Evaluation of a multi-zone modelling concept for large volume buildings and tunnels

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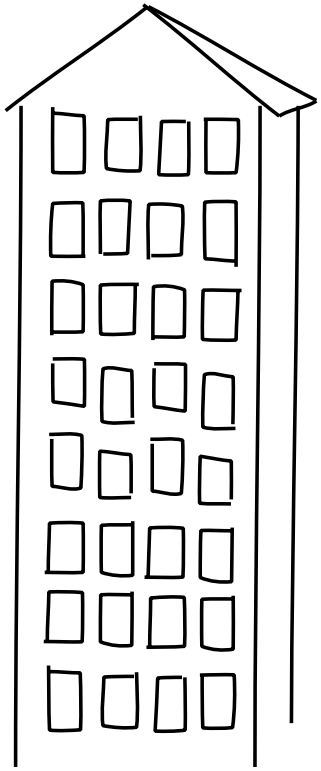
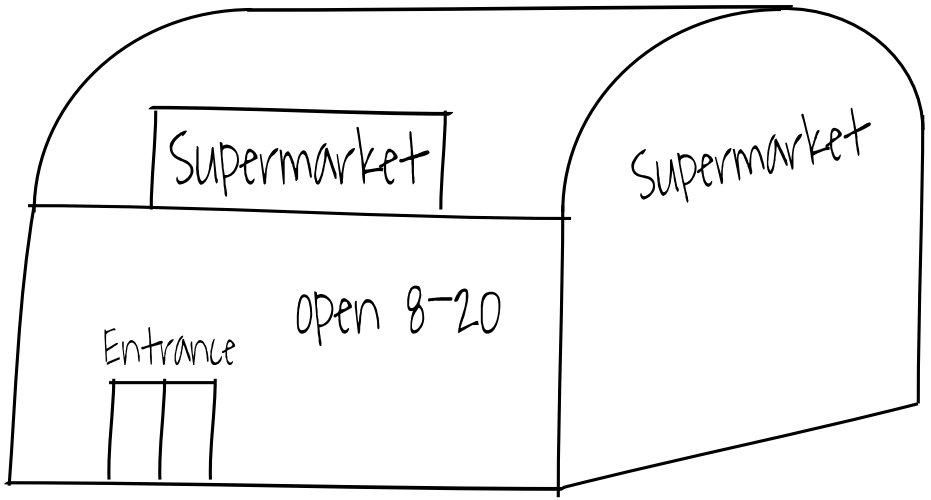
Gas temperatures in enclosure fires



Smaller type enclosure

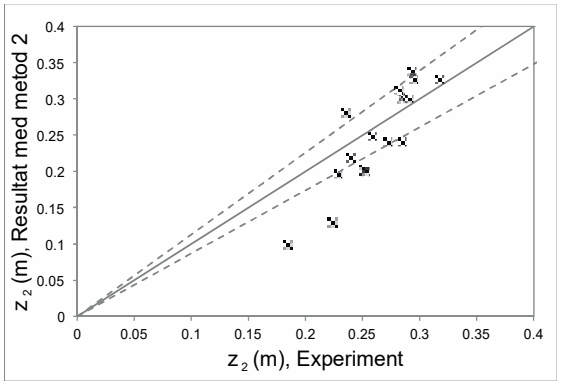
The “compartment fire”

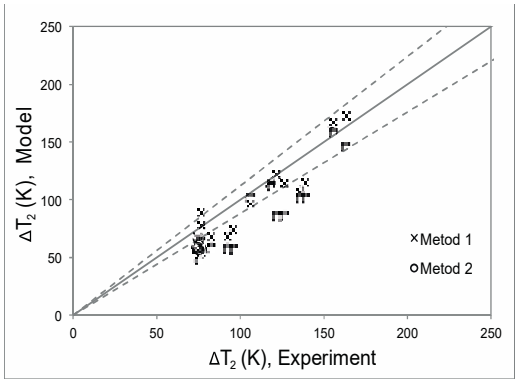
Larger type enclosures

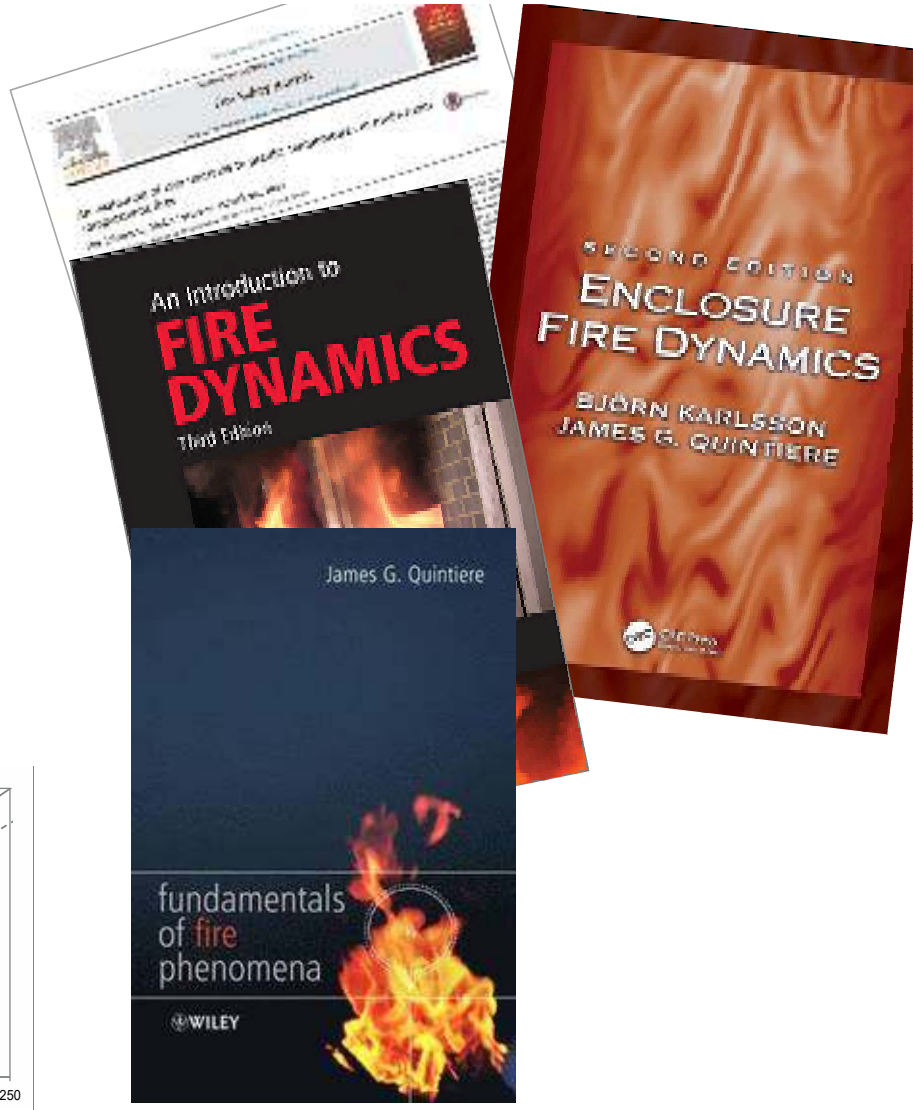


The ”Compartment Fire”

- Advantages
  - Calculations are easy to preform
    - pre- and post-flashover
  - Transparent
  - Short computational time
  - Well evaluated for certain scenarios







The ”Compartment Fire”

- Advantages
  - Calculations are easy to preform
    - pre- and post-flashover
  - Transparent
  - Short computational time
  - Well evaluated for certain scenarios

- Problems
  - Approximate results
  - Limitations of when the concept can be applied

The ”Compartment Fire”: Limits

- The concept is limited by

... Modell assumptions

... Empirical restrictions

- Example 1: Two-zone models

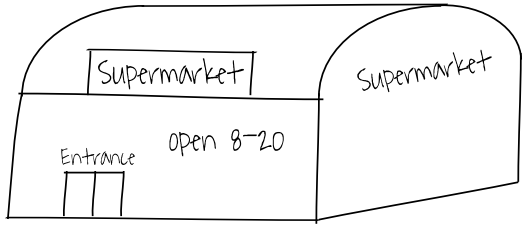
Acceptable value	Special considerations required
$L / W \leq 3$	$3 < L / W < 5$
$L / H \leq 3$	$3 < L / H < 6$

Acceptable ratios between enclosure depth (L), width (W) and height (H)

- Example 2: EUROCODE (EN 1991-1-2)
  - Floor area < 500 m^2
  - Room height < 4 m

Compartment fire vs. fire in large enclosure

- Possible to assume a homogenous gas mixture
- Flashover can occur
- Under-ventilated fire
- Fast fire development and pressure build up
- Prescriptive fire safety design



- Differences in temperature and concentration
- Local flashover, influence of layout
- Openings, leakage
- Slow fire growth

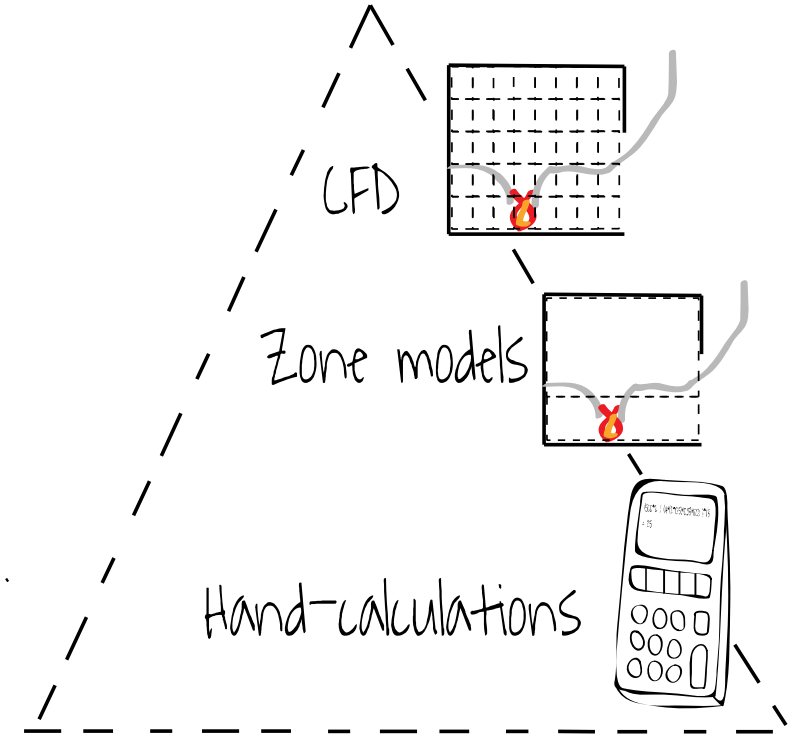
- Performance based design

The ”Compartment Fire” and FSE

Fires in large enclosures

Which tools do we have?

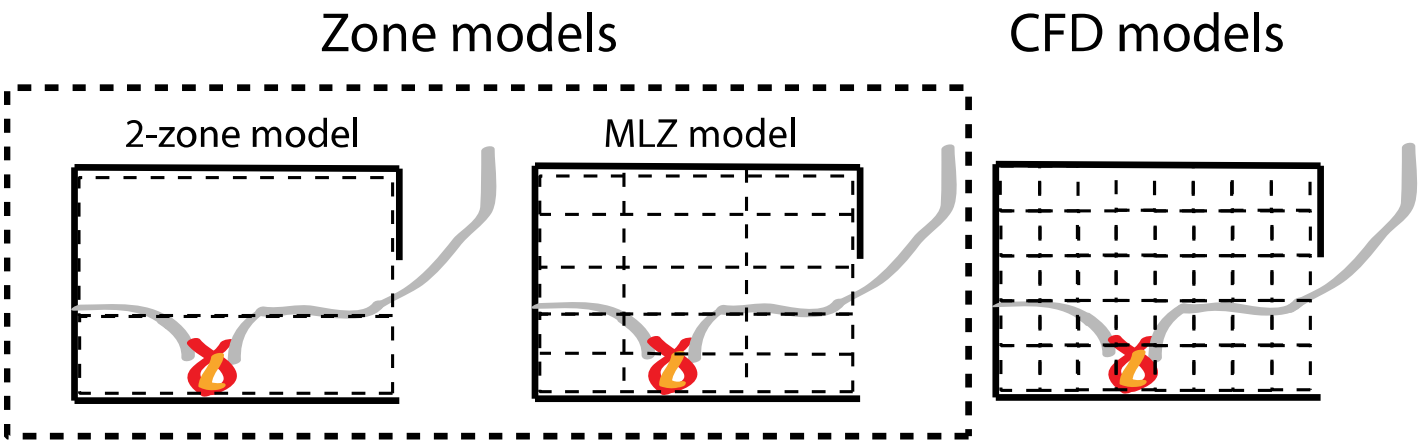
- CFD
  - Computational heavy for large volumes
- Two-zone models
  - Outside limits of the model
- Hand-calculations
  - Few (if any) that are applicable



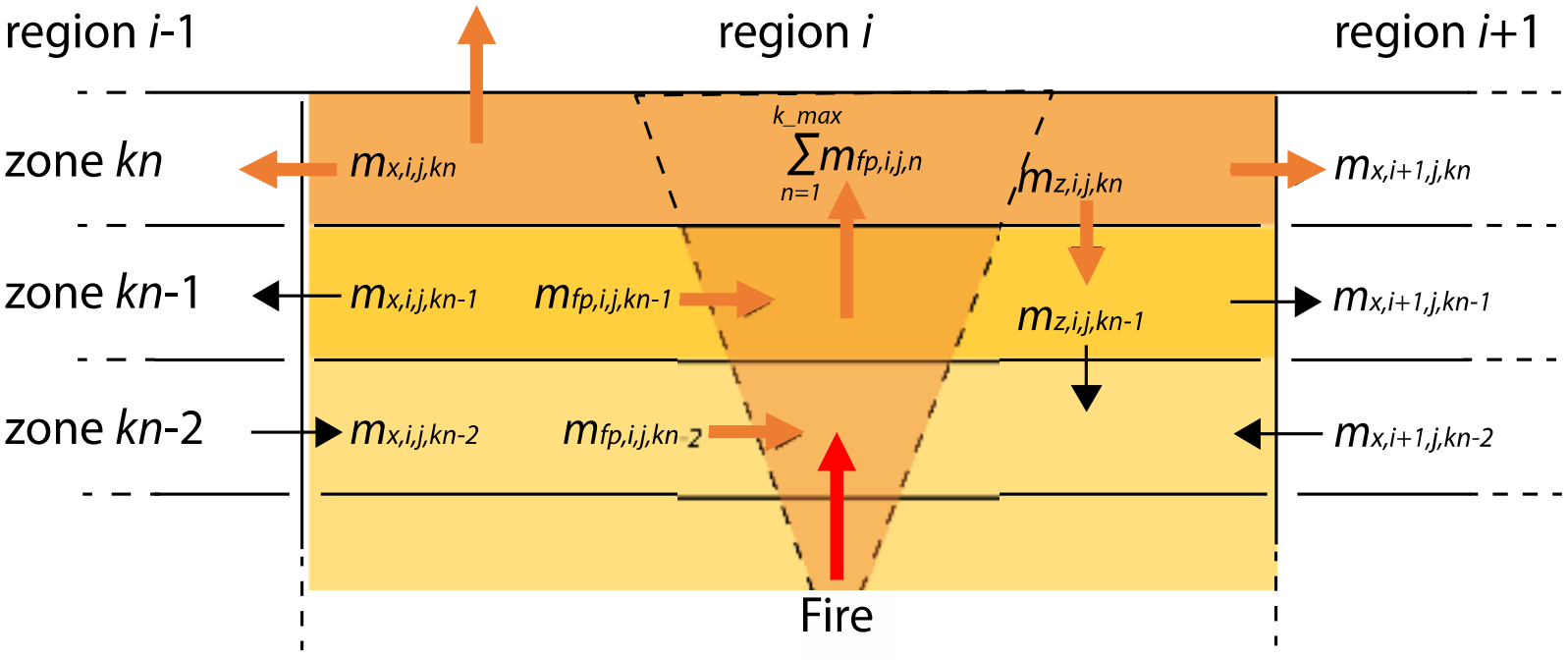
Fires in large enclosures

One option could be to use a multi-zone approach

- Using the same principles as in a two-zone model; however, the volume is divided into more control volumes
  - The uniform temperature assumption can to some degree be relaxed
- Main advantage compared to CFD is the reduced computational time



Multi-zone approach



Based on Multi-Layer Zone model presented by Suzuki et al, (2002) and Suzuki et al (2004)

Model evaluation

Published data from five different experimental tests

1. International Fire Model Benchmarking and Validation Exercise #3 (Hamins et al, 2005)
2. Wall and corner effects on plumes (McGrattan et al, 2018)
3. PolyU fire tests (Chow et al, 2001)
4. Murcia Atrium Fire Tests (Gutiérrez-Montes et al, 2009)

5. Benelux tunnel fire test (Lemaire & Kenyon, 2006)

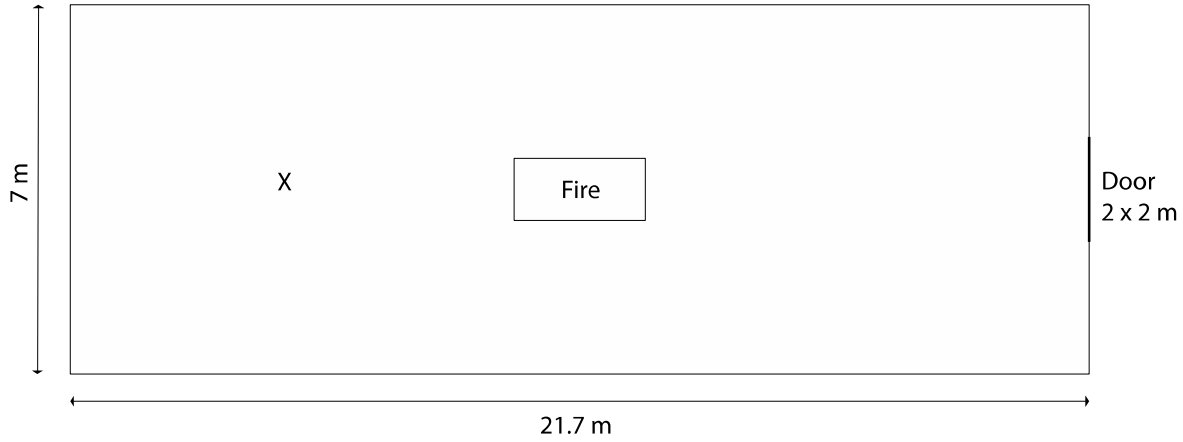
Model evaluation

- Five non-dimensional variables are used to characterize important aspects of each experiment.

Parameter	**Tests in large volume enclosures**				**Tunnel test**
	BE3	**NIST corner**	**PolyU**	**Murcia**	**BeNeLux**
Dimensionless heat release rate	0.31	1.72/3.44	0.20	1.56	0.21/0.36
Enclosure aspect ratio (L/W)	3.10	1.57	2.04	1.00	85.71
Enclosure aspect ratio (H/W)	0.54	0.54	2.45	0.97	0.53
Flame length ratio	0.59	$0.54^{1}/0.70^{2}$	0.08	0.21	$0.70^{3}/1.53^{4}$
Equivalence ratio	0.13	$0.02^{1}/0.04^{2}$	1.50	0.02	$0.03^{3}/0.02^{4}$
Radial distance ratio	3.76	15.02	4.45	6.87	2.09-59.01

Model evaluation

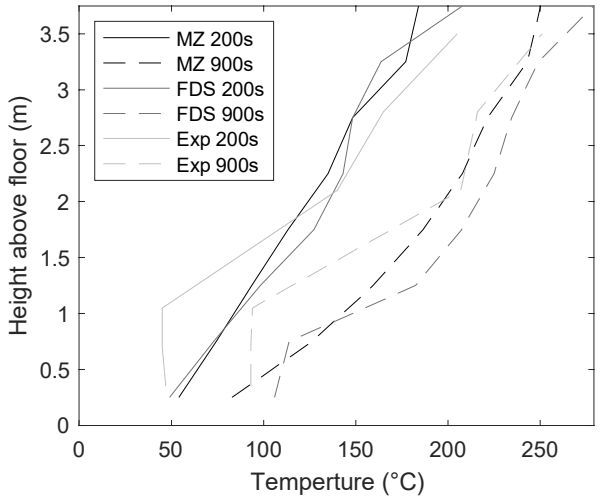
International Fire Model Benchmarking and Validation Exercise #3

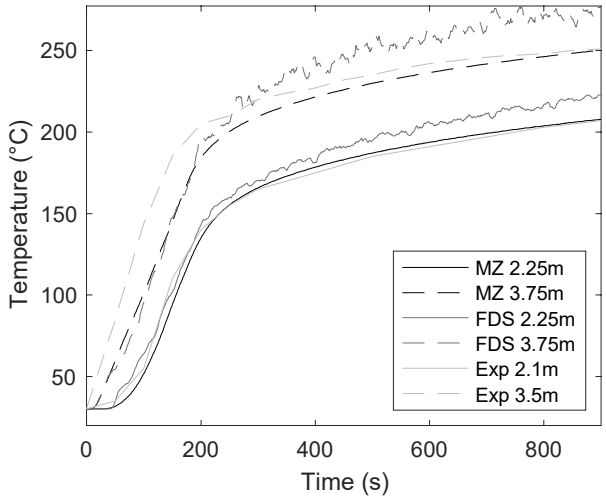


- Test 3
- 1 MW heptane pan fire
- Seven different TC trees

Model evaluation

International Fire Model Benchmarking and Validation Exercise #3





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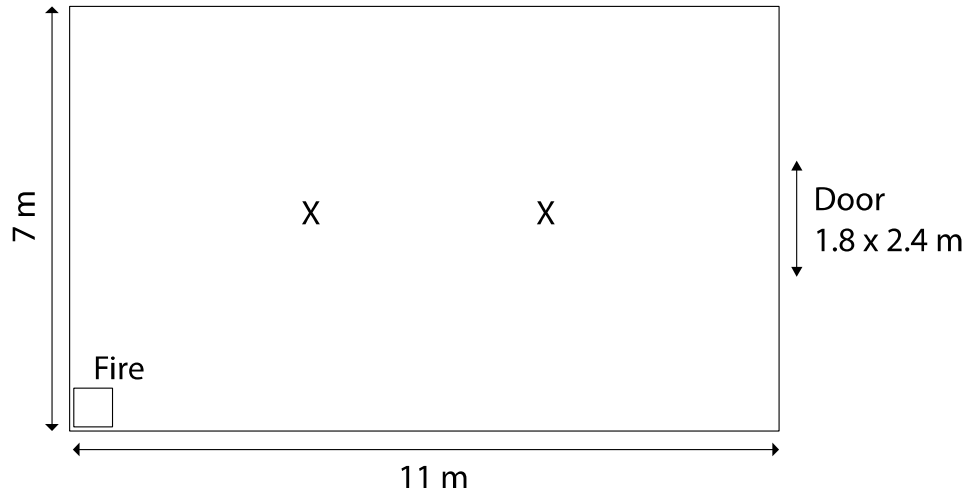
Model evaluation

- Wall and corner effects on plumes

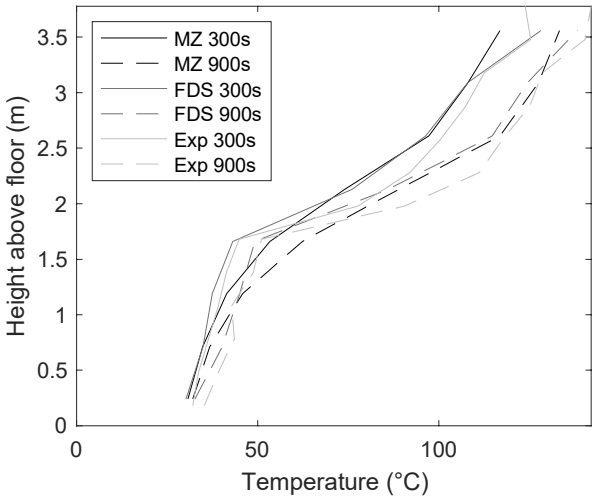


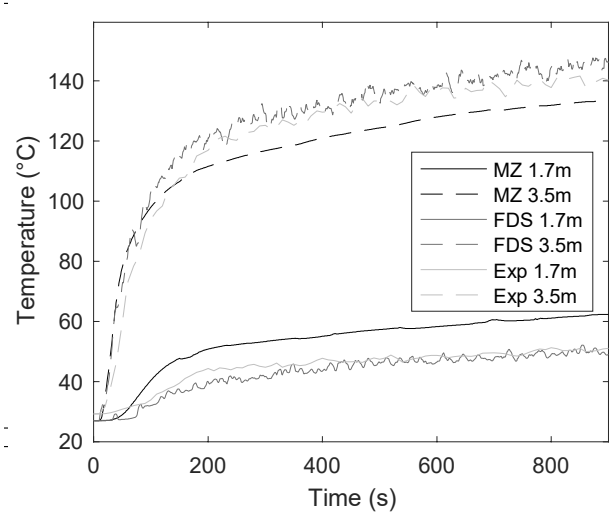
- Corner fire
- Natural gas
- 200 and 400 kW fire

Model evaluation

- Wall and corner effects on plumes

200 kW case





- Corner fire
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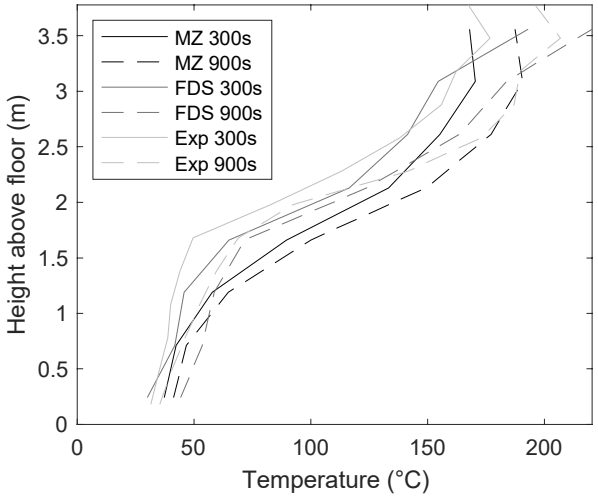
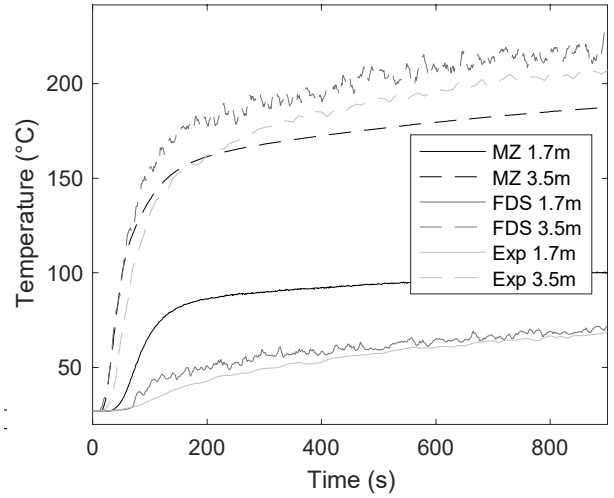
- 200 and 400 kW

Model evaluation

- Wall and corner effects on plumes

400 kW case





- Corner fire
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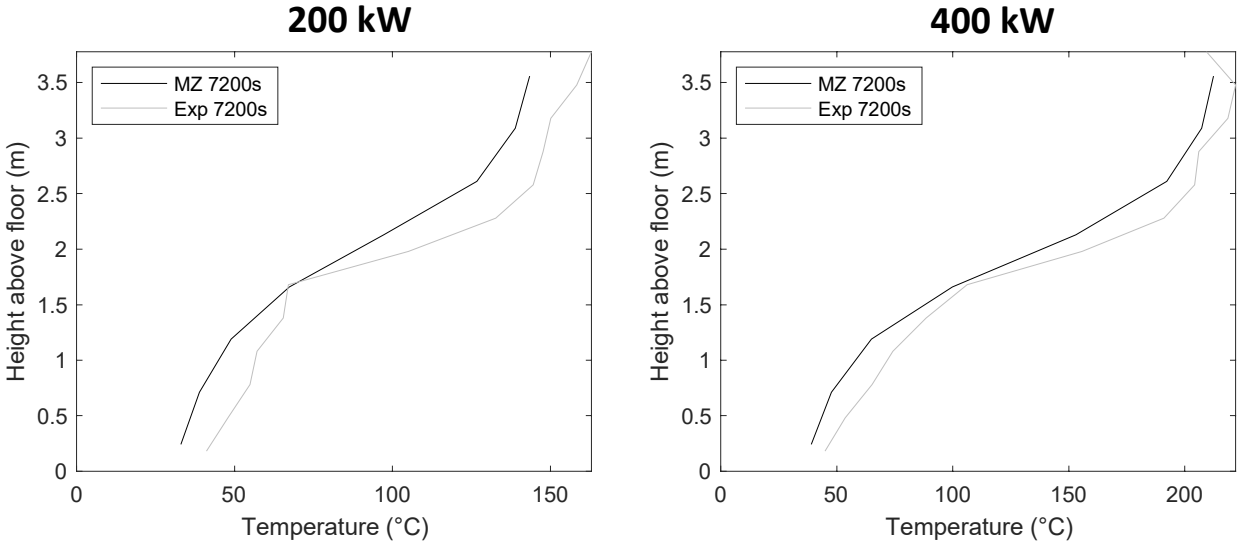
Model evaluation

- Wall and corner effects on plumes

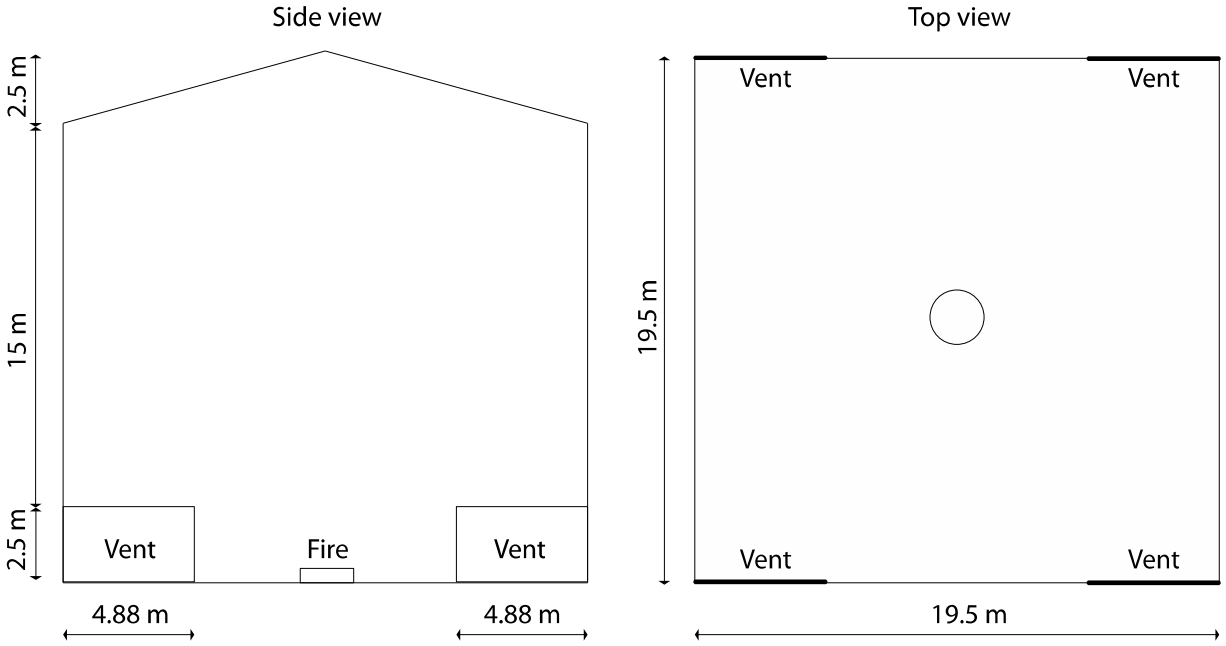
Free burning case (plume not close to wall)



- Natural gas
- 200 and 400 kW

Model evaluation

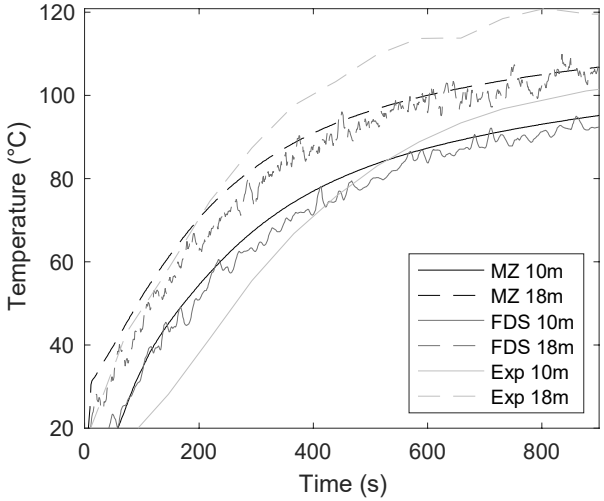
Murcia Atrium Fire Tests

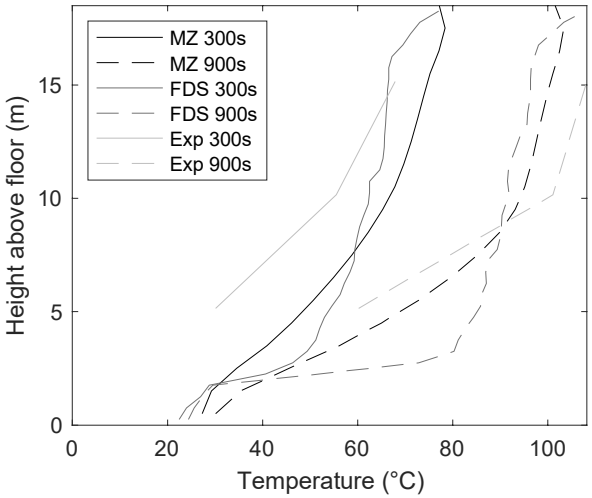


- Test#3
- 2.3 MW heptane pan fire
- Exhaust fans off, natural ventilation

Model evaluation

Murcia Atrium Fire Tests





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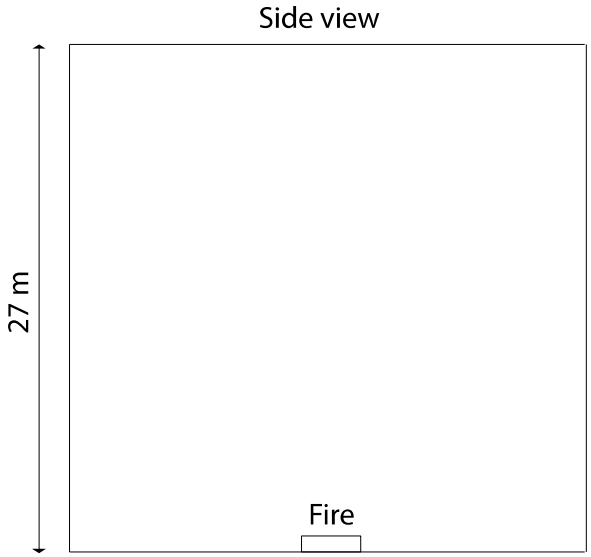
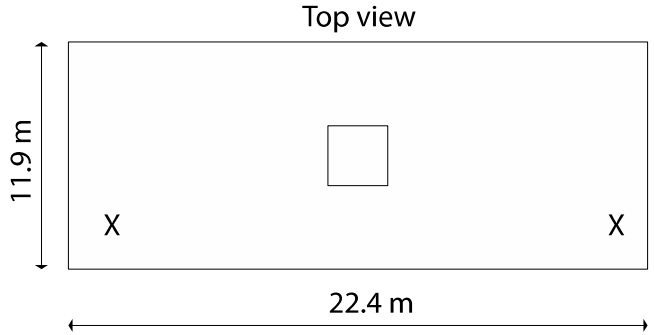
Model evaluation

PolyU Atrium test

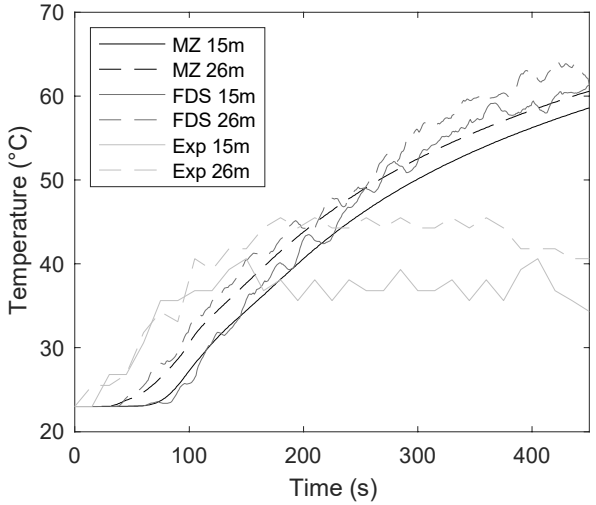


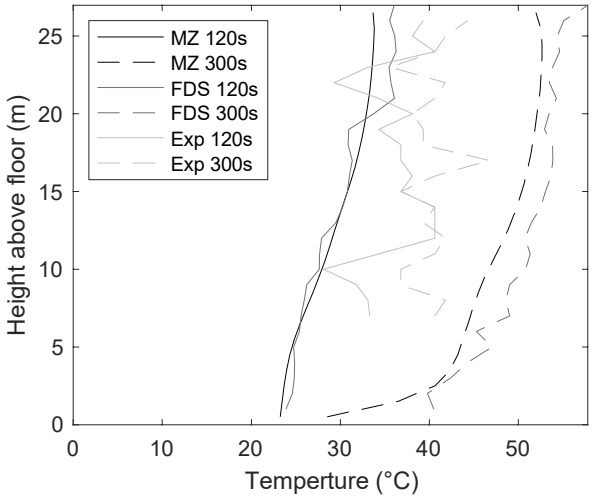


- 1.7 MW diesel pool fire
- Limited ventilation
- Two TC trees with 20 TCs in each

Model evaluation

PolyU Atrium test





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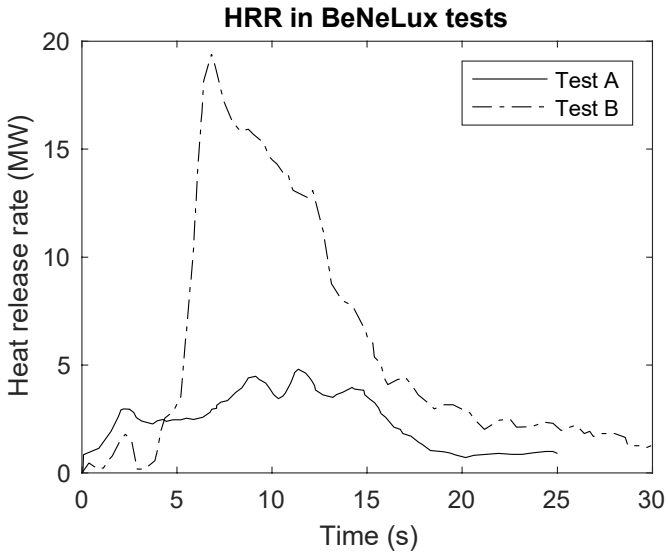
Model evaluation

BeNeLux tunnel fire tests

- Modelled as a 418 m long tube with a 4.4° uphill slope
  - Width: 9.8 m, height: 5.2 m

Test	Ventilation	Type of fire	Maximum HRR (MW)
A	Natural ventilation	Car	5
B	Longitudinal ventilation max 6 m/s	Canvas covered wooden pallets	20

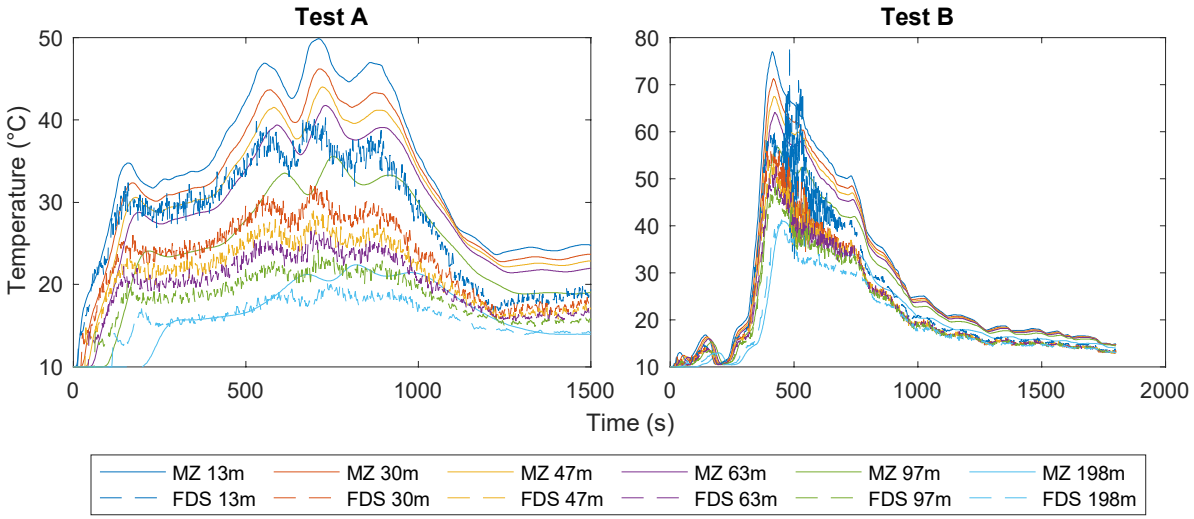


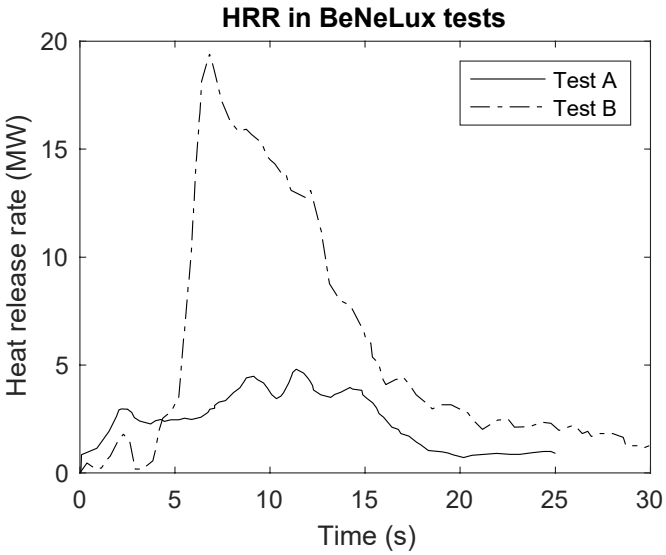
MZ model was adapted for tunnel fires:

- Longitudinal ventilation
- Tunnel gradient
- Fire plume

Model evaluation

BeNeLux tunnel fire tests





Model evaluation - Conclusion

- MZ predicts gas temperatures within 5-10% of FDS results and within 10% of the experimental data in the well-ventilated large spaces.
  - However, in one case there are larger discrepancy between the experimental data and simulation results this was probably due to ventilation conditions
- MZ performed well in regard to the tunnel fire scenario
  - But the fire dynamics is different in several aspects and more work is needed
- The results are promising and there is a future for the multi-zone concept; however, further studies are needed in order to quantify the accuracy of the model and its limitations

Acknowledgment

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  - Benjamin Waldeck
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  - Annachiara Nardone

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