Numerical Modeling Of Scaled Down Fire Experiments

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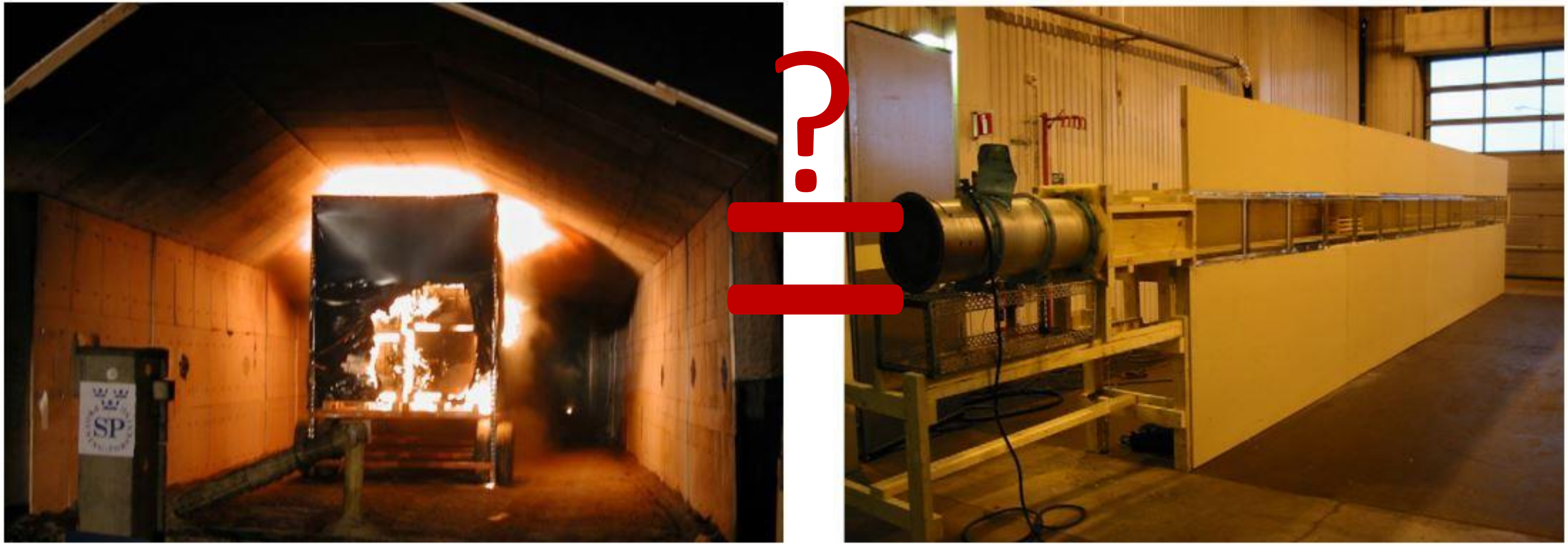
Is this the same?



(a) Source: (Ingason, Li 2010)

(b) Source: (Li et. al, 2011)

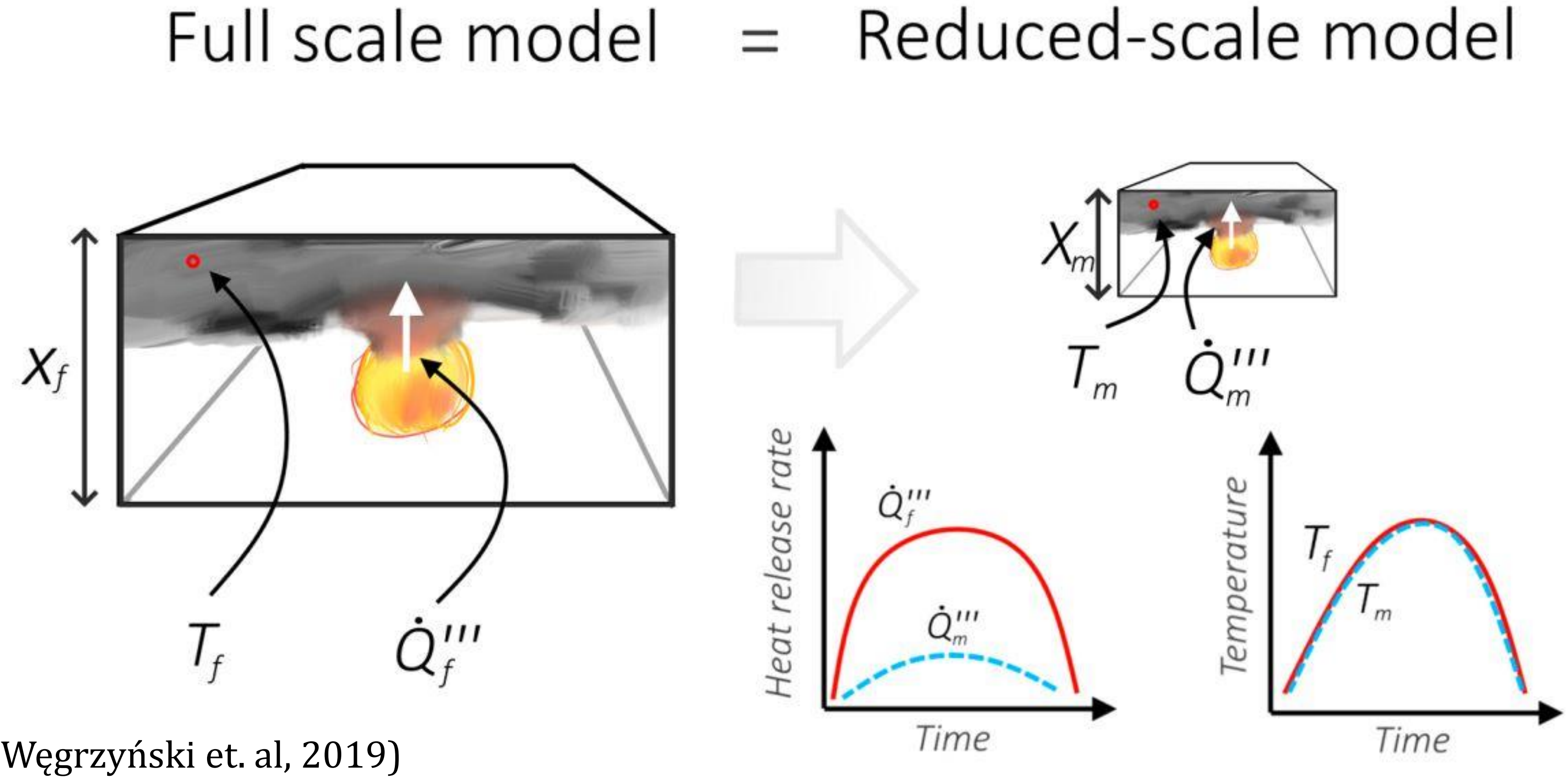
Fire experiments in model scale

Table: Examples of scale size used in fire modeling experiments

Scale	Compartment of interest	Number of experiments	HRR (Reduced scale)	Source
1:1	Road tunnel	5	6000 -202,000 kW	(Li et. al, 2011)
1:2	Railway car	10	90 -1247 kW	(Lönnermark et. al., 2011)
1:2	Compartment	n/a	n/a	(Heskestad, 1973)
1:3,5	Single family house	2	up to 100,000 kW	(Himoto et. al, 2018)
1:4	Compartment	165	n/a	(Croce, P.A et. al, 2005)
1:7	Room	3	300 -1500 kW	(Quintiere et. al, 1978)
1:8	Cellar	1	18.31 kW	(Arini et. al, 2017)
1:8	Corridor	5	50-300 kW	(Carey, 2010)
1:10	Shopping mall	48	7.6 kW	(Węgrzyński, 2018)
1:10	Shopping mall	25	6-10.3 kW	(Harrison and Spearpoint, 2007)
1:12	Road tunnel	5	15.1-72.8 kW	(Tanaka et. al, 2017)
1:13	Road tunnel	61	7.81-215.1 kW	(Kayili et. al,, 2012)
1:15	Road tunnel	28	6.7-430.1 kW	(Li and Ingason, 2013)
1:20	Road tunnel	54	n/a (5-25 MW in full scale)	(Li et. al, 2012)
1:20	Subway tunnel	116	1.48-3.52 kW	(Zhao et. al, 2019)
1:23	Road tunnel	12	102.2-320.8 kW	(Ingason and Li, 2010)
1:48	Train tunnel	1	0.31-1.88 kW	(Kim and Park, 2006)

?

Introduction



Source: (Węgrzyński et. al, 2019)

Full and model scale

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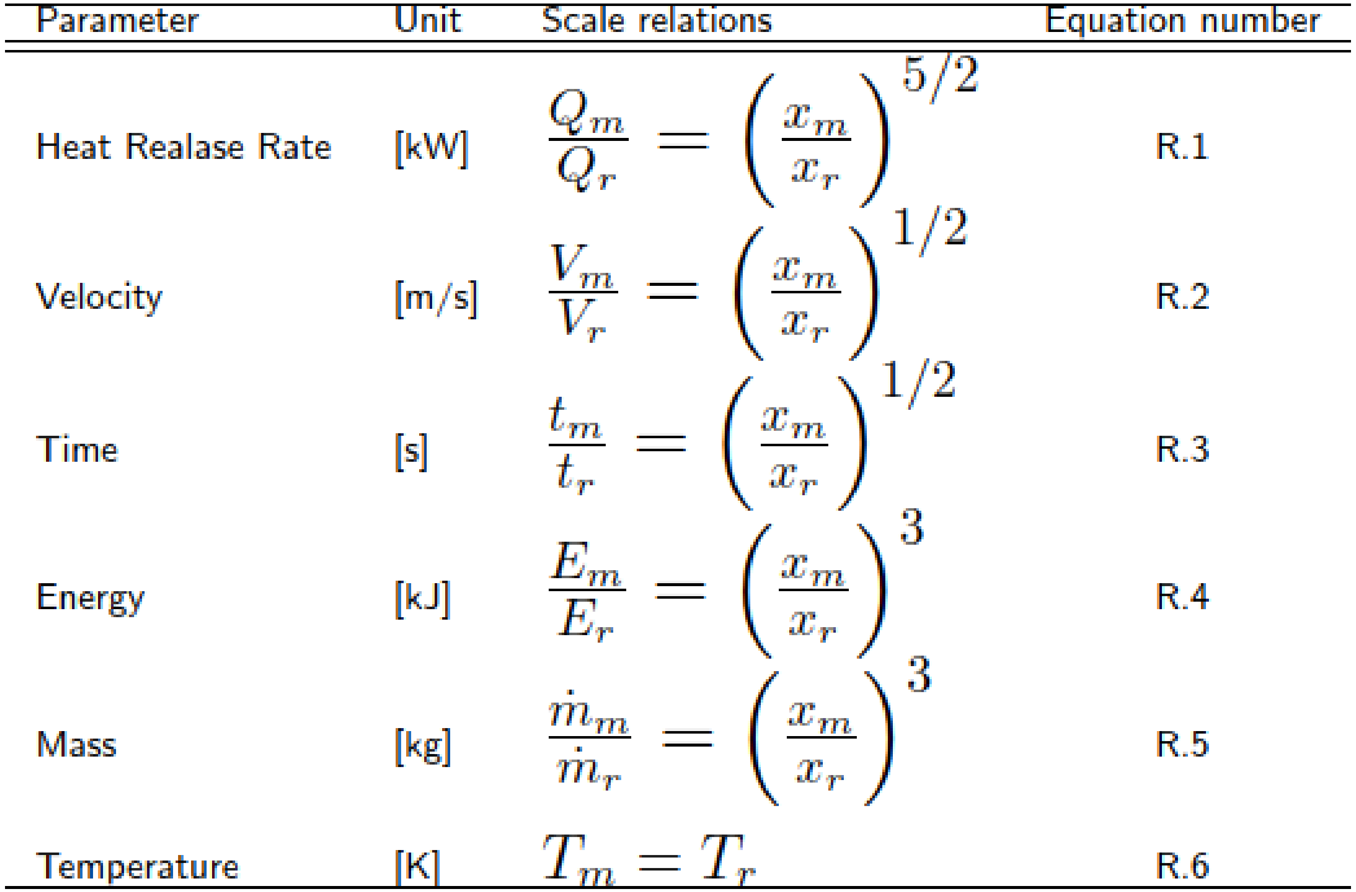
Table : Relations between the values in the full and model scale

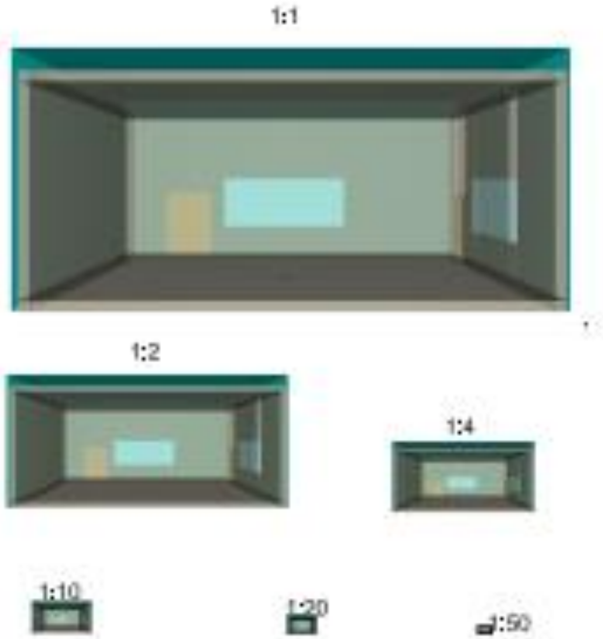


Parameter	Unit	Scale relations	Equation number
Heat Realase Rate	[kW]	$\frac{Q_m}{Q_r} = \left(\frac{x_m}{x_r}\right)^{5/2}$	R.1
Velocity	[m/s]	$\frac{V_m}{V_r} = \left(\frac{x_m}{x_r}\right)^{1/2}$	R.2
Time	[s]	$\frac{t_m}{t_r} = \left(\frac{x_m}{x_r}\right)^{1/2}$	R.3
Energy	[kJ]	$\frac{E_m}{E_r} = \left(\frac{x_m}{x_r}\right)^{3}$	R.4
Mass	[kg]	$\frac{\dot{m}_m}{\dot{m}_r} = \left(\frac{x_m}{x_r}\right)^{3}$	R.5
Temperature	[K]	$T_m = T_r$	R.6

The range of investigations

(a) Hand calculatons

(a)Physical experiments



(a) CFD simulations

Physical experiments - Overview

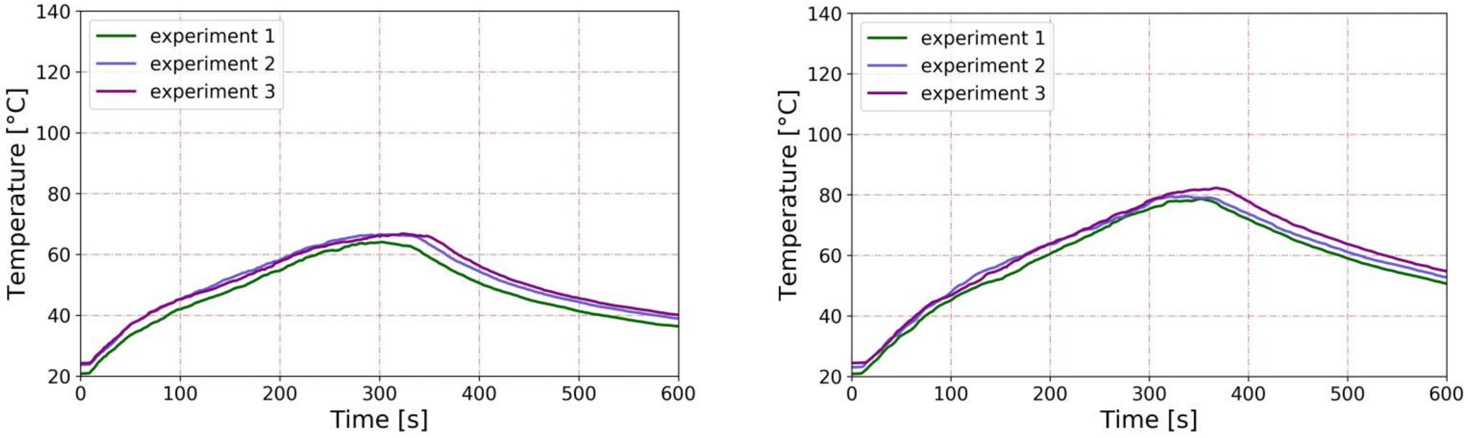
Table: Summary of the physical experiments

Series	Series A		Series B	
	1:1	1:4	1:1	1:4
HRR [kW]	81.7 kW	2.55 kW	158 kW	4.94 kW
volume of fuel [L]	1.015 L	0.0158 L	1.015 L	0.0158 L
mass of fuel [g]	0.6943 kg	0.0108 kg	0.6943 kg	0.0108 kg
duration of the fire (real time) [s]	350 s	175 s	181 s	90.5 s
tray size [m]	0.33 × 0.33 m	0.075 × 0.075 m	0.50 × 0.50 m	0.125 × 0.125 m

Flame height in full scale experiment

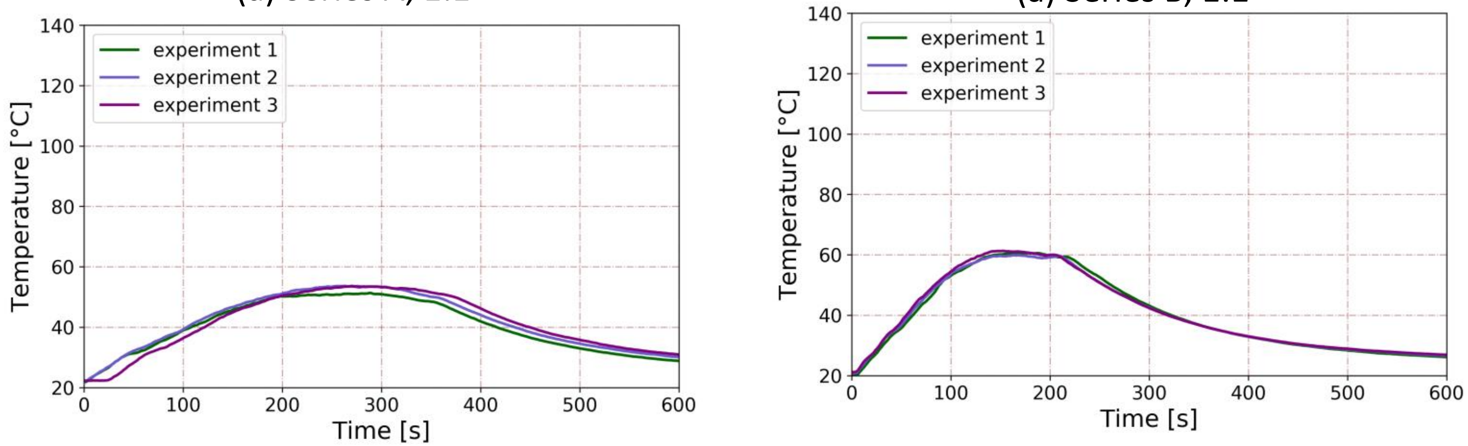
Flame height in model scale experiment

Physical experiments - Results



(a) Series A, 1:1

(a) Series B, 1:1

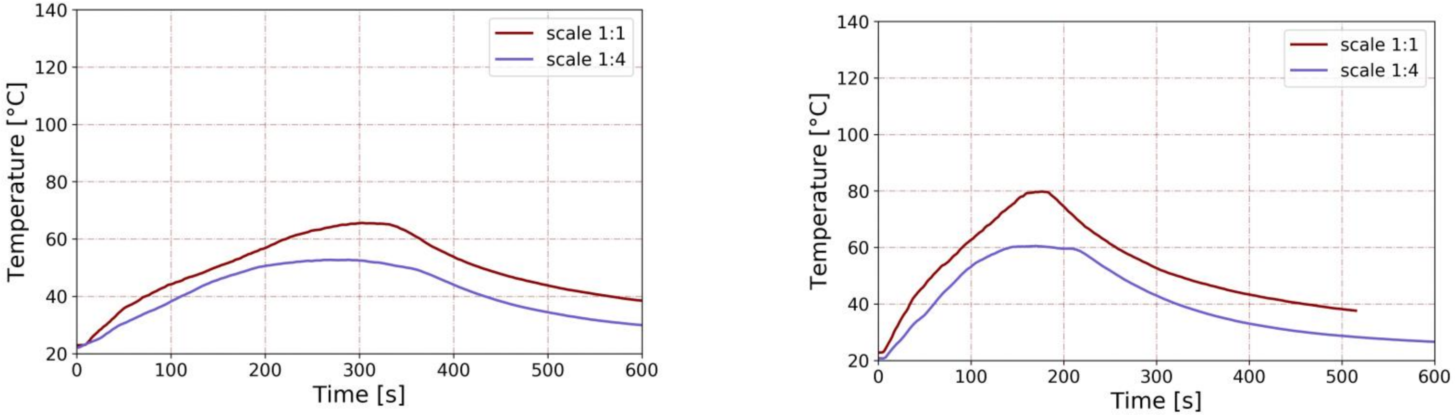


(a) Series A, 1:4

(a) Series B, 1:4

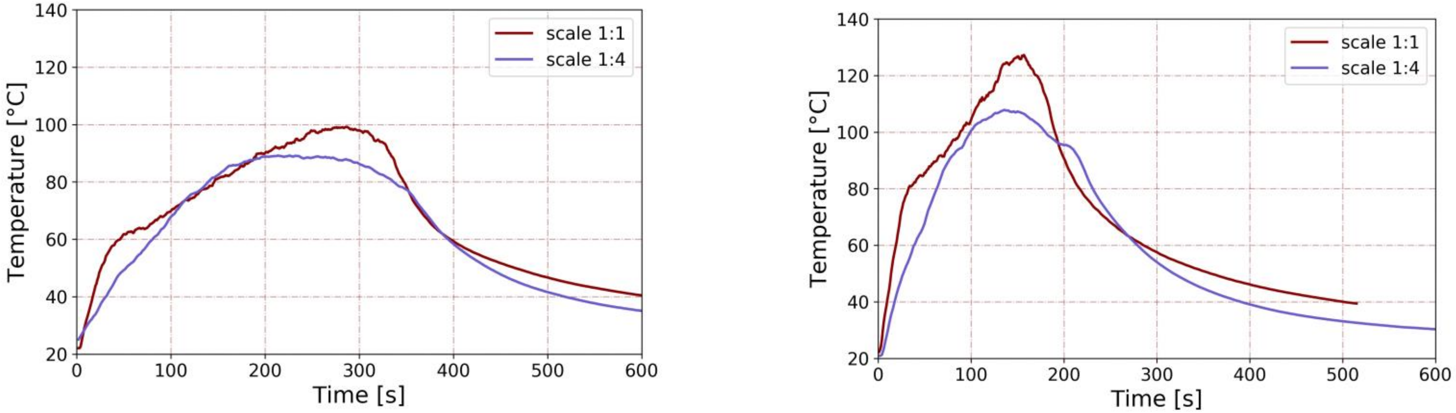
Mean temperature in full- and reduced scale experiments.

Physical experiments - Results



(a) Series A, mean layer temperature

(b) Series B, mean layer temperature



(c) Series A, plume centerline temperature

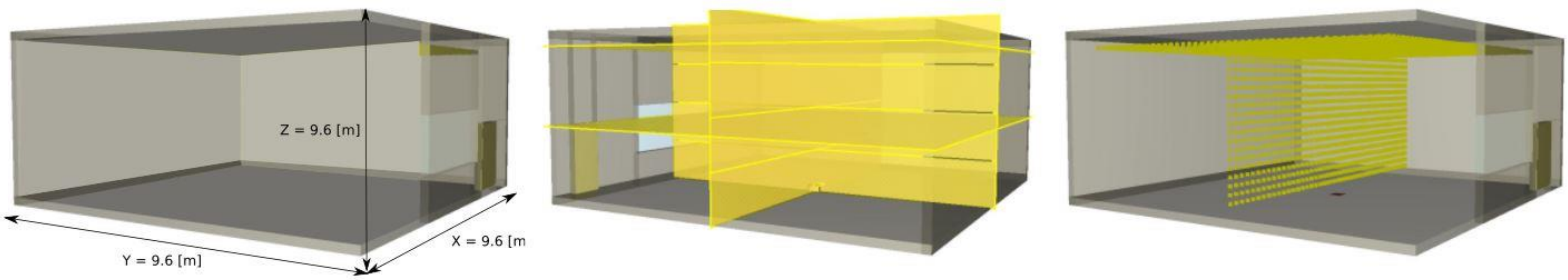
(d) Series B, plume centerline temperature

Comparison of averaged and maximum recorded temperatures

CFD simulations - Overview

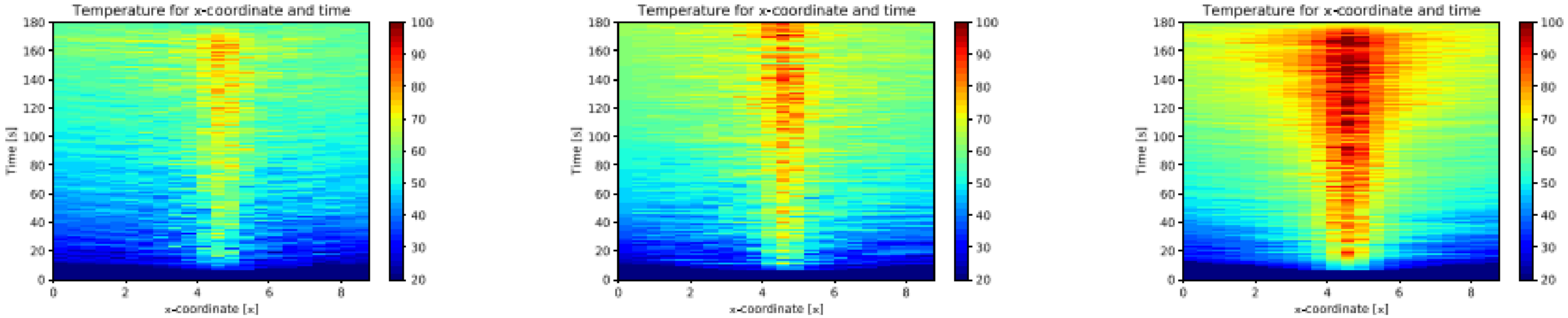
Table: Parameters of the Fire Dynamics Sumulator (FDS) numerical model

Scenario	Scale	Model Dimensions [m]	Grid Size [m]	Number of Grid Cells
1 A, B	1:1	9.6 × 9.6 × 4.2	0.05	3,897,600
2 A, B	1:2	4.8 × 4.8 × 2.1	0.025	3,897,600
3 A, B	1:4	2.4 × 2.4 × 1.05	0.0125	3,897,600
4 A, B	1:10	0.96 × 0.96 × 0.42	0.005	3,897,600
5 A, B	1:20	0.48 × 0.48 0.21	0.0025	3,897,600
6 A, B	1:50	0.192 × 0.192 × 0.084	0.001	3,897,600



3D model of the labolatory in full-scale with measuring devices

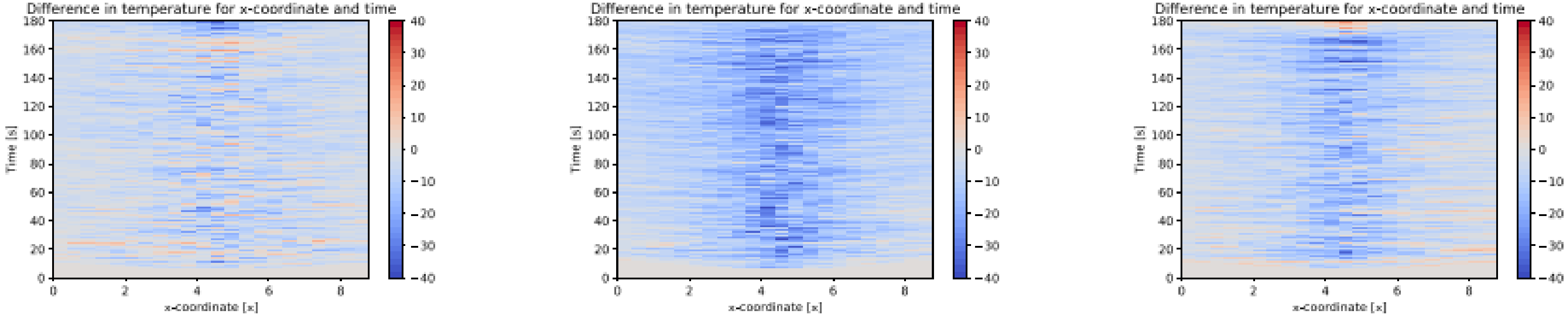
CFD simulations - Mesh Sensitivity Analysis



(a) 20 cm

(b) 10 cm

(c) 5 cm



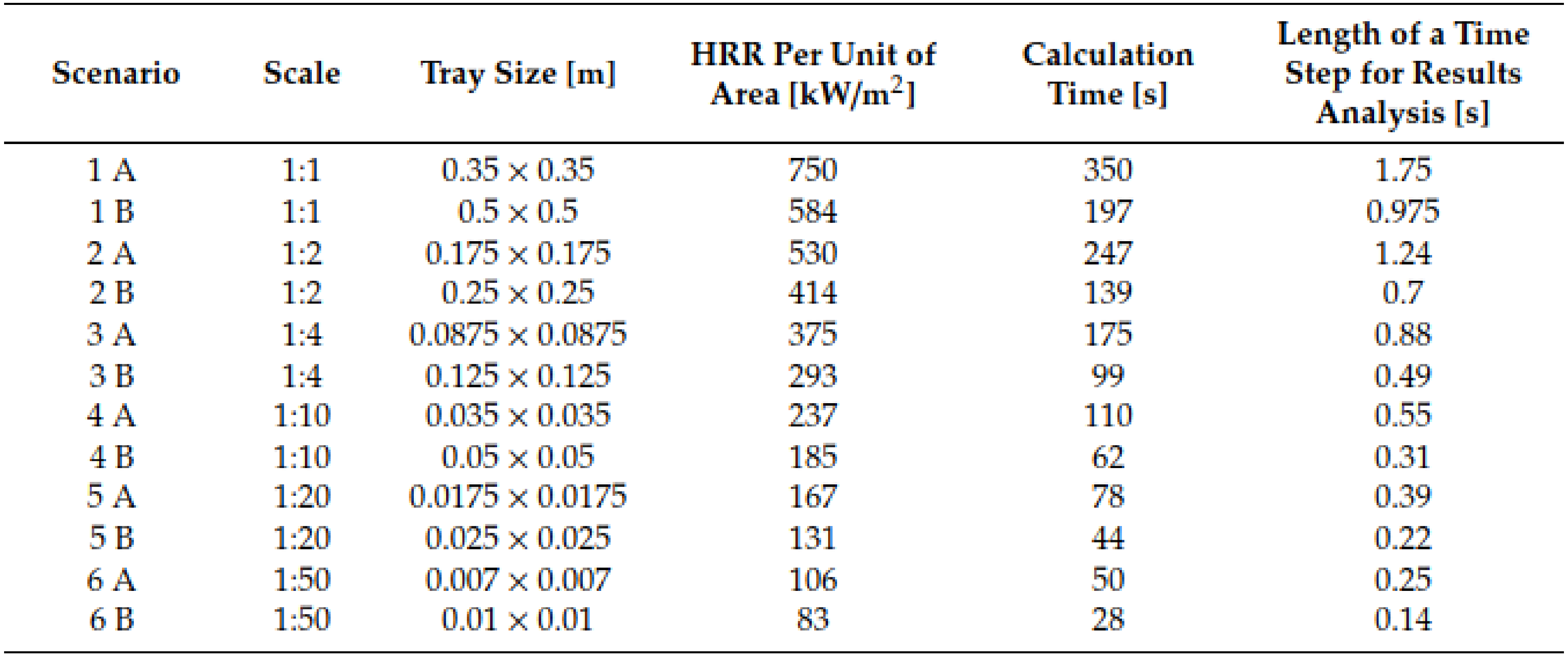
(d) 20 to 10 cm

(e) 20 to 5 cm

(f) 10 to 5 cm

Comparison of results of mesh sensitivity analysis

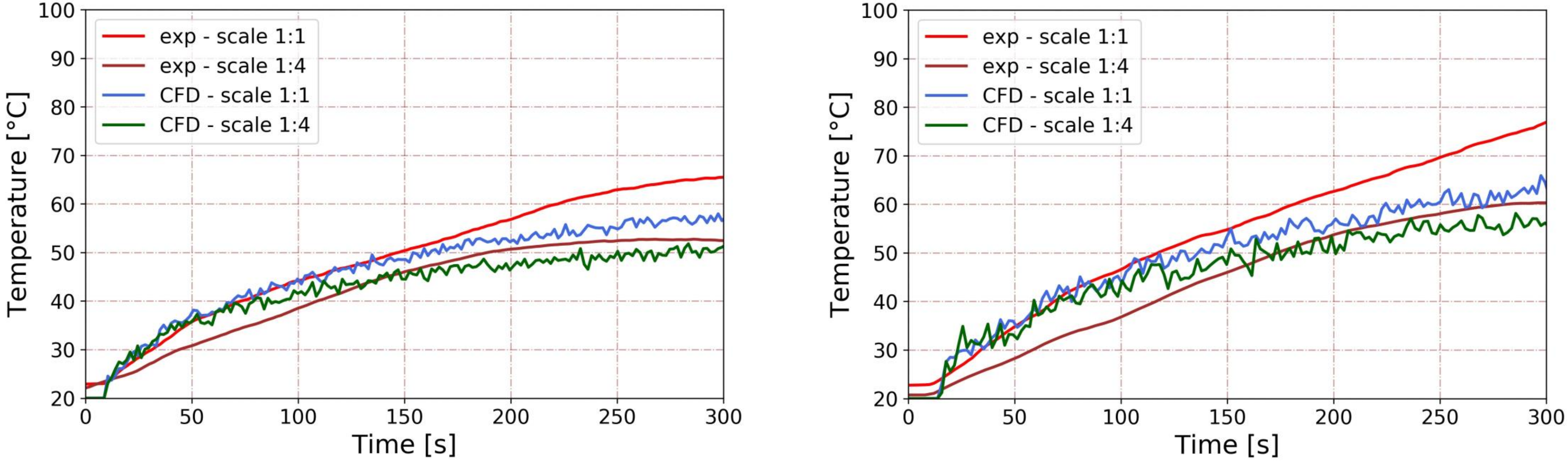
CFD simulations - Input



Scenario	Scale	Tray Size [m]	HRR Per Unit of Area [kW/m^2]	Calculation Time [s]	Length of a Time Step for Results Analysis [s]
1 A	1:1	0.35 × 0.35	750	350	1.75
1 B	1:1	0.5 × 0.5	584	197	0.975
2 A	1:2	0.175 × 0.175	530	247	1.24
2 B	1:2	0.25 × 0.25	414	139	0.7
3 A	1:4	0.0875 × 0.0875	375	175	0.88
3 B	1:4	0.125 × 0.125	293	99	0.49
4 A	1:10	0.035 × 0.035	237	110	0.55
4 B	1:10	0.05 × 0.05	185	62	0.31
5 A	1:20	0.0175 × 0.0175	167	78	0.39
5 B	1:20	0.025 × 0.025	131	44	0.22
6 A	1:50	0.007 × 0.007	106	50	0.25
6 B	1:50	0.01 × 0.01	83	28	0.14

Overview ot the Computational Fluid Dynamics (CFD) imput parameters

CFD simulations - Results

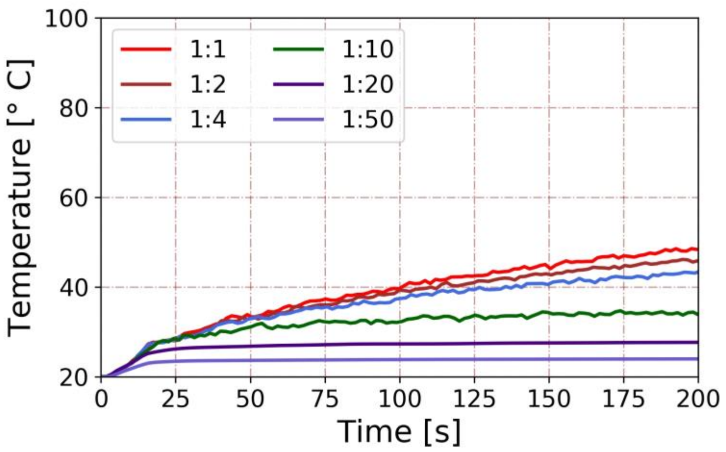


(a) Series A, mean layer temperature

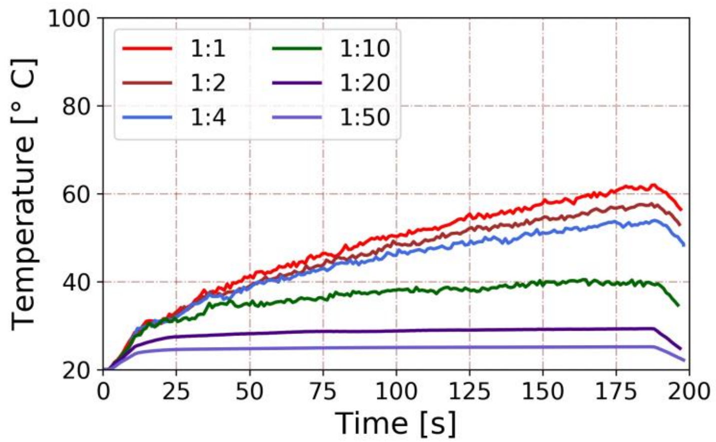
(a) Series B, mean layer temperature

Comparison of the temperaturę measurements in experiments and numerical simulations in full (1:1) and reduced-scale (1:4) experiments

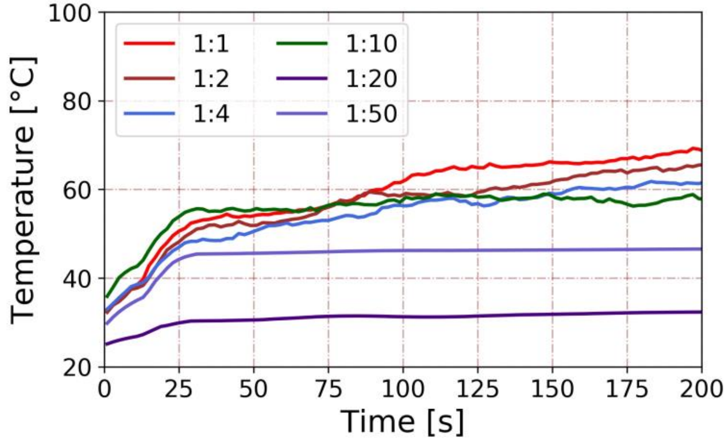
CFD simulations - Results



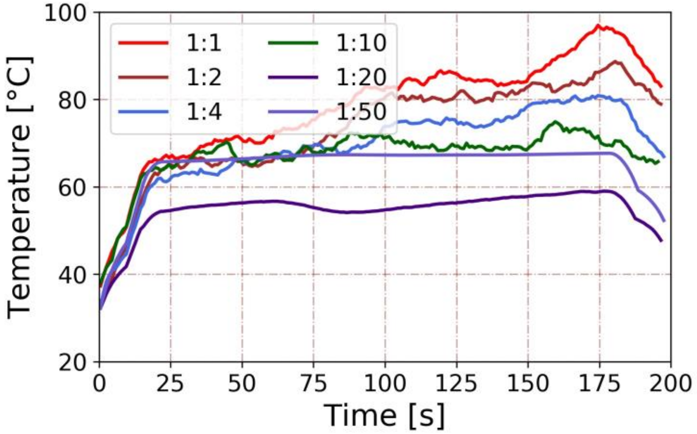
(a) Series A, mean layer temperature



(b) Series B, mean layer temperature

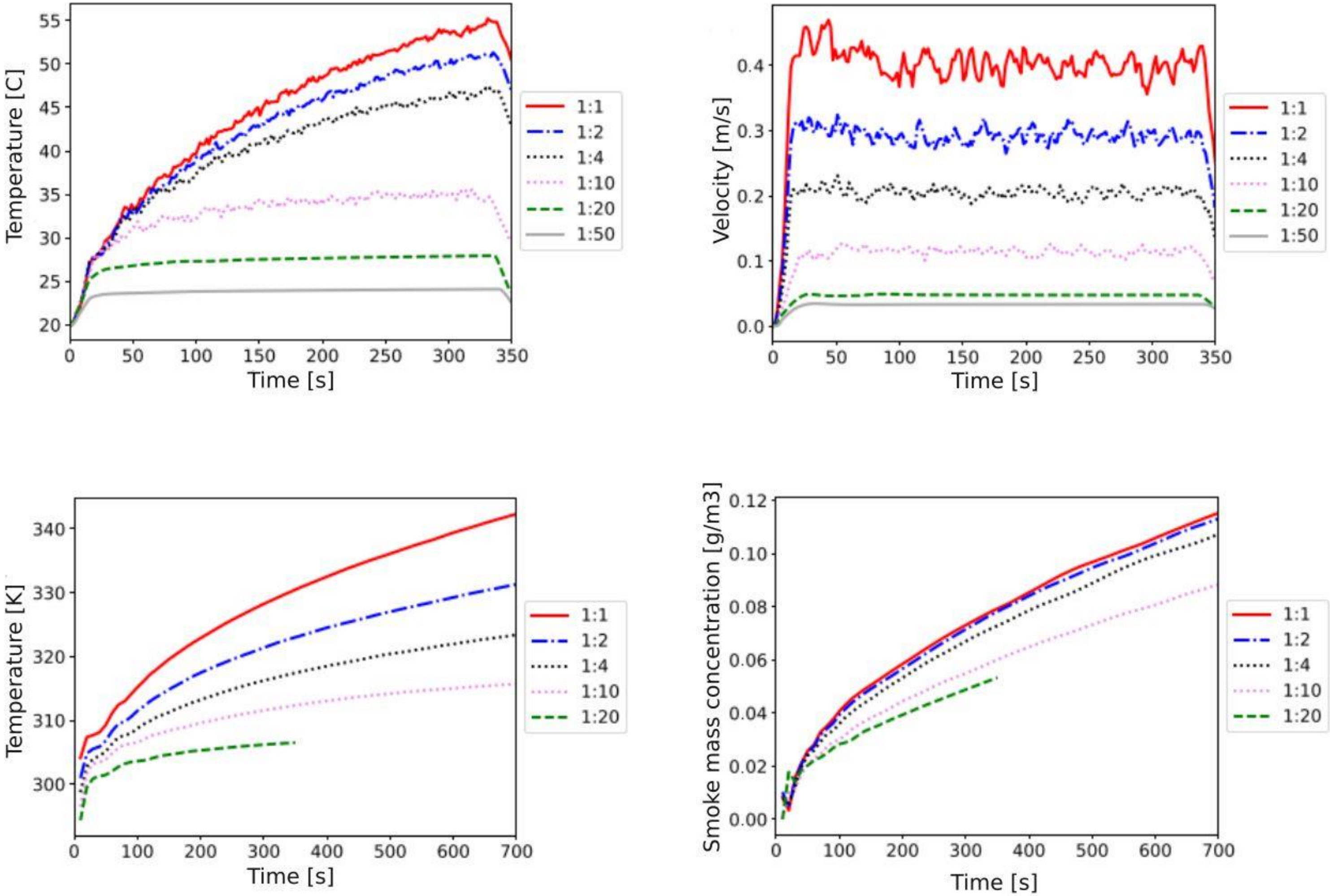


(c) Series A, plume centerline temperature



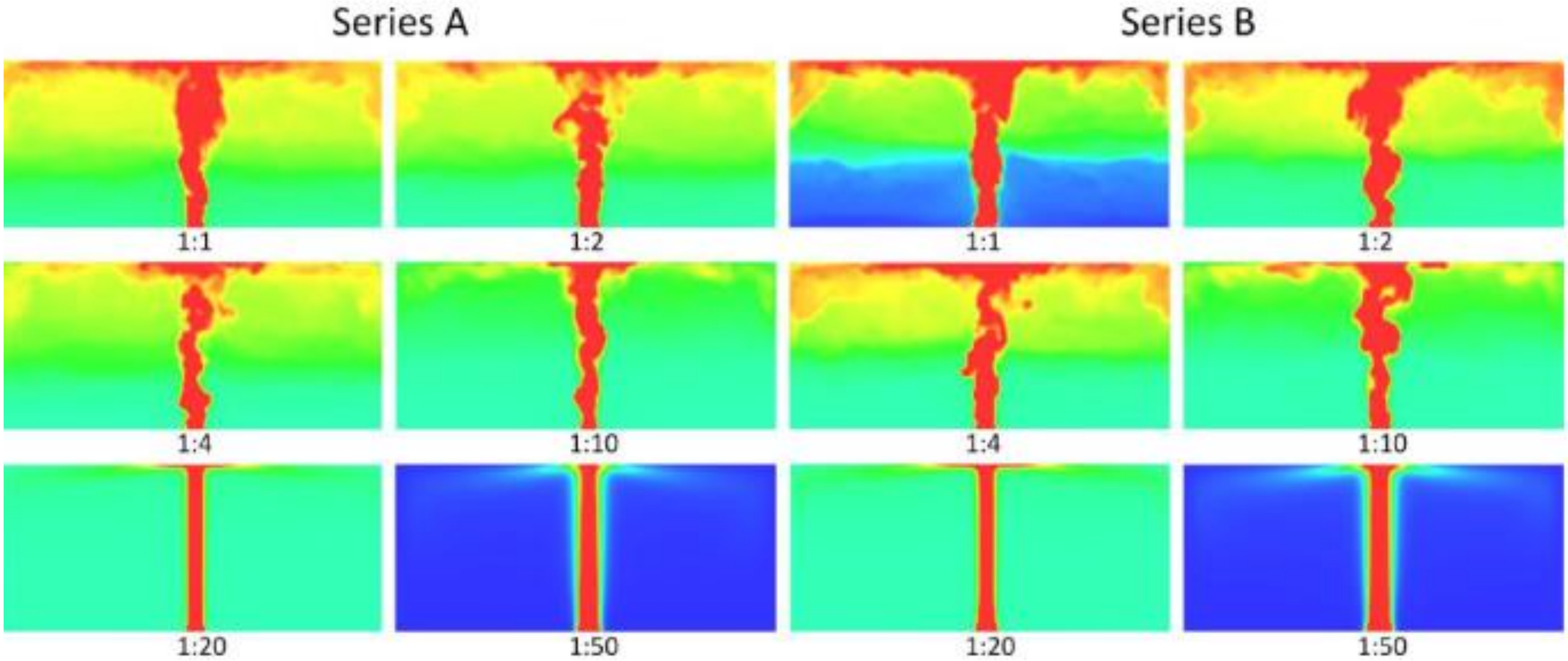
(d) Series B, plume centerline temperature

CFD simulations - Results



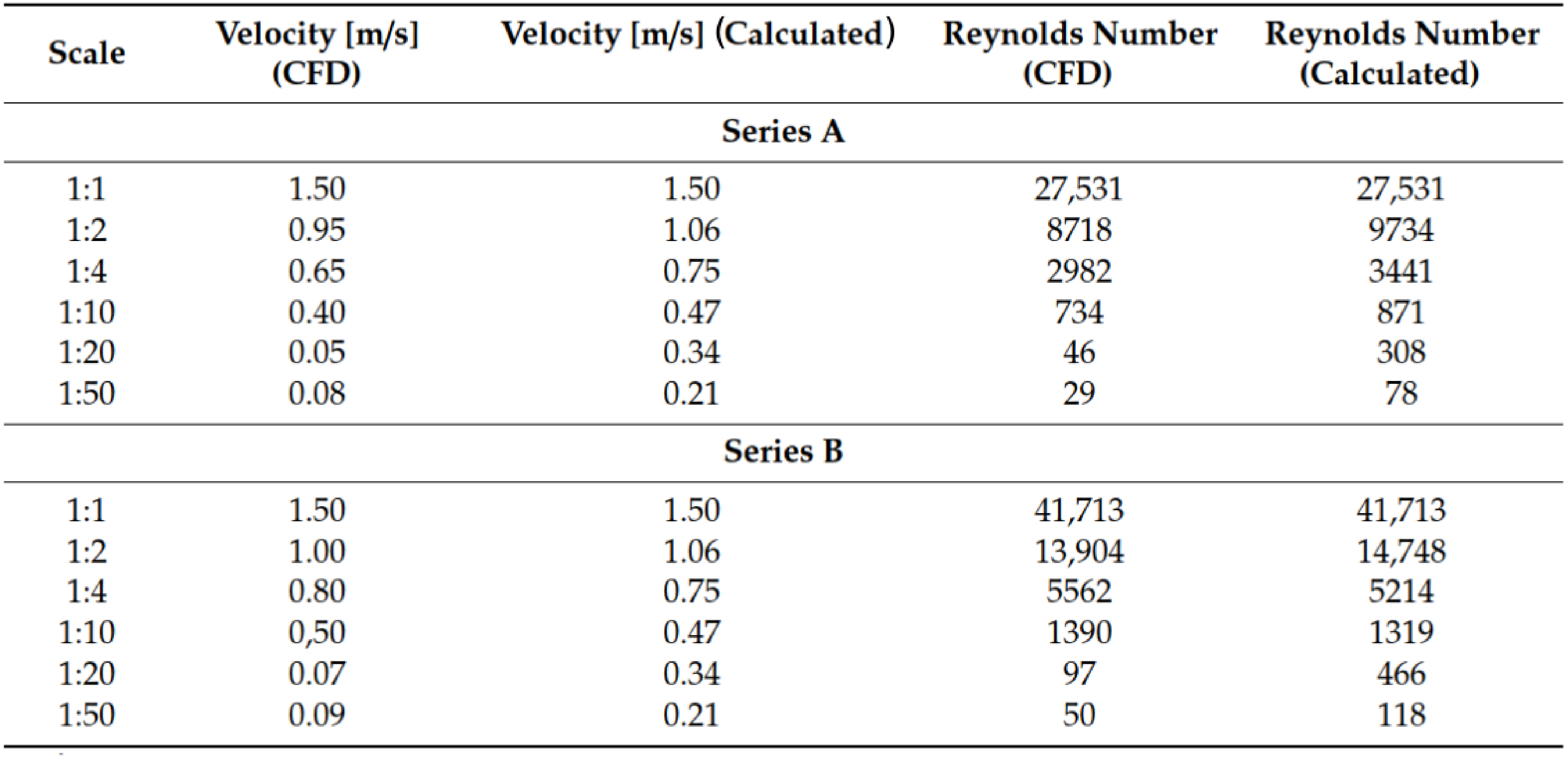
Comparision between FDS 6.7.0 and Ansys Fluent

CFD simulations - Results



Temperature slice through the centerline of the smoke plume

The Reynolds number



Scale	Velocity [m/s] (CFD)	Velocity [m/s] (Calculated)	Reynolds Number (CFD)	Reynolds Number (Calculated)
		Series A		
1:1	1.50	1.50	27,531	27,531
1:2	0.95	1.06	8718	9734
1:4	0.65	0.75	2982	3441
1:10	0.40	0.47	734	871
1:20	0.05	0.34	46	308
1:50	0.08	0.21	29	78
		Series B		
1:1	1.50	1.50	41,713	41,713
1:2	1.00	1.06	13,904	14,748
1:4	0.80	0.75	5562	5214
1:10	0,50	0.47	1390	1319
1:20	0.07	0.34	97	466
1:50	0.09	0.21	50	118

Approximation of the plume centerline Reynolds number

Summary

1. Turbulent flow has the essential role on the temperatures in the plume and the compartment;

2. Conducted CFD simulations confirmed, that maintenance a sufficiently high Reynolds number (above 10,000) minimizes the error of the method related to the flow turbulence;

3. The results indicate that the scaling method can be useful for investigation of the flow of smoke in buildings where experiments scales are usually higher than 1:10;

4. Maintaining sufficiently high value of HRR for full scale will improve the results in small scale

5. For smaller scales (smaller than 1:10) the differences in the temperatures measured were significant.

6. In case of very small scales (1:20 and 1:50) the results have no scientific value due to change of the flow from turbulent to laminar.

7. Numerical modeling may help with investigating the effects of materials used in the reduced-scale model on the heat transfer to the model boundaries

8. FDS software can be used before experiment, to verify the sensitivity of the experiment to the scale, and estimate the Reynolds number

Future work

Fires with bigger HRR (up to 5 MW)

Different experimental setup

Comparison of other parameters

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Thank you!