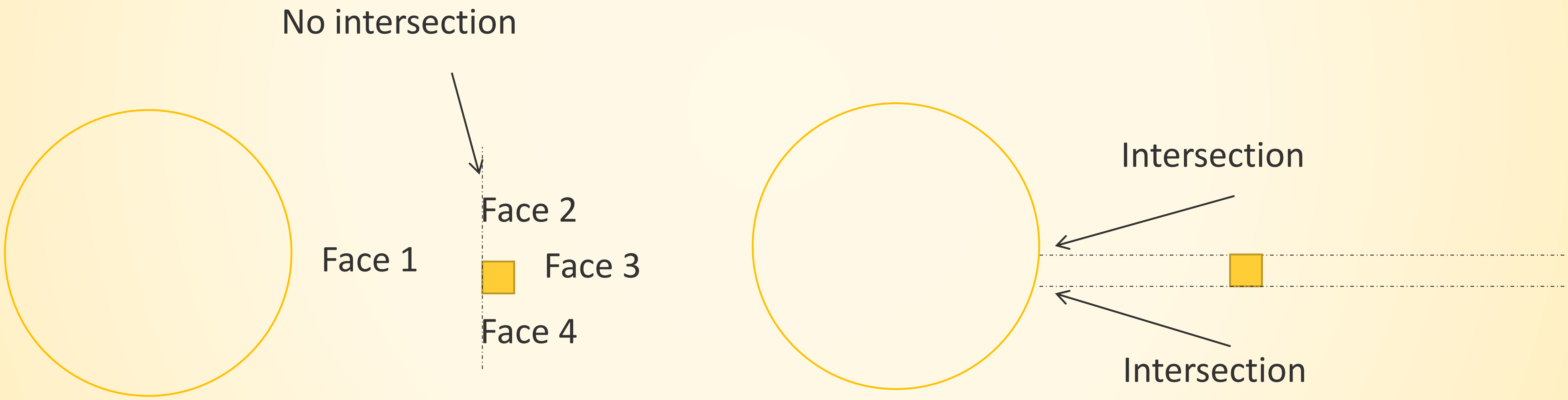


! By neglecting the contribution of rings, we underestimate the received flux and could even obtain a received flux equal to 0 above the fire !

3. Analytical method and validation

3.3. Simplified model

Sub-division of the flame into cylinders and rings (Adaptation 2)

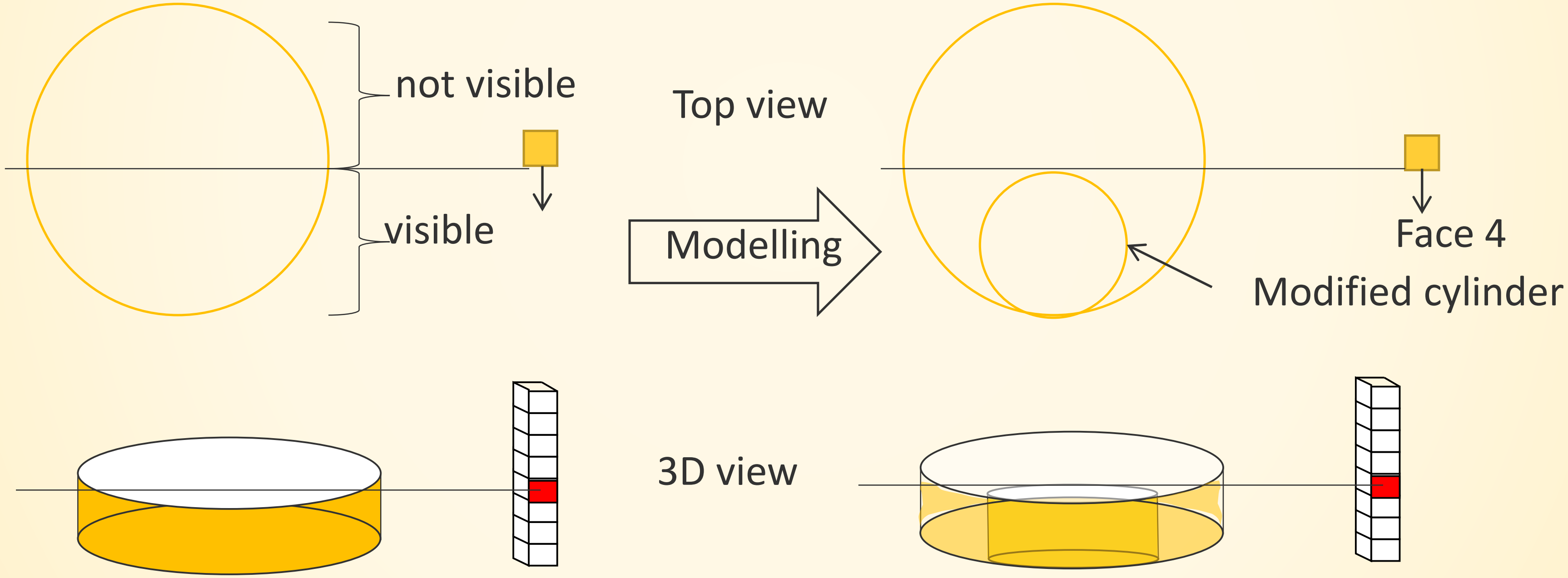


! The formula for cylinder is not valid if the receiving surface intersect the cylinder !

3. Analytical method and validation

3.3. Simplified model

Sub-division of the flame into cylinders and rings (Adaptation 2)

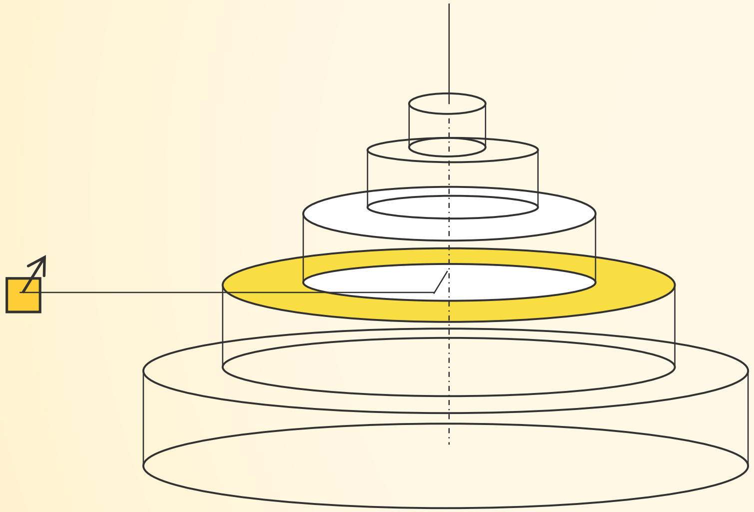


In this case, initial cylinder transformed into a modified cylinder in the visible zone

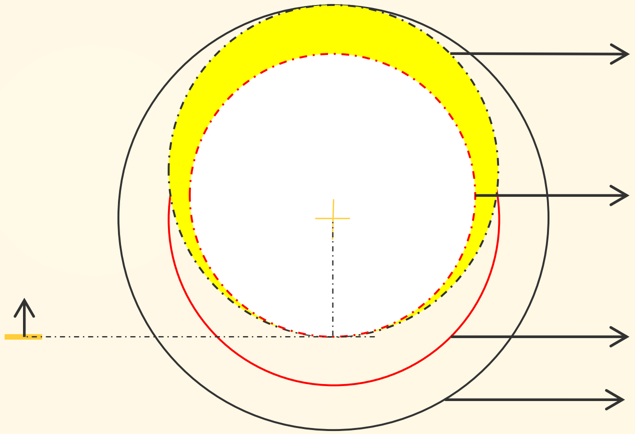
3. Analytical method and validation

3.3. Simplified model

Sub-division of the flame into cylinders and rings (Adaptation 3)



3D view



Top view

A portion of rings is « hidden » by the cylinder situated above → A reduced zone should be considered (safe-sided to ignore this reduction…)

3. Analytical method and validation

3.3. Simplified model

Additional remarks

- Recommended width of cylinder is 50 cm
- For elements situated below the ceiling, convection should be added → Hasemi
- For several fires, the fluxes received from each fire must be added. The total received flux is limited to 100 kW/m^2 $\dot{h}_{tot} = min(\dot{h}_{rad\_section} + \dot{h}_{conv}; 100000)$ [W.m^{-2}]
- The member temperature is calculated by stating the thermal balance of the member

$$\rho C_p(T)\frac{dT}{dt} = \frac{A_m}{V}\left[\dot{h}_{z_j} + \alpha_c(20-\theta) + \varepsilon\left(\sigma(293^4 - (\theta+273)^4)\right)\right]$$ [W.m^{-2}]

ρ, C_p, and A_m/V are density [kg.m^{-3}], specific heat [J.kg^{-1}.K^{-1}] and massivity [m^{-1}] of the member

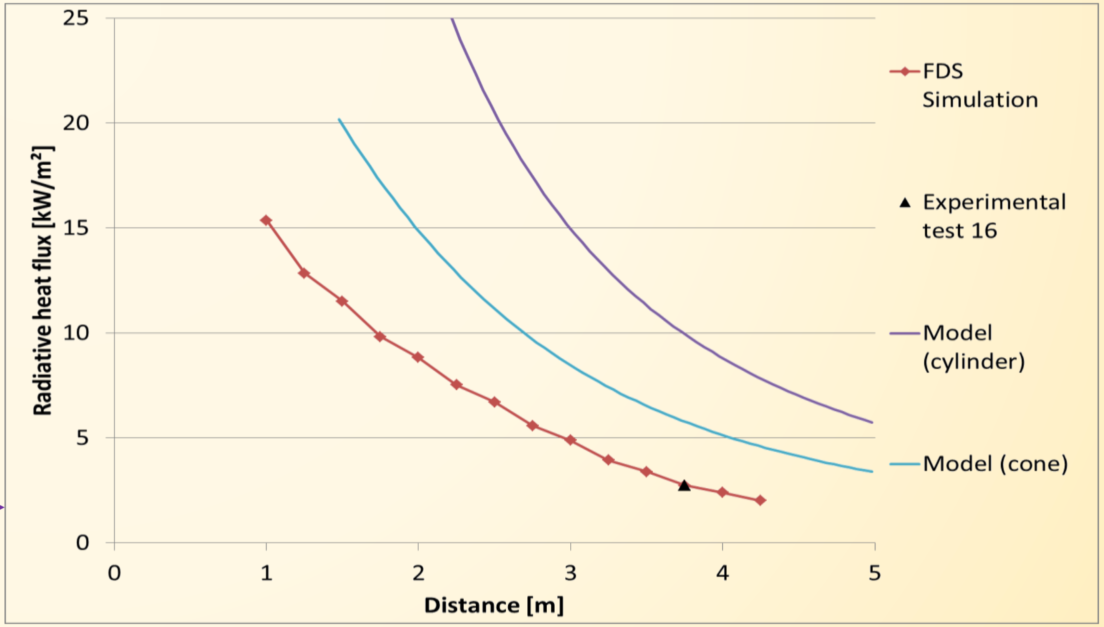
3. Analytical method and validation

3.3. Simplified model

Model validation based on Liège tests (and FDS modelling)

- Gauge situated at 3.75 m from the fire source (height : 1.75 m)
- Orientation of the gauge : perpendicular to the fire-gauge axis

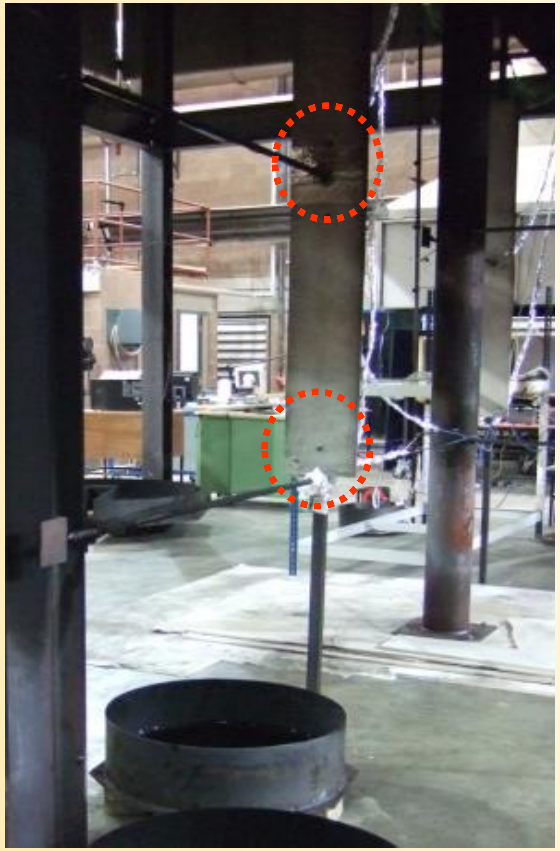
Diam.	Experiment mean value	Tests no	Cylindric flame	Conic flame
[m]	[kW/m²]	[-]	[kW/m²]	[kW/m²]
0.60	0.31	1 to 4	1.20	0.74
1.00	0.73	5 to 8	3.23	1.95
1.40	1.36	9 to 14	6.19	3.67
1.80	2.12	15 to 18	9.95	5.78
2.20	3.39	19 to 22	14.55	8.30

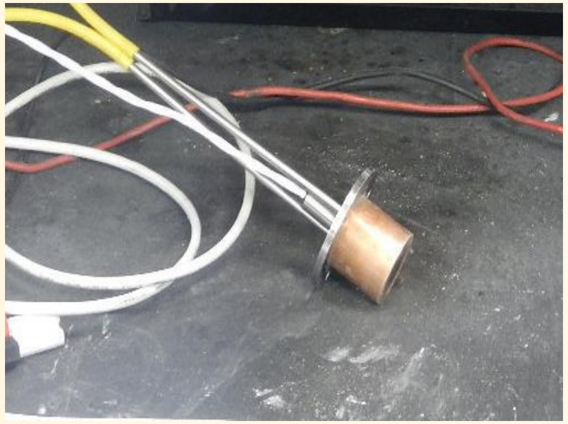


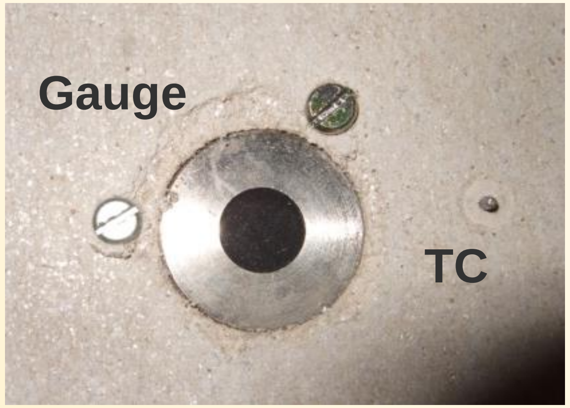
3. Analytical method and validation

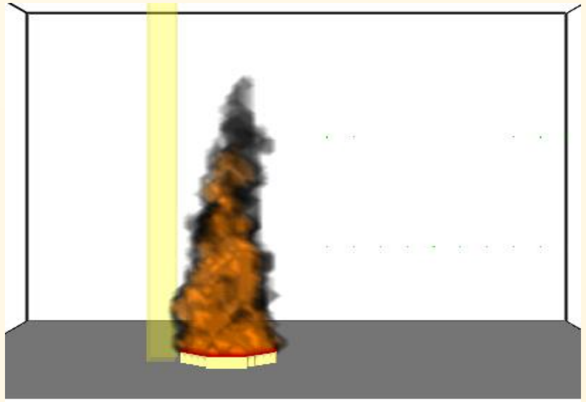
3.3. Simplified model

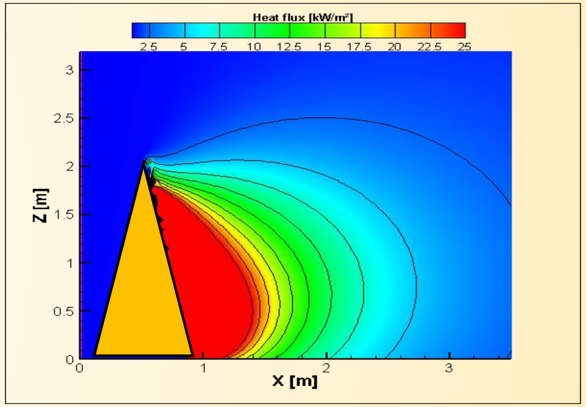
Model validation based on Ulster tests (and FDS modelling)

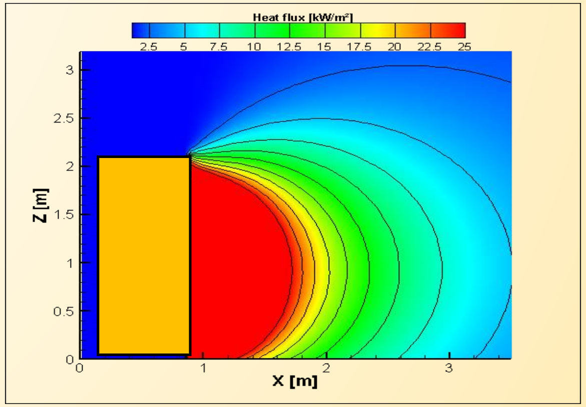








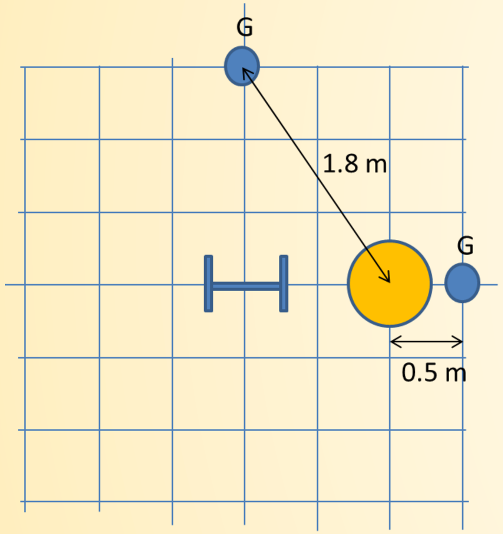




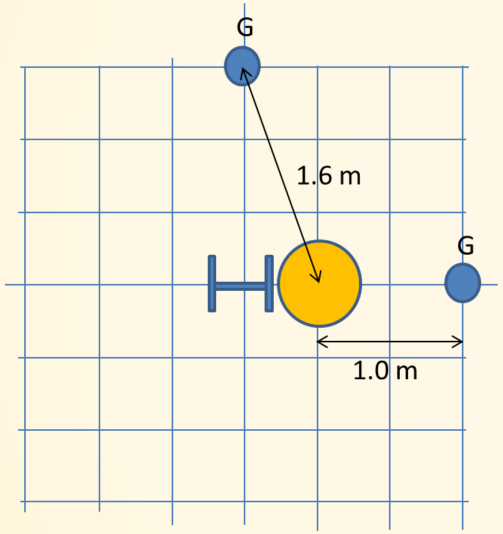
3. Analytical method and validation

3.3. Simplified model

Model validation based on Ulster tests (and FDS modelling)



Case 1a
1 pan
D = 0.7 m
Gauges at 0.5/1.8 m



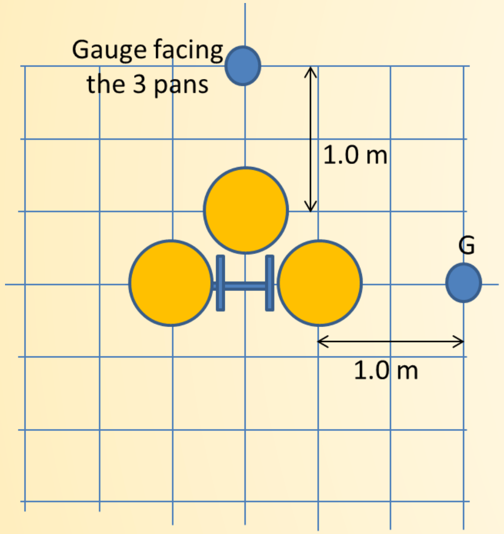
Case 1b
1 pan
D = 0.7 m
Gauges at 1.0/1.6 m

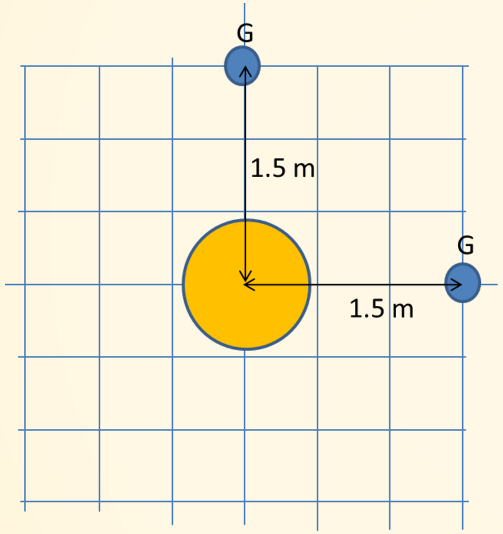
Gauge location		Experiment mean	FDS Simulation	Cylindric flame	Conic flame
Height	Distance				
m	m	kW/m²	kW/m²	kW/m²	kW/m²
1.0	0.5	30.6	28.5	74.0	39.0
1.0	1.0	13.8	12.9	33.2	17.9
1.0	1.6	5.9	5.5	15.5	8.5
1.0	1.8	4.2	3.8	10.8	6.0
2.0	0.5	6.2	11.2	22.0	5.9
2.0	1.0	4.5	5.9	14.1	5.5
2.0	1.6	3.0	3.7	8.8	4.1
2.0	1.8	2.3	2.6	6.7	3.3

3. Analytical method and validation

3.3. Simplified model

Model validation based on Ulster tests (and FDS modelling)





Case 3
3 pans
D = 0.7 m
Gauges at 1.0 m

Case 5
1 pan
D = 1.6 m
Gauges at 1.5 m

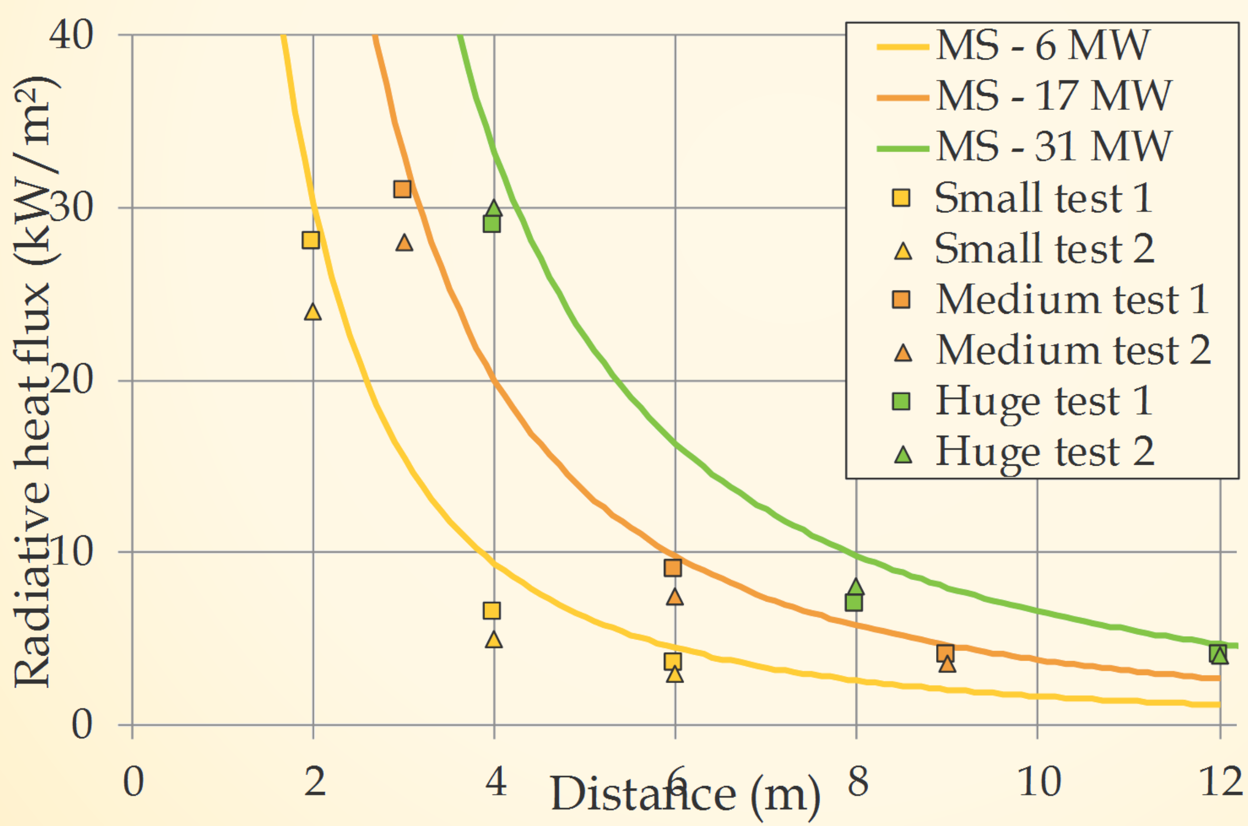
Gauge location		Experiment mean	Simulation mean	Cylindric flame	Conic flame
Height	Distance				
m	m	kW/m²	kW/m²	kW/m²	kW/m²
1.0	1.0	31.0	26.6	66.3	37.4
1.0	1.0	24.3	21.6	62.0	34.6
2.0	1.0	15.0	17.7	40.9	16.2
2.0	1.0	13.0	13.6	38.5	15.9

Gauge location		Experiment mean	Simulation mean	Cylindric flame	Conic flame
Height	Distance				
m	m	kW/m²	kW/m²	kW/m²	kW/m²
1.0	1.5	37.6	33.6	53.9	38.9
2.0	1.5	26.5	24.5	55.2	29.7

3. Analytical method and validation

3.3. Simplified model

Model validation for large diameters (LCPP tests)



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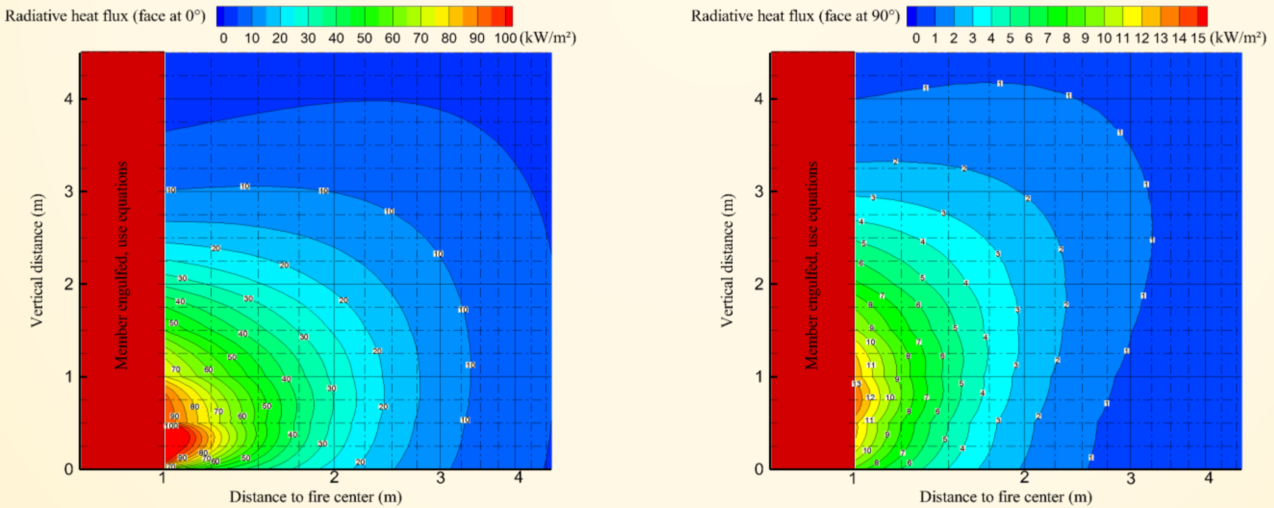
3. Analytical method and validation

3.4. Contour plots

- Provide a new set of results for validation of SAFIR and OZone implementations
- Provide quick and safe results for a wide range of configurations (predesign) and an interpolation method to apply it to a much wider range of configurations
- Provide a set of reference results for validation of implementation of analytical methods by practitioners (spreadsheets or software)



D = 2m, RHR = 500 kW/m^2, θ = 0° (left) or θ = 90° (right)

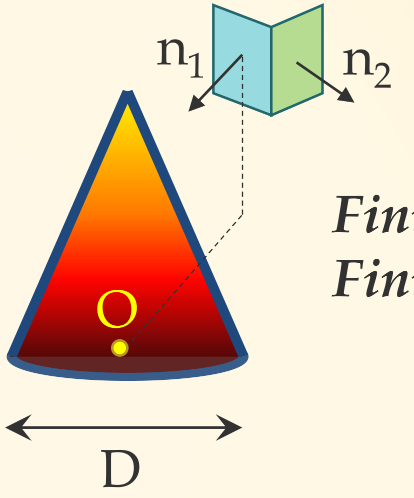
3. Analytical method and validation

3.4. Contour plots

- Each nomogram is characterised by :
  - the diameter of the fire (m)
  - the RHR (kW/m^2)
  - the orientation of the receiving surface (°)

- Nomograms only account for radiation. Not used :
  - Inside the fire → HESKESTAD
  - At the ceiling level → HASEMI

- Assumes that the flame emissivity is 1.0



Finite Surface 1 : θ = 0°
Finite Surface 2 : θ = 90°

3. Analytical method and validation

3.4. Contour plots

Case	1	2	3	4	5	6	7	8	9	10	11	12
D (m)	2	2	2	2	3	3	3	3	4	4	4	4
HRR (kW/m²)	250	500	1000	1500	250	500	1000	1500	250	500	1000	1500
Power (MW)	0.8	1.6	3.1	4.7	1.8	3.5	7.1	10.6	3.1	6.3	12.6	18.8

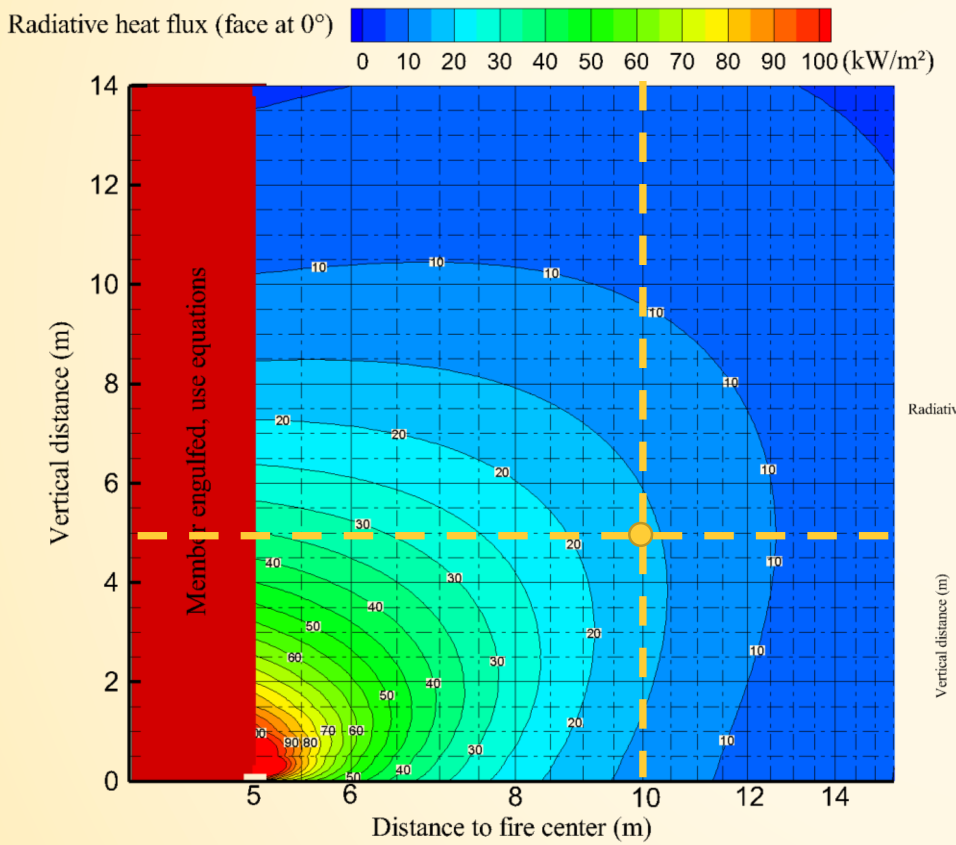
Case	13	14	15	16	17	18	19	20	21	22	23	24
D (m)	6	6	6	6	8	8	8	9	9	9	10	10
HRR (kW/m²)	250	500	1000	1500	250	500	1000	250	500	750	250	500
Power (MW)	7.1	14.1	28.3	42.4	12.6	25.1	50.3	47.7	15.9	31.8	19.6	39.3

Scope of application of the method (idem Annex C of EN 1991-1-2) : $D \leq 10$ m ; $Q \leq 50$ MW

→ *The chosen configurations cover the field of application of the calculation method*

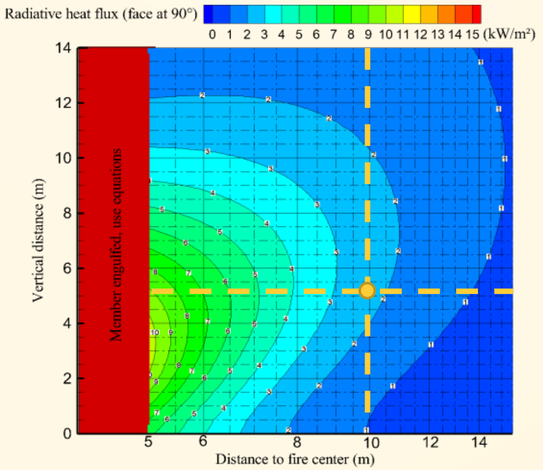
3. Analytical method and validation

3.4. Contour plots



- Localised fire characteristics :
  - D = 10 m
  - RHR : 500 kW/m^2
- Target position
  - Z = 5m
  - X = 10 m
  - Orientation : 0°

Received Flux = 16 kW/m^2



- Target position
  - Z = 5m
  - X = 10 m
  - Orientation : 90°

Received Flux = 2.4 kW/m^2

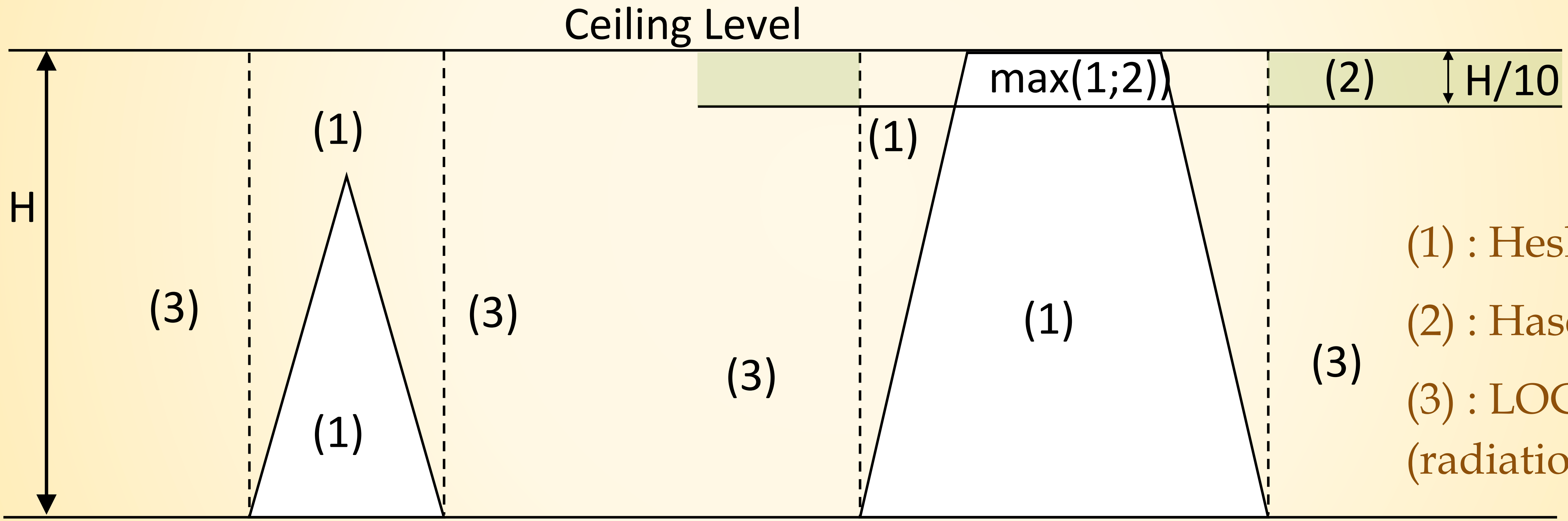
3. Analytical method and validation

3.5. Conclusions

- LOCAFI project introduces the new concept of Virtual Solid Flame.
- The distribution of temperature on the perimeter of the Virtual Solid Flame is based on existing equations of EN 1991-1-2 Annex C (Heskestad, Hasemi).
- The exchange of radiative fluxes is based on the configuration factor of EN 1991-1-2 Annex G.
- The simplified model is based on mathematical equations providing the radiative flux received by an infinitesimal surface from cylinders and rings.
- The convective fluxes must be calculated separately. However, convective heat fluxes have a significant effect only in configurations already covered by EN 1991-1-2 Annex C (members engulfed into fire or situated at the ceiling level).

3. Analytical method and validation

3.5. Conclusions



(1) : Heskestad

(2) : Hasemi

(3) : LOCAFI (radiation)

LOCAFI+

Temperature assessment of a vertical member subjected to LOCAlised FIre
Dissemination

4. Software

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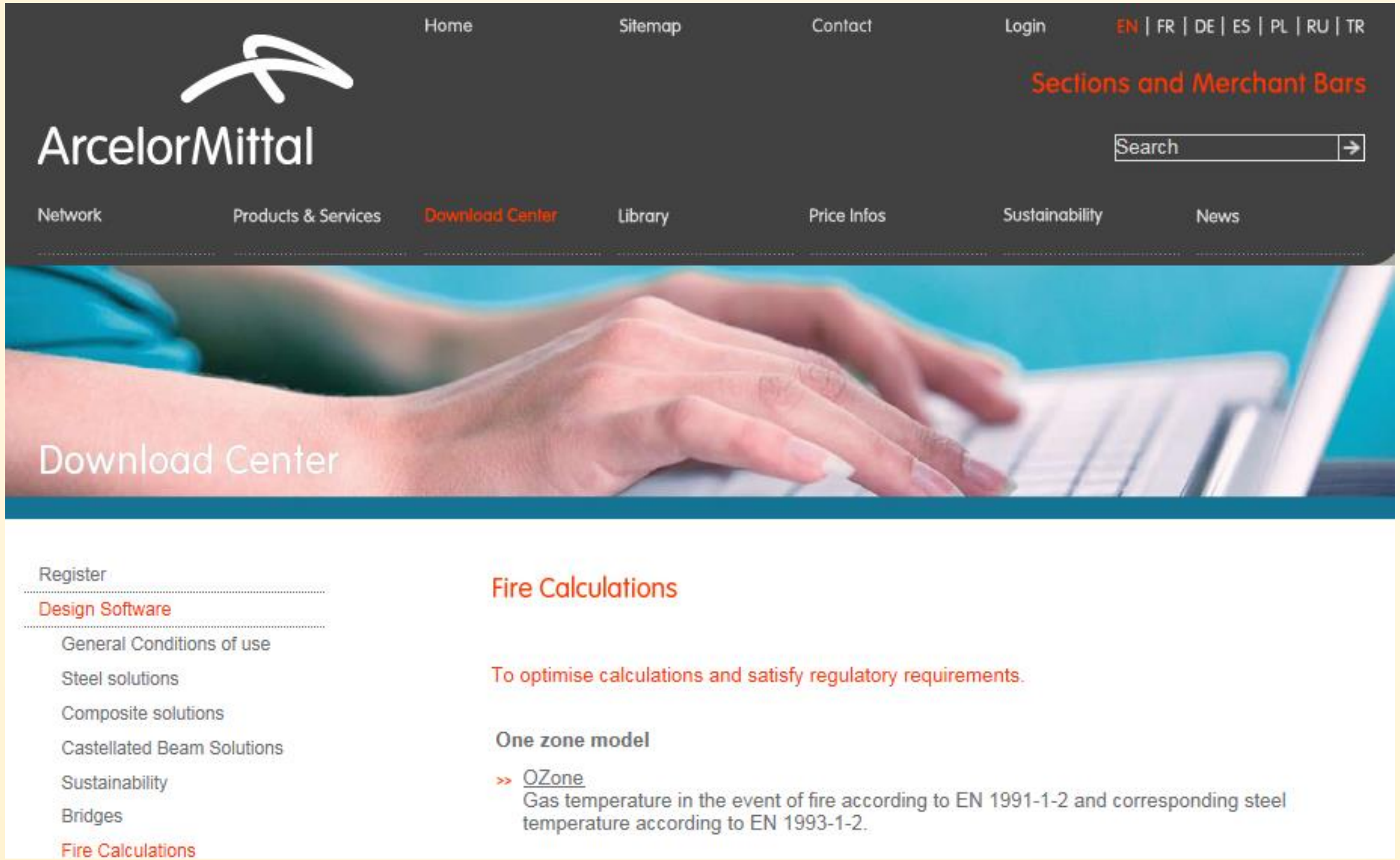
4. Software

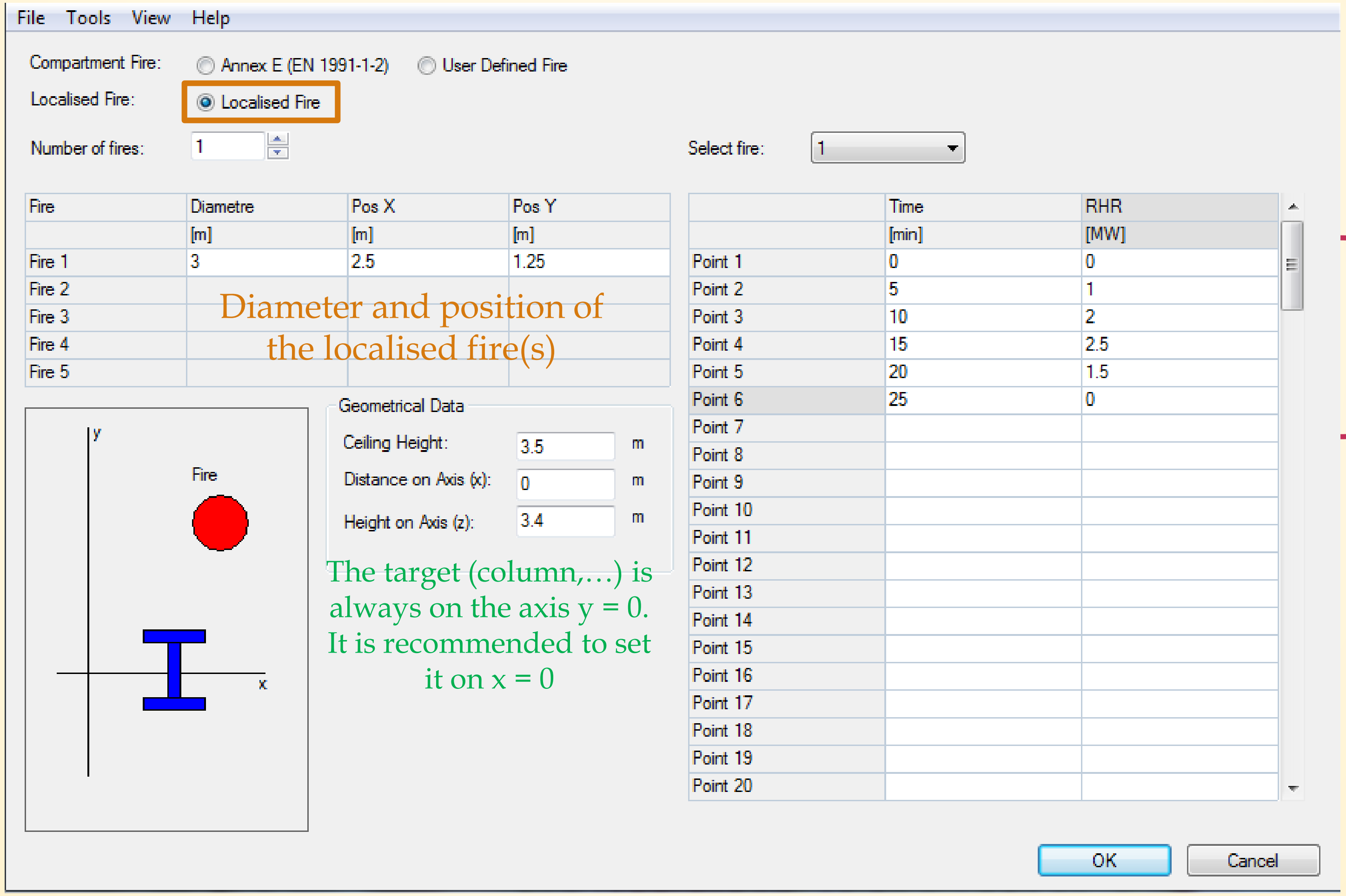
4.1. OZone



http://sections.arcelormittal.com/download-center/design-software/fire-calculations.html

4. Software

4.1. OZone



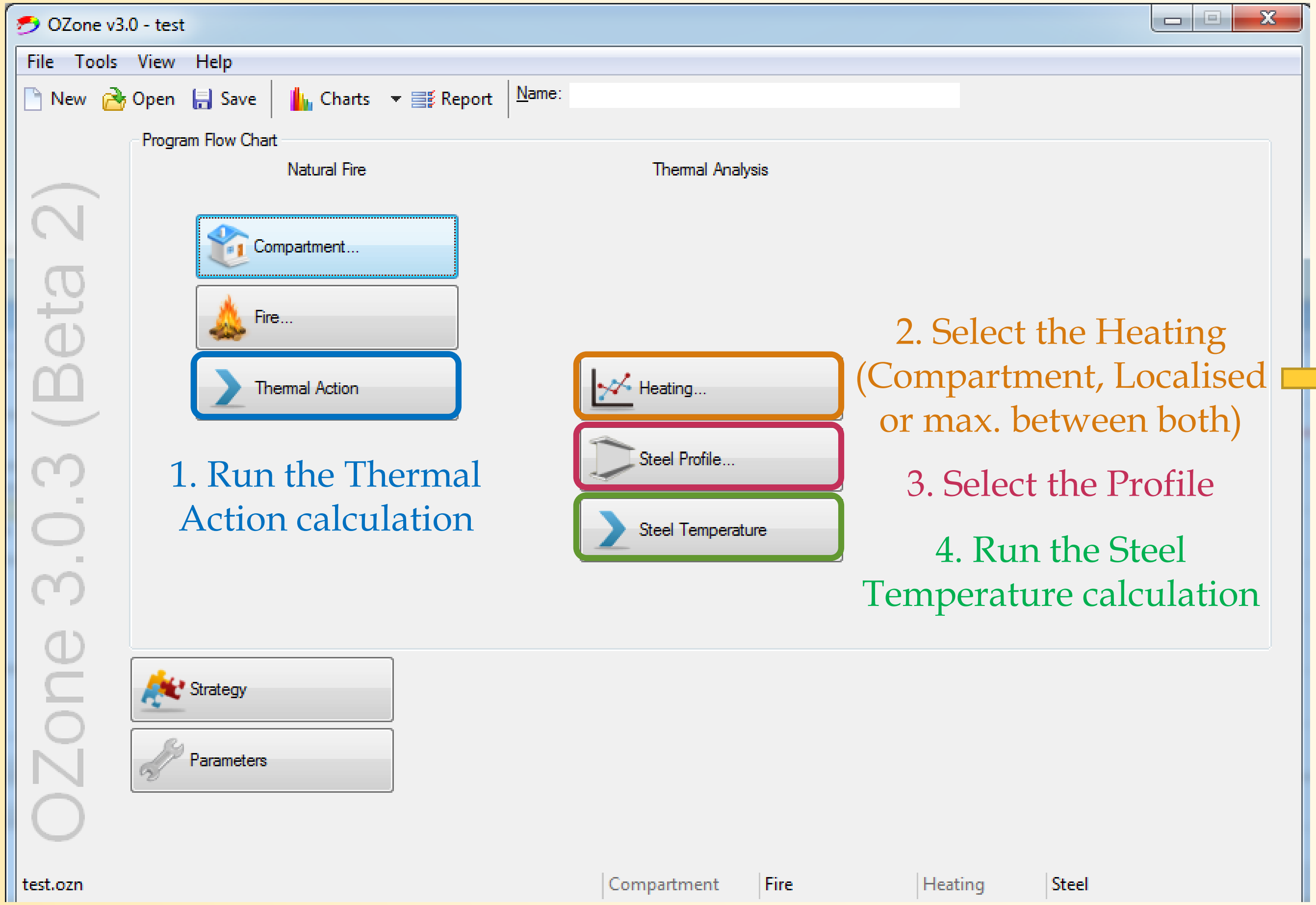
Diameter and position of the localised fire(s)

The target (column,…) is always on the axis y = 0. It is recommended to set it on x = 0

Evolution of RHR

4. Software

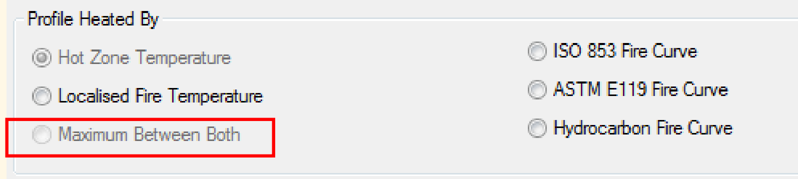
4.1. OZone

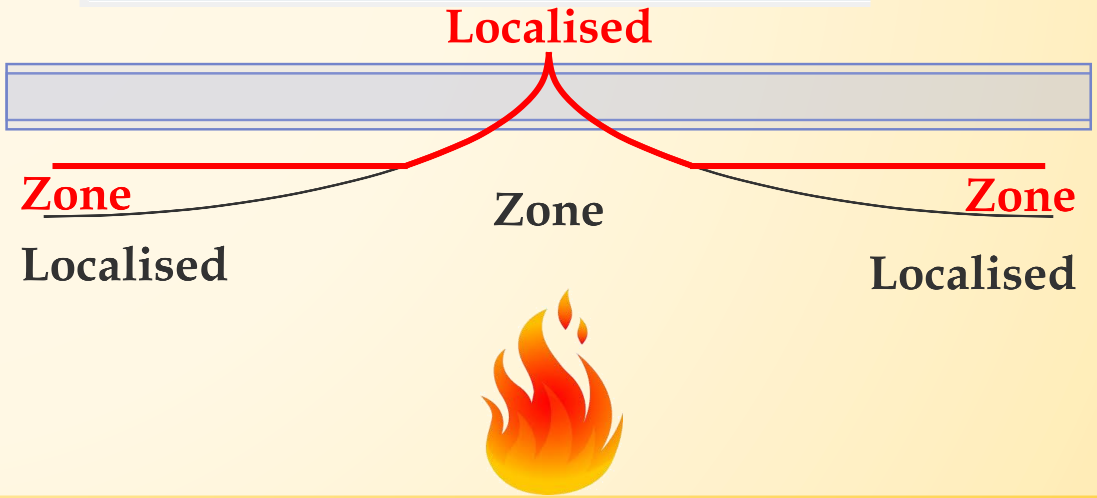


<u>EN 1991-1-2 § 3.3.2 (4)</u>

In order to calculate more accurately the temperature distribution along a member, in case of a localised fire, a combination of results obtained with a two-zone model and a localised fire approach may be considered.

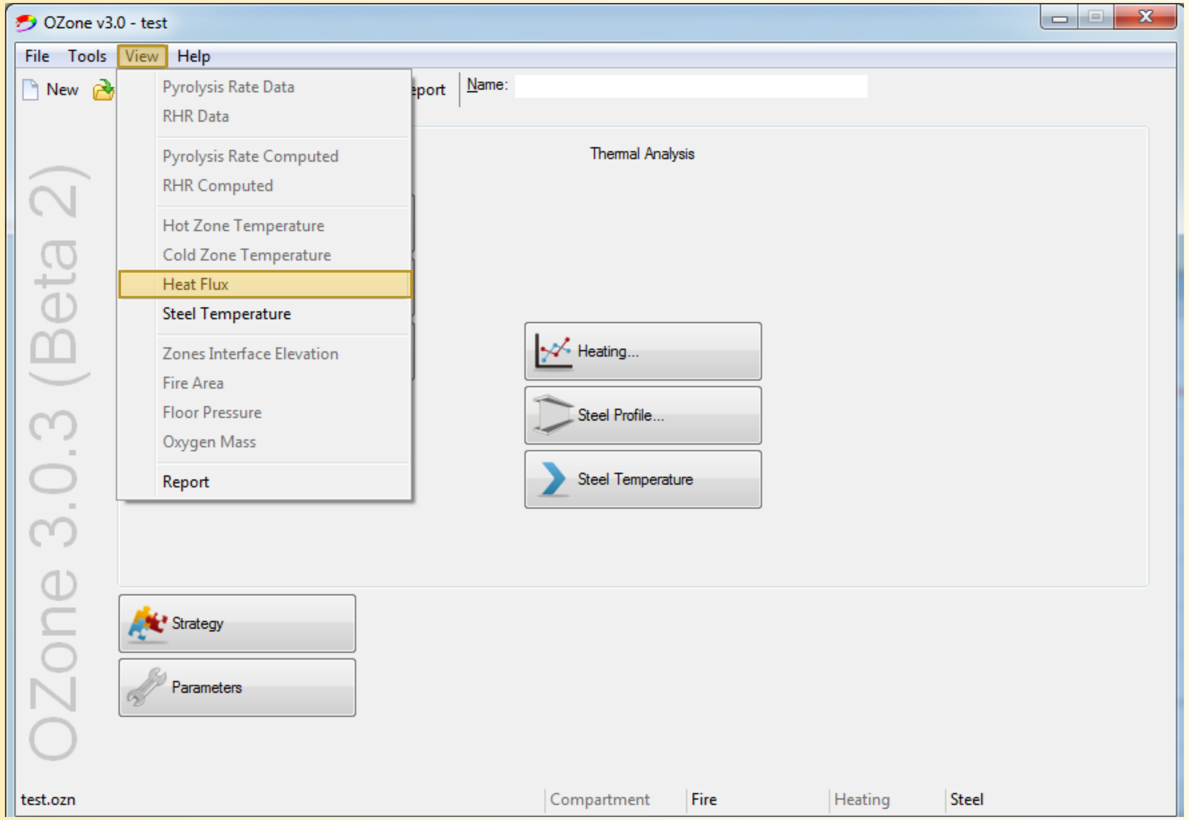
NOTE The temperature field in the member may be obtained by considering the maximum effect at each location given by the two fire models.

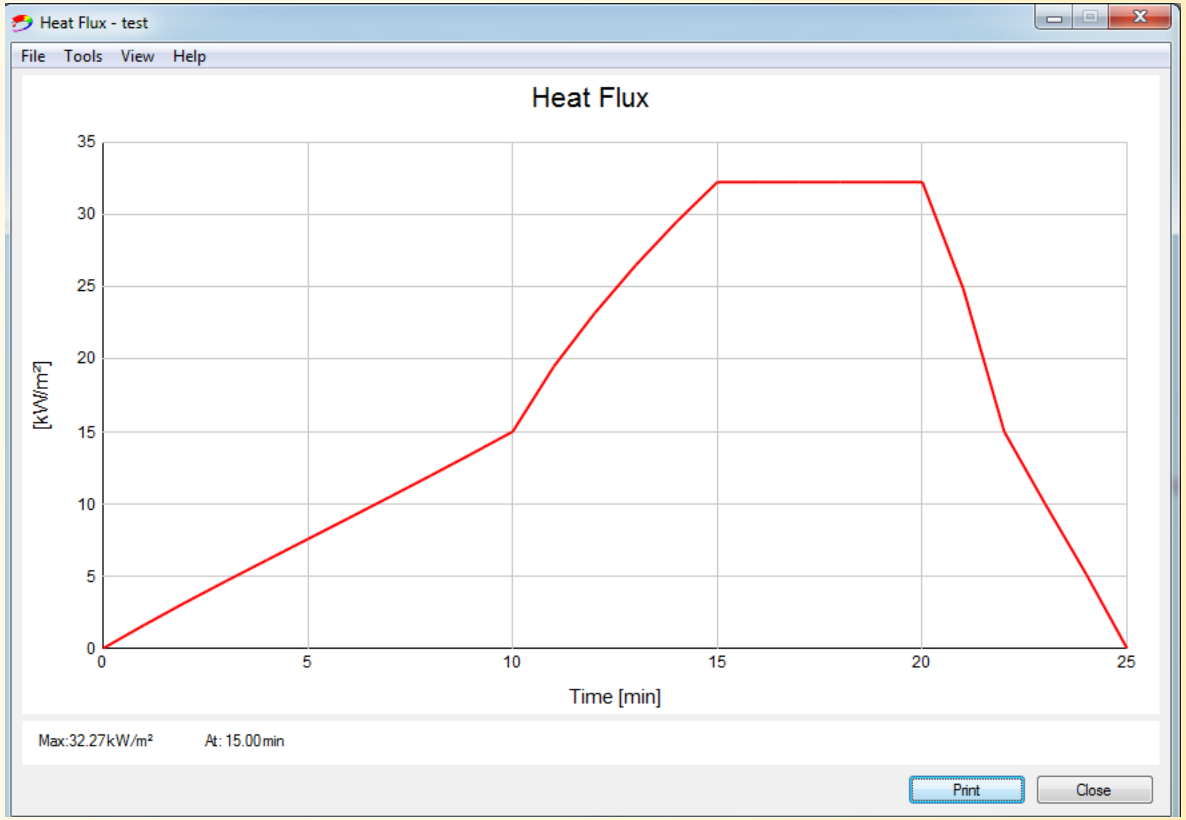




4. Software

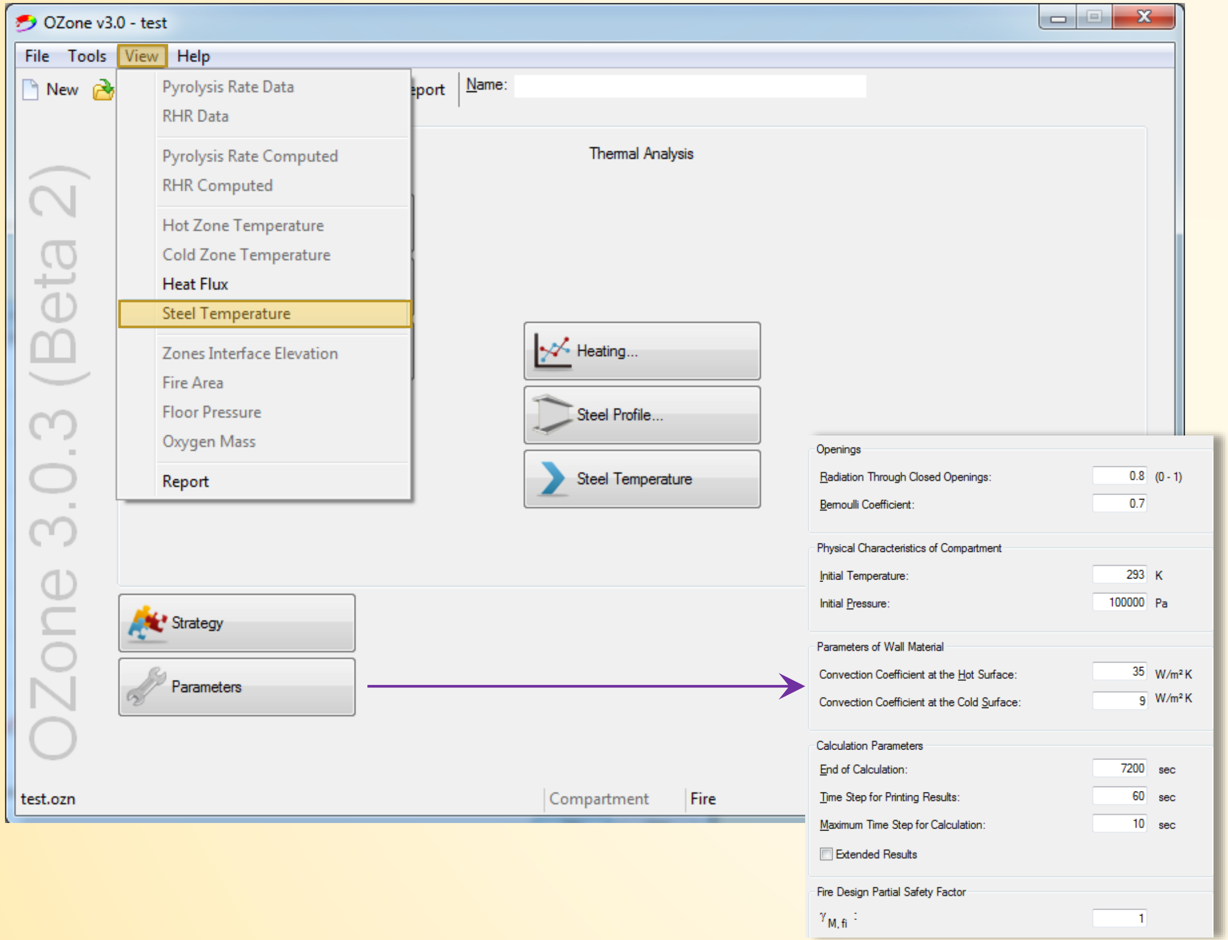
4.1. OZone

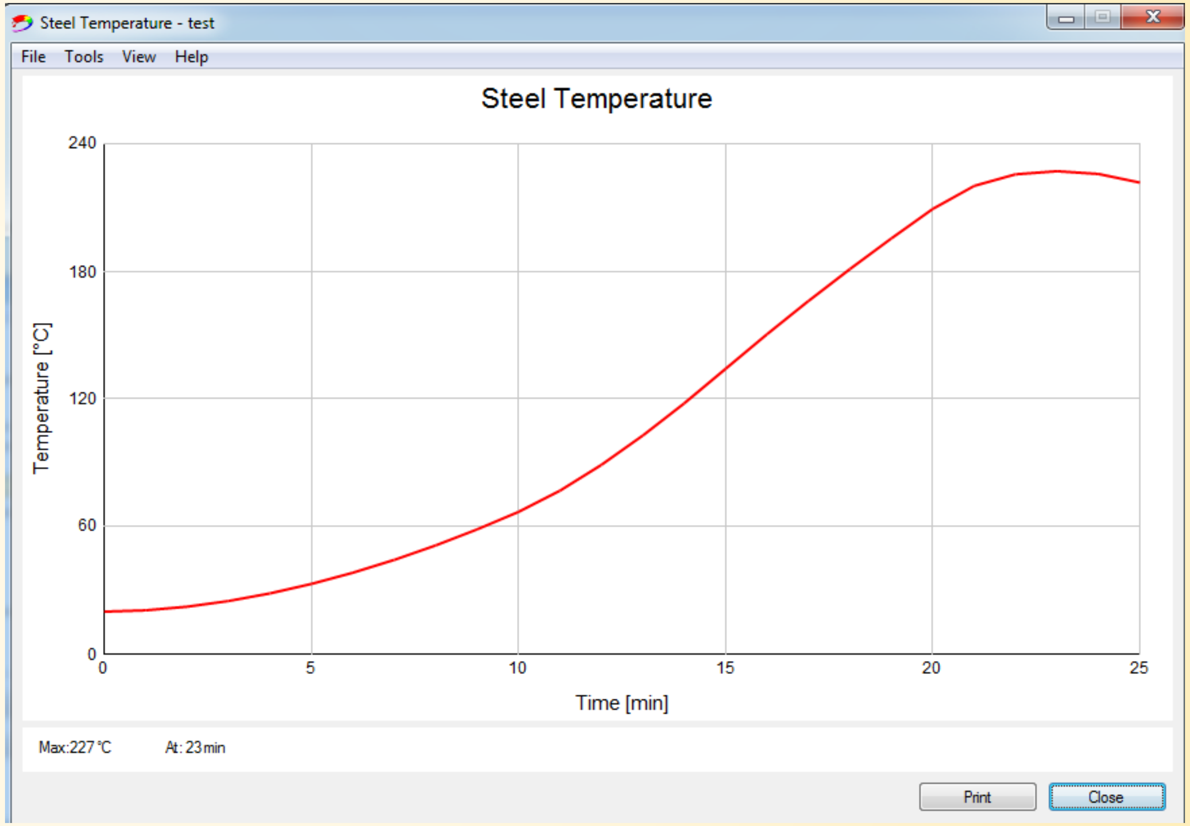




4. Software

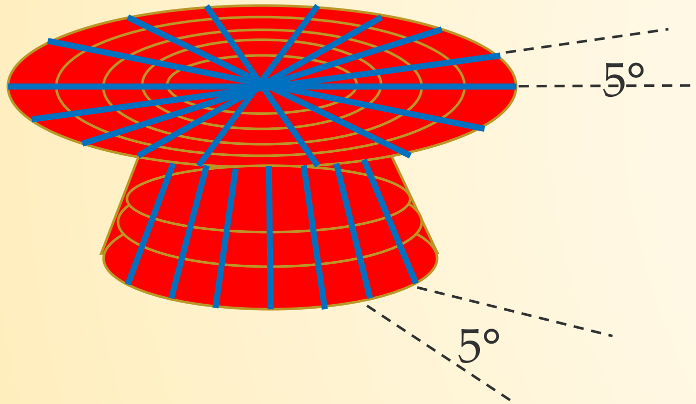
4.1. OZone





4.2. SAFIR® Localised fire

Cylinder flame
(touching the ceiling)



- Geometrical method has been implemented into SAFIR (direct heat exchange between finite surfaces).

- This generates non-uniform distributions of temperature in the analysed sections.

- Each fire source is described by position (x, y, z), shape (cylinder or cone), vertical position of the ceiling, evolution of diameter according to time, evolution of RHR according to time.

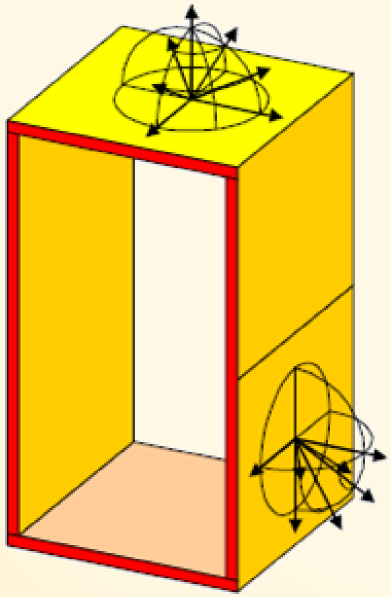
- In case of several fires, contributions are summed up and limited to 100 kW/m^2

Franssen, J.-M., & Gernay, T. (2017). Modeling structures in fire with SAFIR®: Theoretical background and capabilities. Journal of Structural Fire Engineering, 8(3), 300-323.

4.2. SAFIR® Localised fire

- In a concave section, shadow effect is automatically considered if the section is outside the fire.

Convex shape



Concave shape