Aalto University

Fire Modelling of Energy-Efficient Apartment Buildings – Consideration of air-tightness and mechanical ventilation

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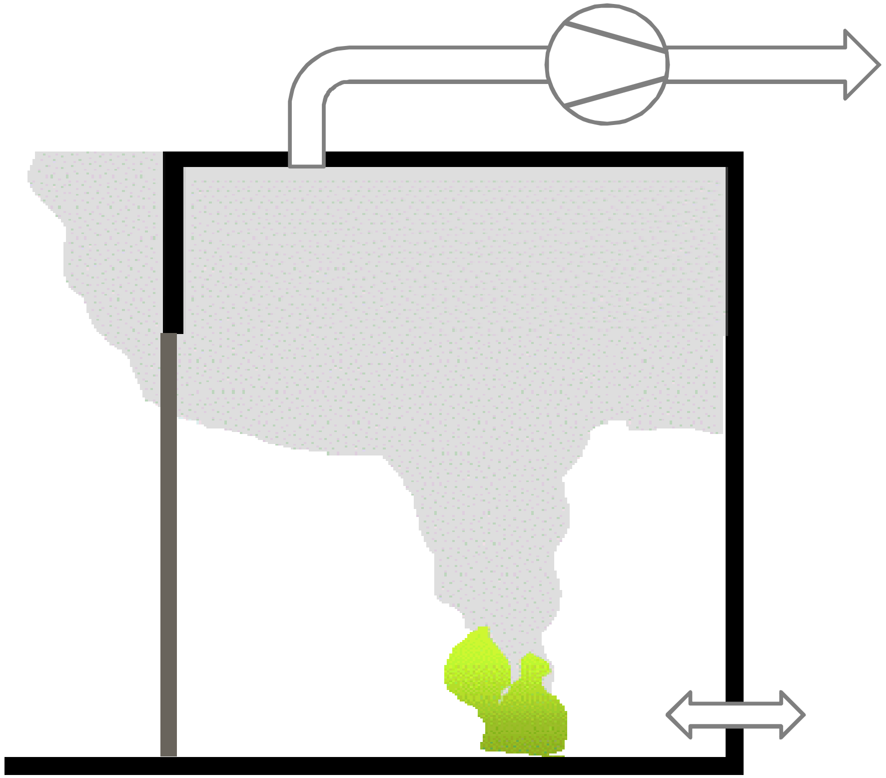
Background



The project

Partners

- Aalto University
- Stravent Oy
- Southwest Finland Rescue Service
- Markku Kauriala Oy
- VTT Technical Research Centre of Finland Ltd.

Sponsors

- Finnish Fire Protection Fund
- Hagab AB
- Criminal Sactions Agency
- Ministry of Environment

Thanks to

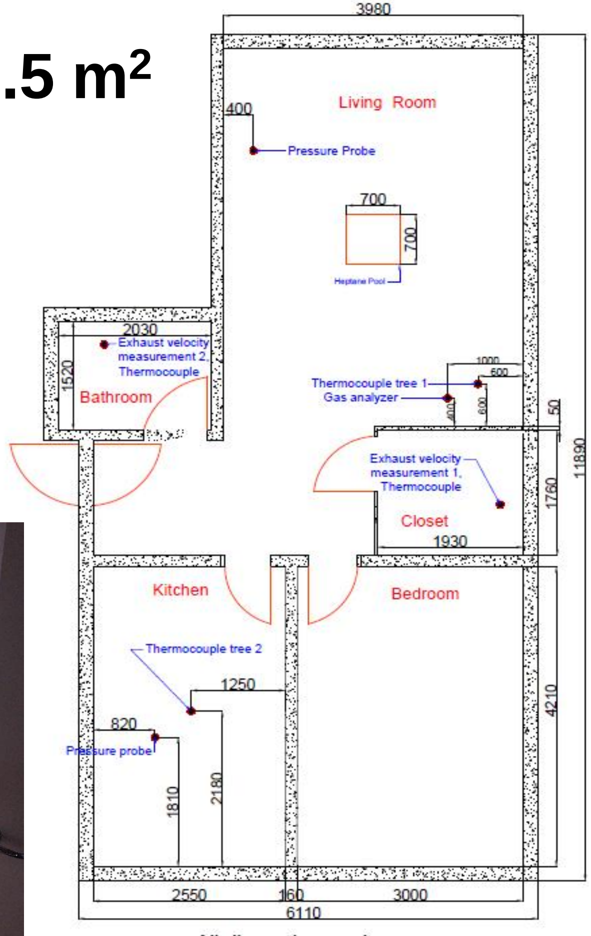
- Rahul Kallada Janardhan
- Umar Riaz
- Topi Sikanen (VTT)

Fire experiments

- **3-storey apartment building in Kurikka, western Finland**
- **Built in 1970's.**
- **Windows renewed few years ago.**
- **Tests in a 1st floor apartment**

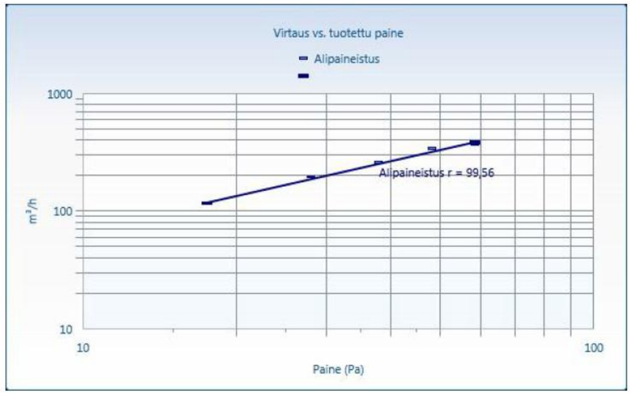
https://www.youtube.com/watch?v=0Ss_ONolzLY

58.5 m^2



Air tightness measurements

SFS-EN 13829, Mikko Yli-Piipari / Vertia Oy



Results of the air-tightness

Direction	Δp [Pa]	$\dot{V}_{\lvert\Delta p\rvert}$ [m^3/s]	$q_{\lvert\Delta p\rvert}$ [m^3/hm^2]	$n_{\lvert\Delta p\rvert}$ [1/h]	A_{leak} [m^2]	A_{leak}/A_{env}
Underpressure	-30	0.047	1.0	1.1	0.011	0.70×10^{-4}
Underpressure	-50	0.078	1.7	1.9	0.015	0.89×10^{-4}
Underpressure	-70	0.10	2.2	2.4	0.016	0.97×10^{-4}
Overpressure	30	0.091	2.0	2.2	0.022	1.4×10^{-4}
Overpressure	50	0.12	2.7	2.9	0.023	1.4×10^{-4}
Overpressure	70	0.15	3.3	3.6	0.024	1.5×10^{-4}

RakMK D3 (2012)

Requirement: q_{50} £ 4 m^3/hm^2

Recommendation: q_{50} £ 1 m^3/hm^2

$$\dot{V}_{leak} = A_L C_d \mathrm{sign}(\Delta p) \left(\frac{2\,|\Delta p|}{\rho}\right)^{1/2}$$

NFPA 92 (2012):

Very loose: A_{leak}/A_{env} = 12 ´ 10^{-4}

Loose: A_{leak}/A_{env} = 3.5 ´ 10^{-4}

Average: A_{leak}/A_{env} = 1.7 ´ 10^{-4}

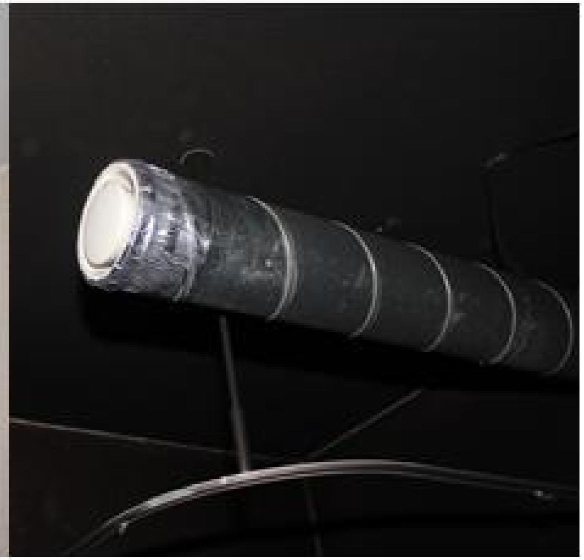
Tight: A_{leak}/A_{env} = 0.50 ´ 10^{-4}

Ventilation configurations

CLOSED

OPEN

NORMAL



Fire loads

Group 1 (10 tests)

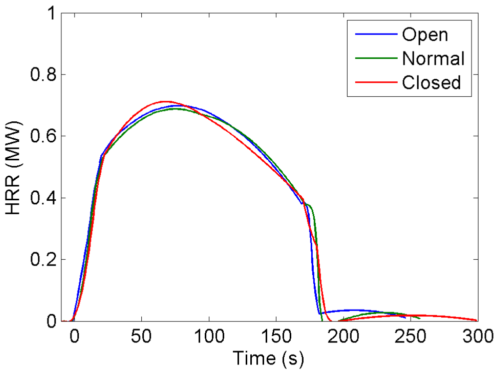
3 L n-heptane

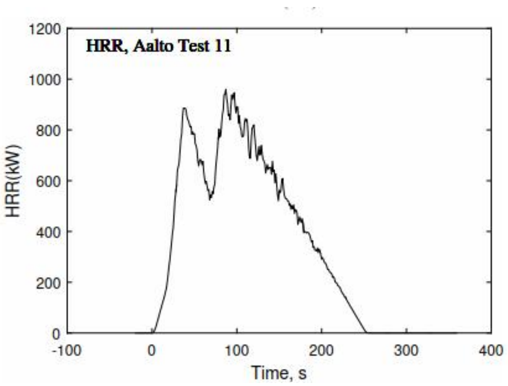
0.7 m x 0.7 m pool

Group 2 (3 tests)

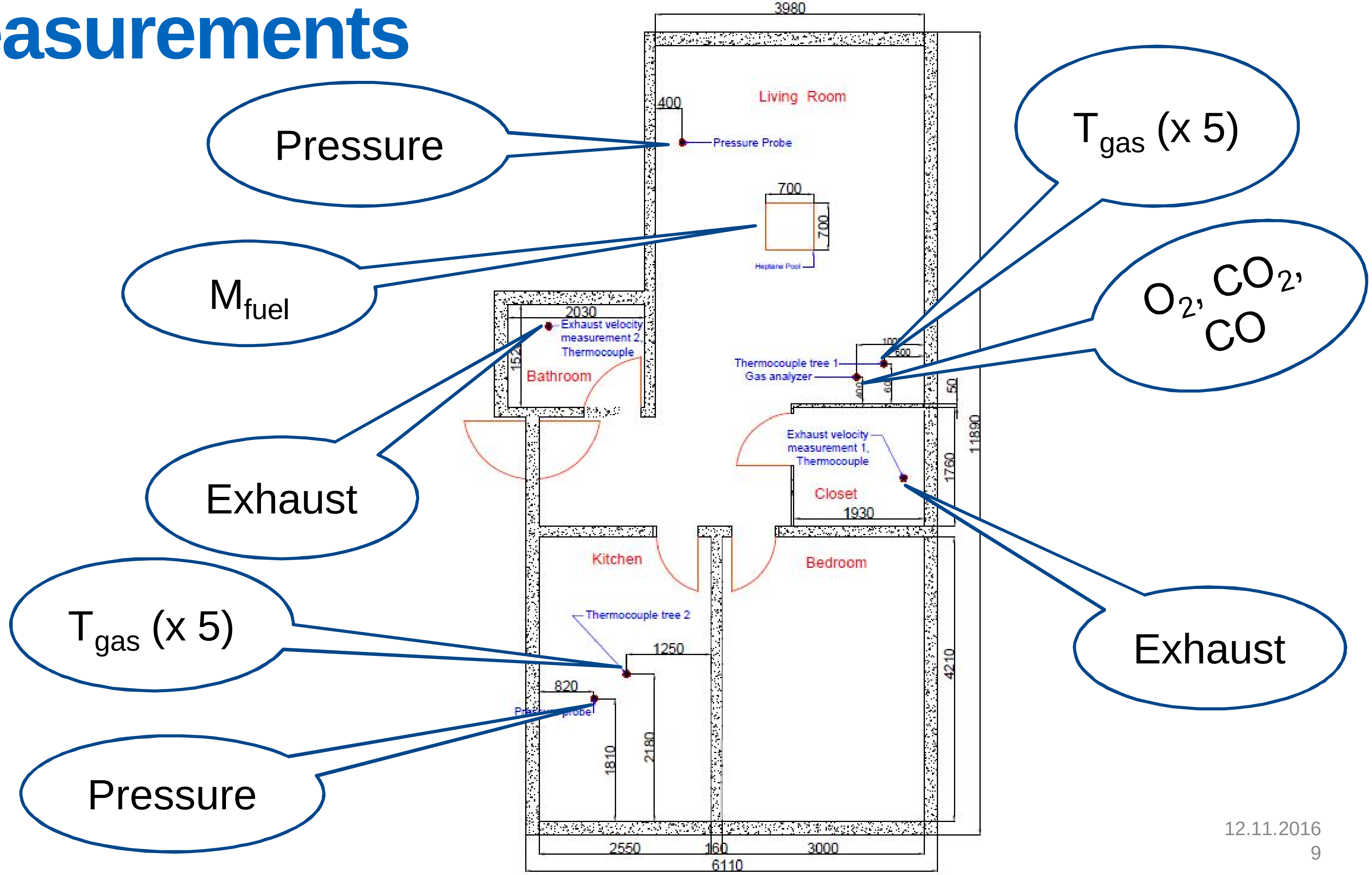
PUF matress of about 3 kg

Both fires were ultrafast (t_g < 75 s)





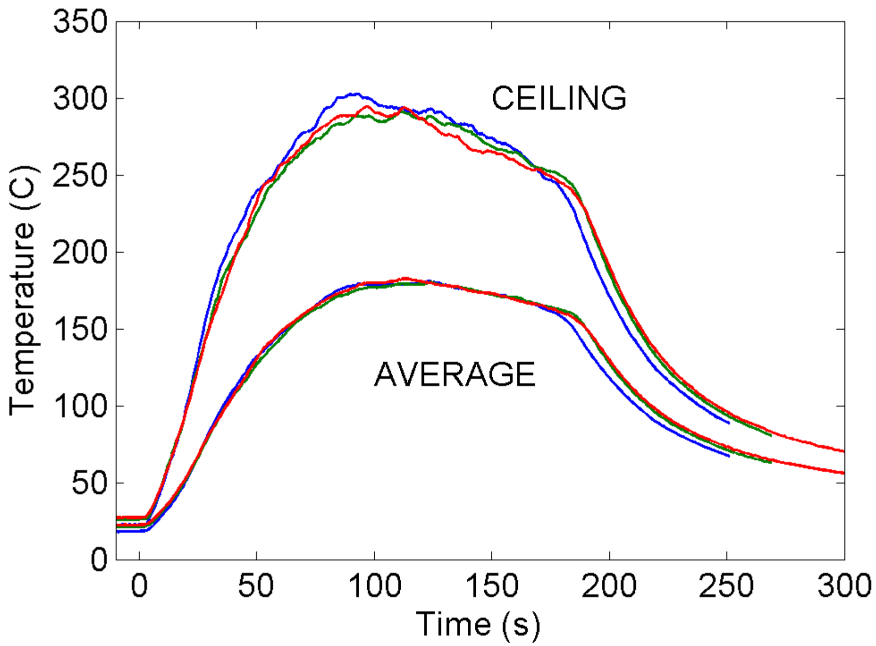
Measurements



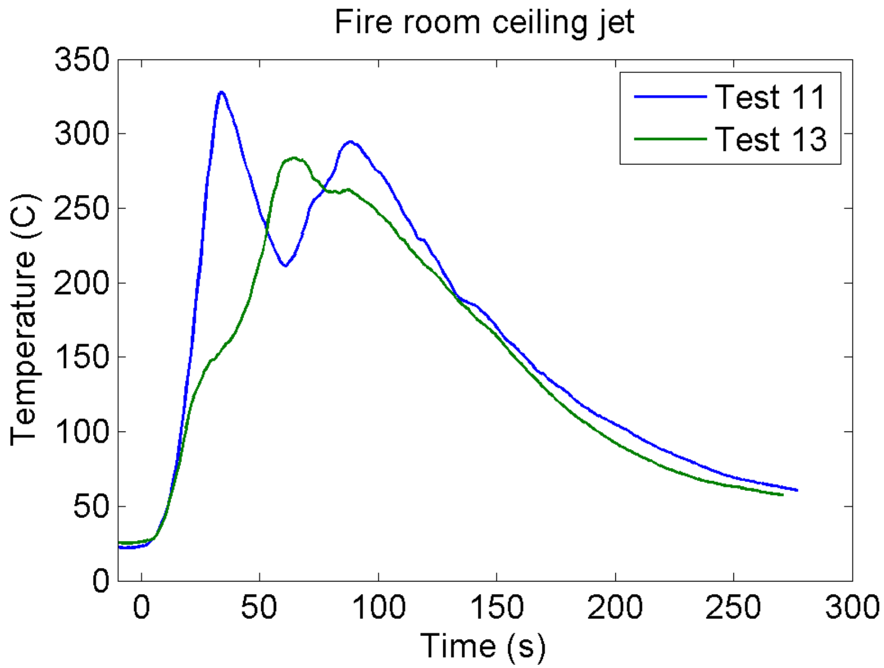
All dimension are in mm

Gas temperatures

Heptane fires

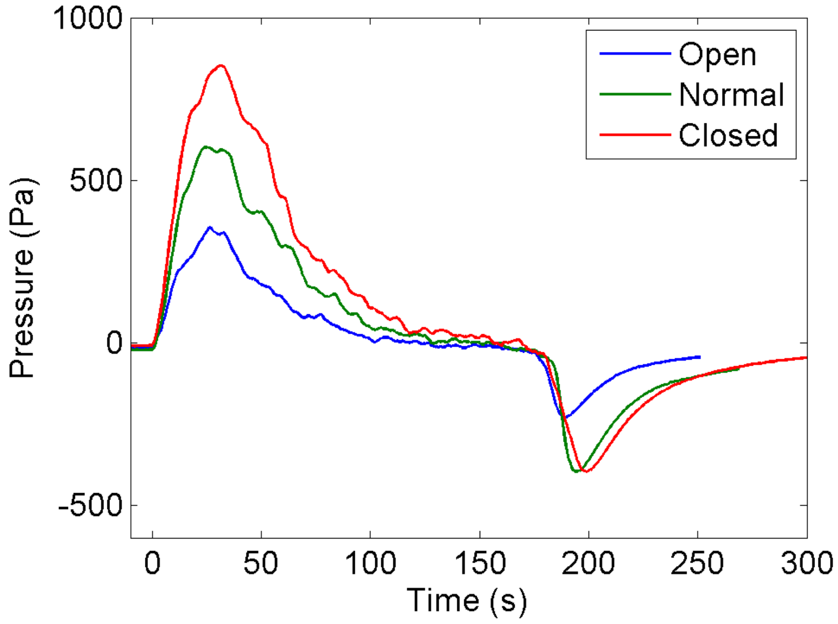


PUF fires

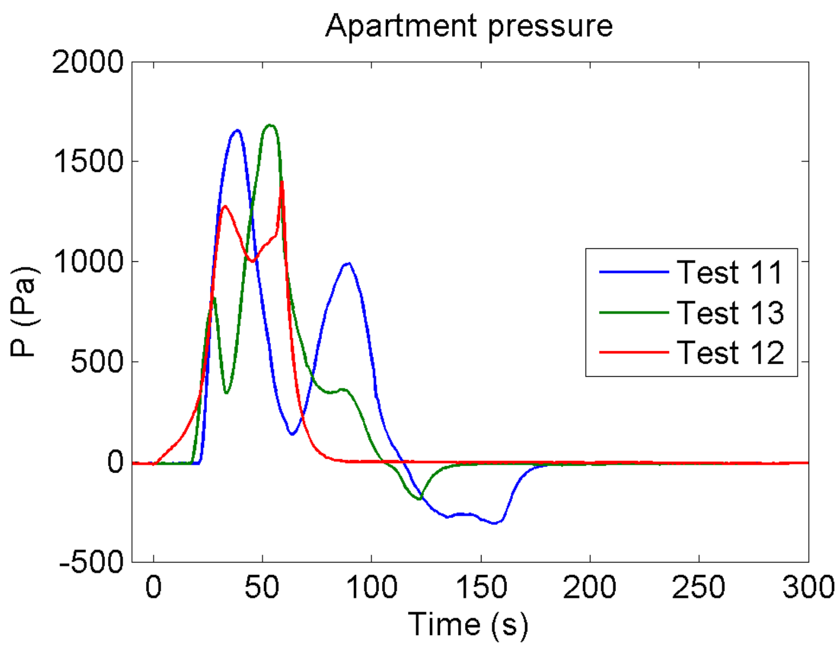


Gas pressure

Heptane fires



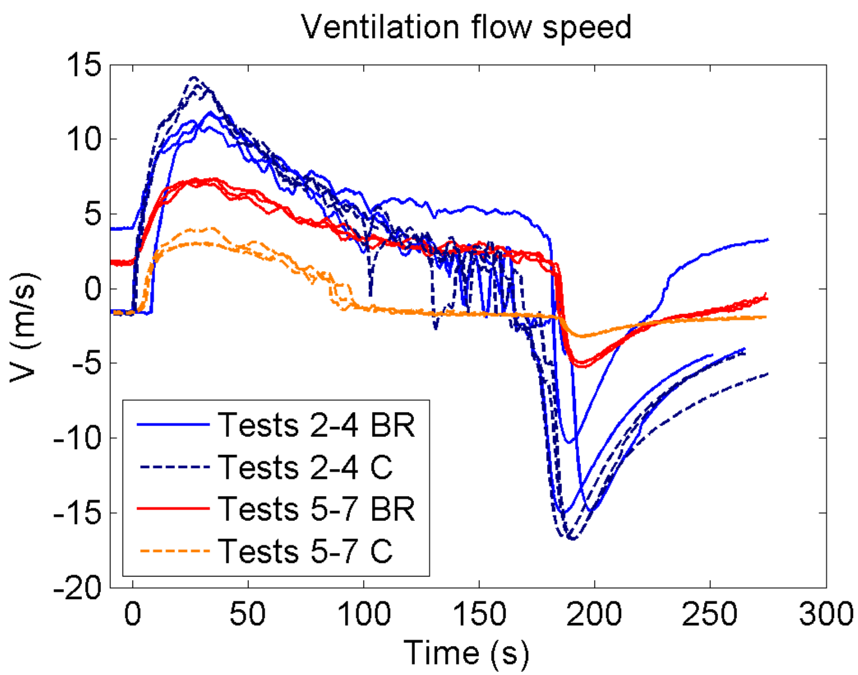
PUF fires



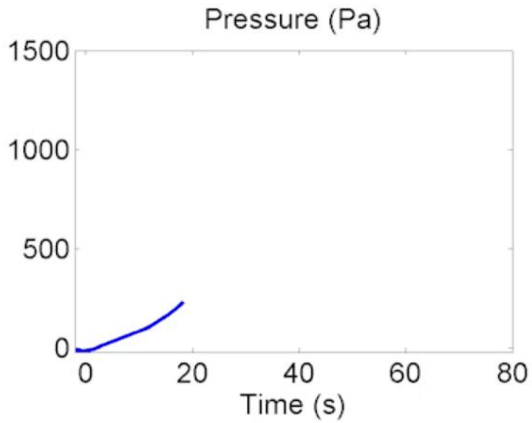
Flow speed in exhaust duct

Test 2-4: OPEN
Test 5-7: NORMAL
BR = bathroom
C = closet

Heptane pool fires



PUF in closet, normal ventilation

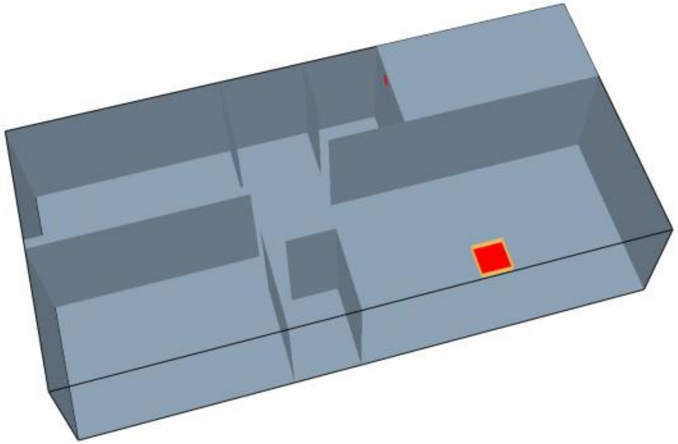


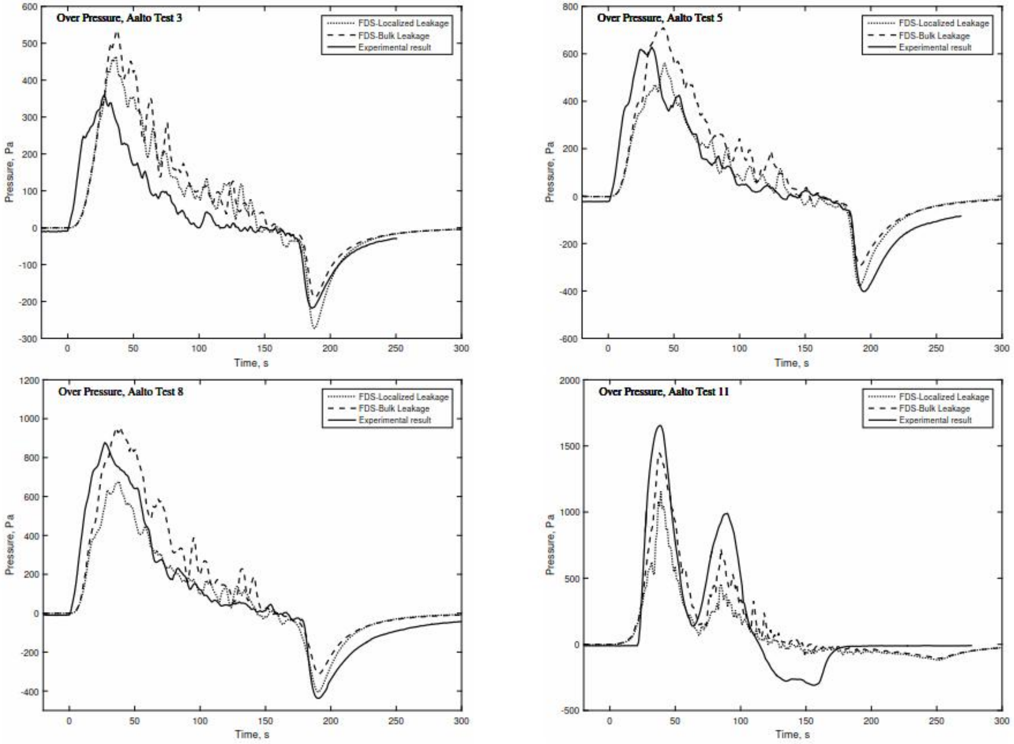
Validation of FDS modelling

Prescribed HRR

Simple HVAC

Local / bulk leakage



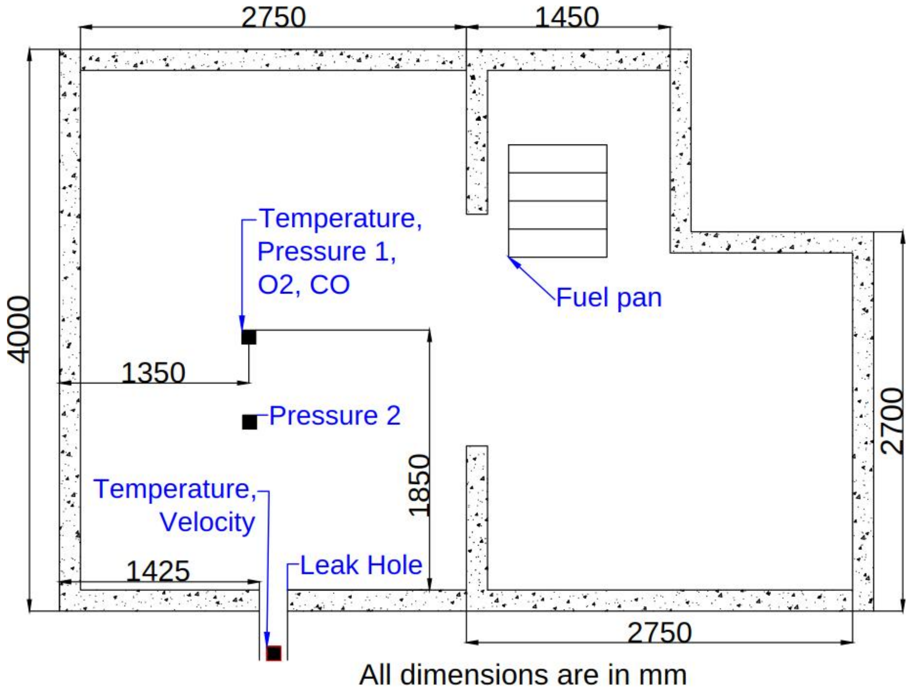


Additional validation data

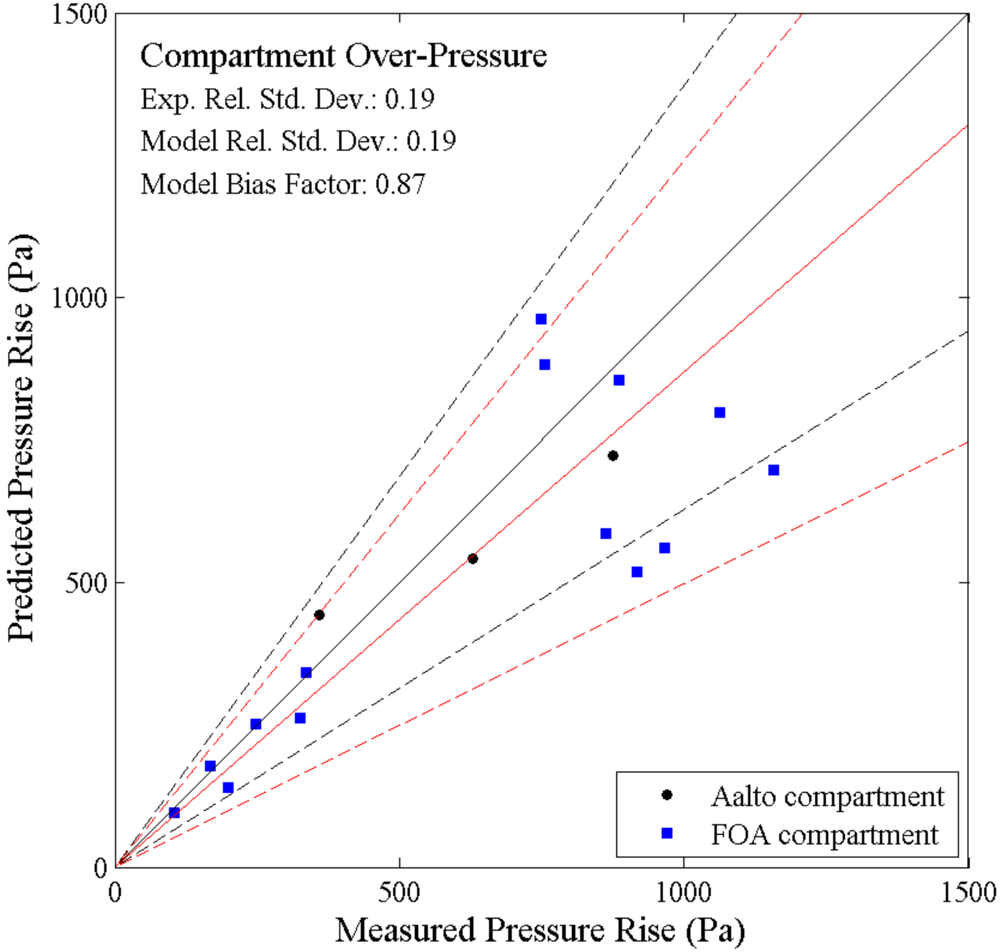
FOA experiments by Hägglund et al. 1996 and 1998.

Heptane pool fires in concrete enclosure.

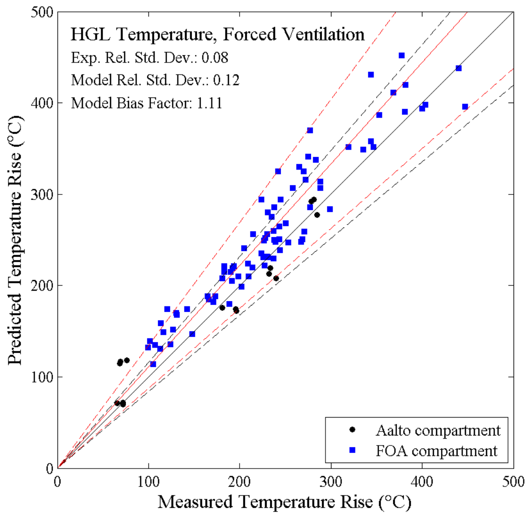
No HRR measurement.



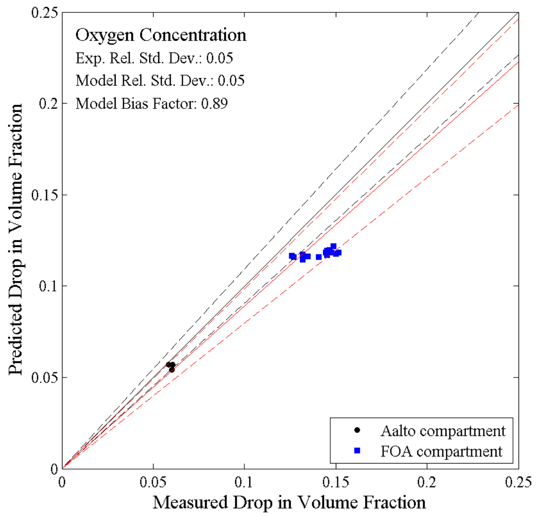
Summary



Compartment Over-Pressure
Exp. Rel. Std. Dev.: 0.19
Model Rel. Std. Dev.: 0.19
Model Bias Factor: 0.87
Aalto compartment
FOA compartment
Predicted Pressure Rise (Pa)
Measured Pressure Rise (Pa)
0
500
1000
1500

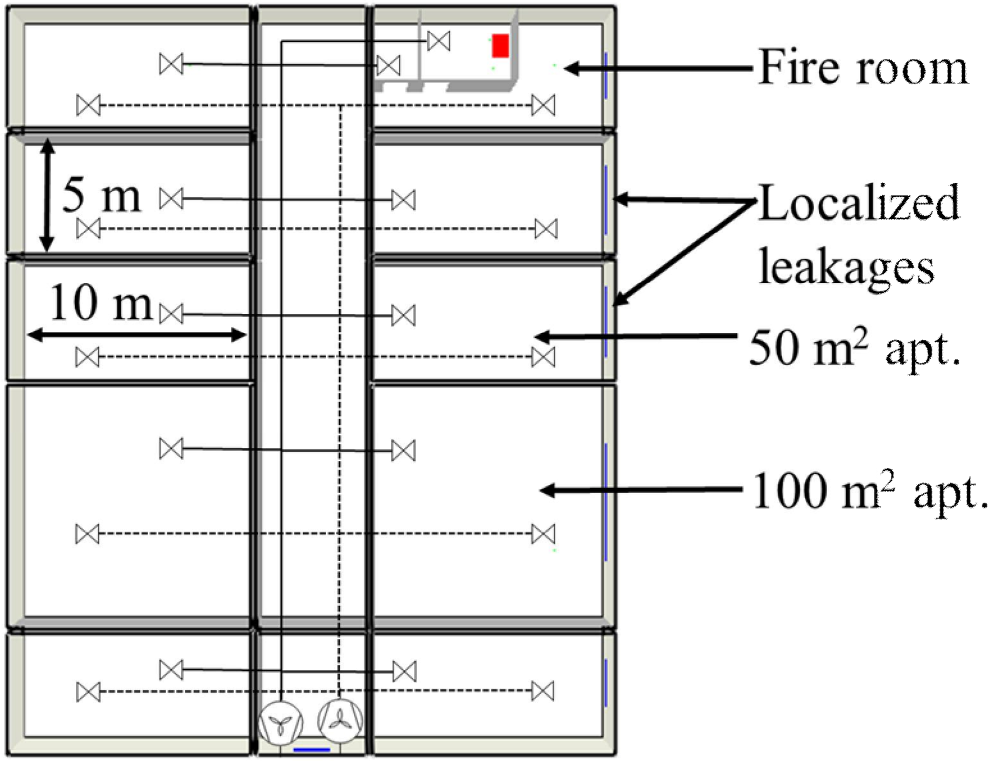


HGL Temperature, Forced Ventilation
Exp. Rel. Std. Dev.: 0.08
Model Rel. Std. Dev.: 0.12
Model Bias Factor: 1.11
Aalto compartment
FOA compartment
Predicted Temperature Rise (°C)
Measured Temperature Rise (°C)
0
100
200
300
400
500



Oxygen Concentration
Exp. Rel. Std. Dev.: 0.05
Model Rel. Std. Dev.: 0.05
Model Bias Factor: 0.89
Aalto compartment
FOA compartment
Predicted Drop in Volume Fraction
Measured Drop in Volume Fraction
0
0.05
0.1
0.15
0.2
0.25

Apartment case study



Three air-tightness levels

1. Traditional: $q50 = 3.0\ m^3/m^2h$
2. Normal: $q50 = 1.5\ m^3/m^2h$
3. Near-zero: $q50 = 0.75\ m^3/m^2h$

HRR: t^2-fires medium – ultra-fast

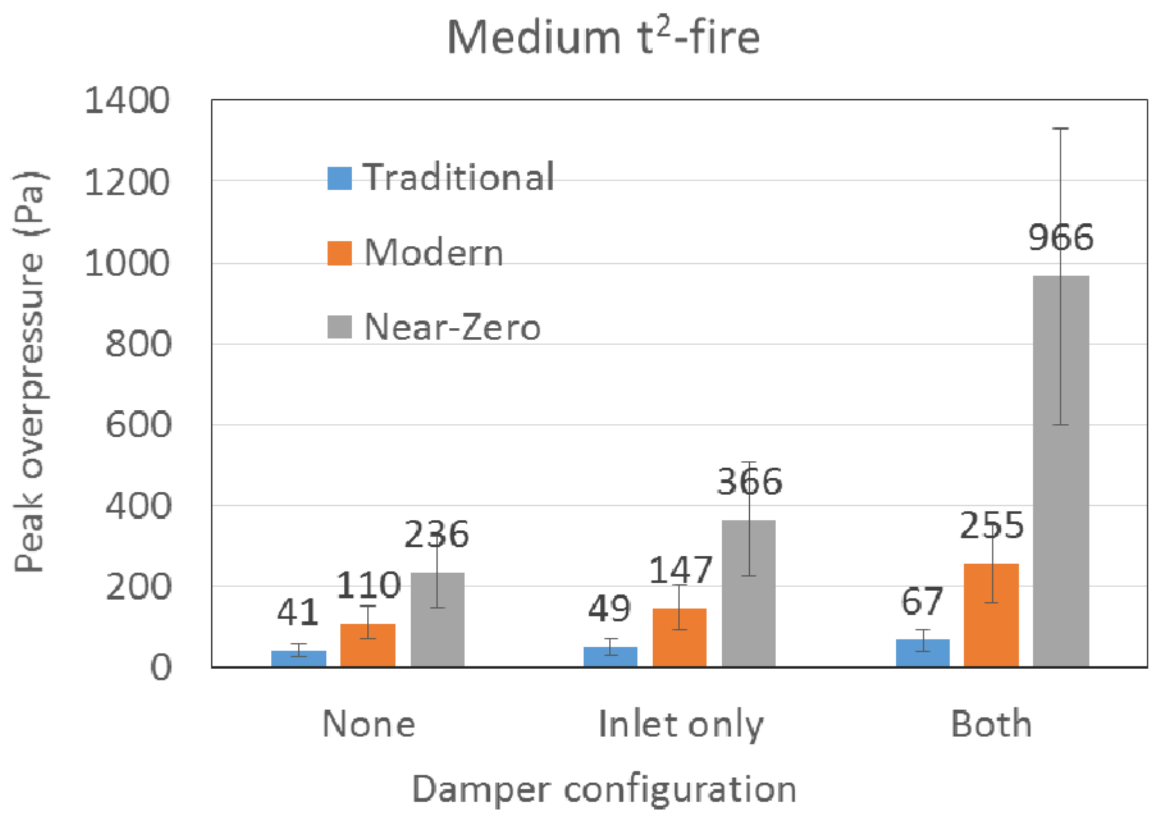
Damper configurations:

1. No dampers
2. Only inlet branch closed
3. Both inlet and outlet closed

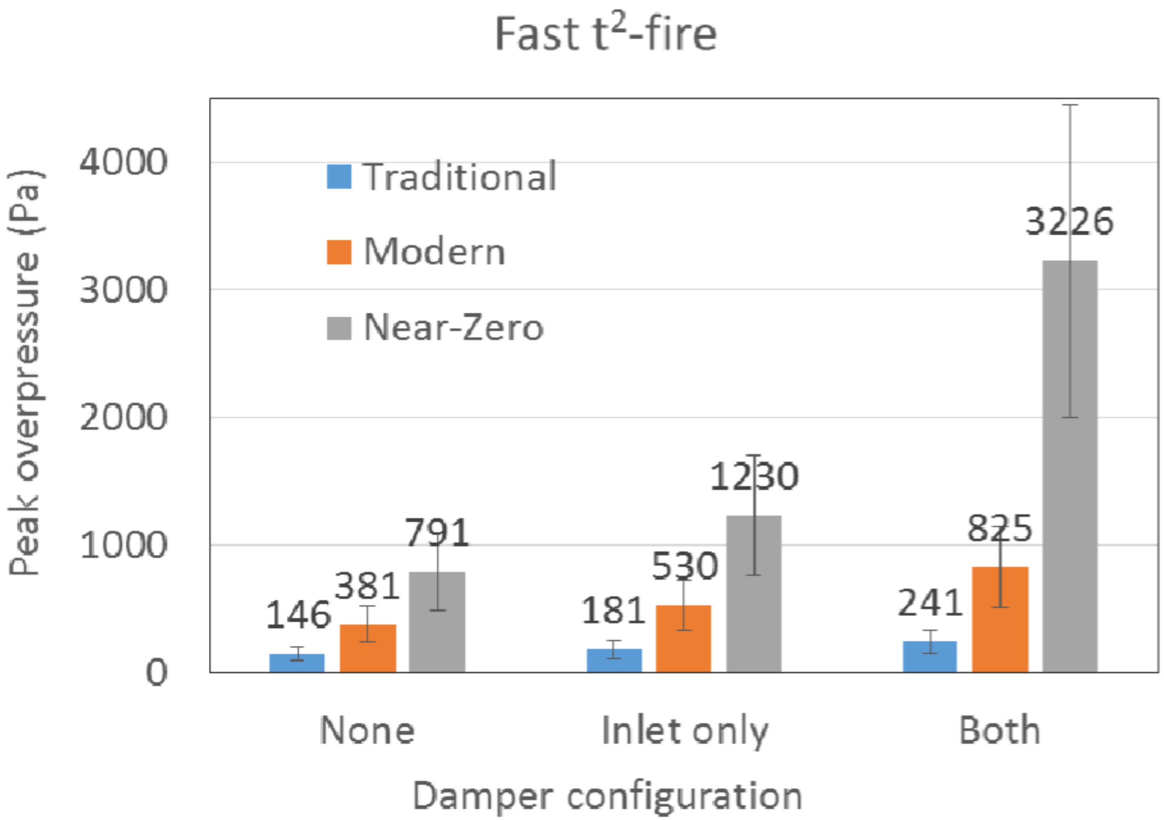
Fan configurations

1. On
2. Off and open
3. Off and outside damper closed

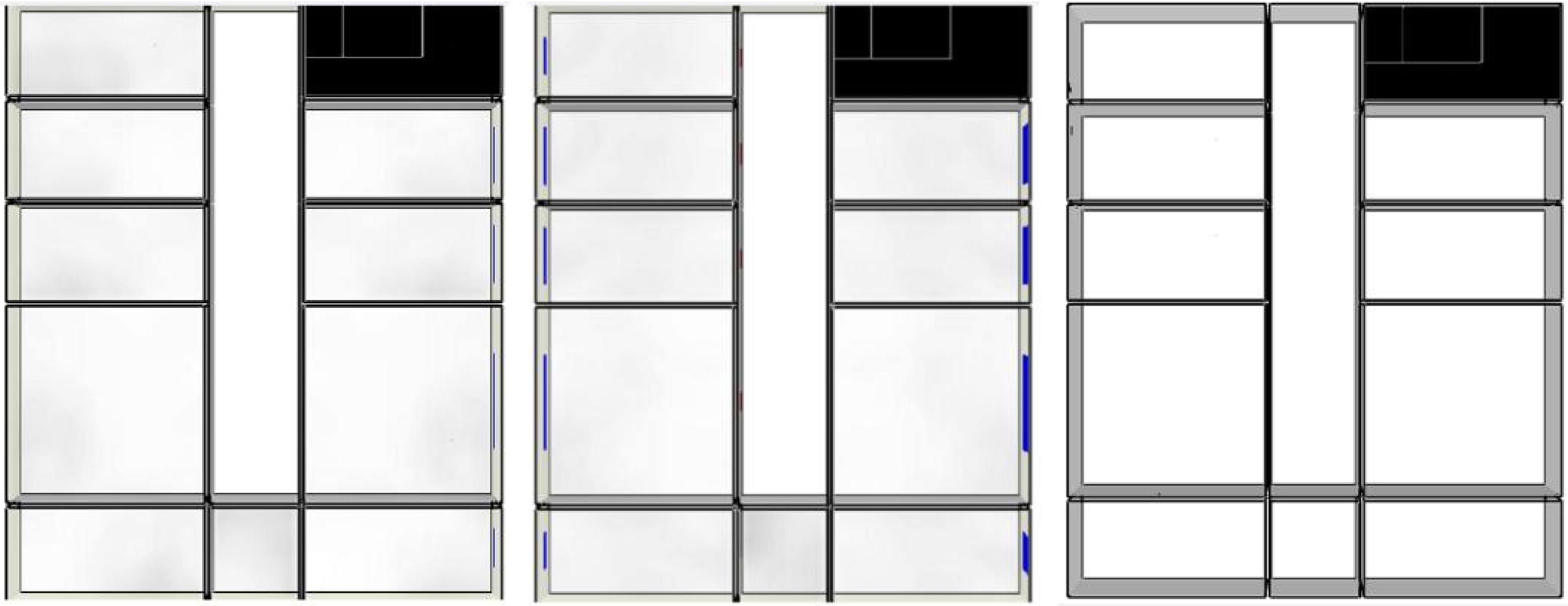
Peak pressures with medium fire



Peak pressures with fast fires

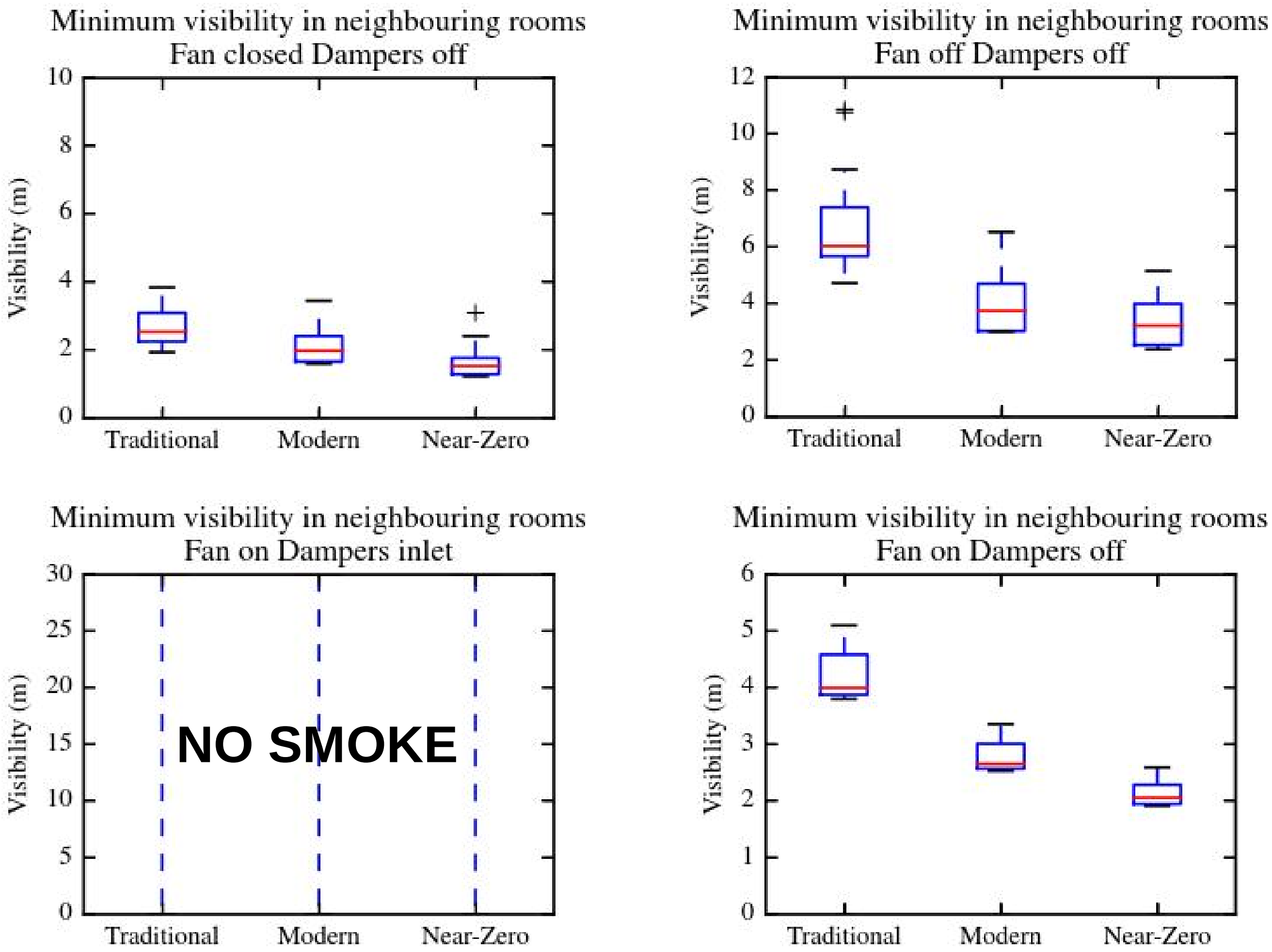


Smoke spreading to neighbours

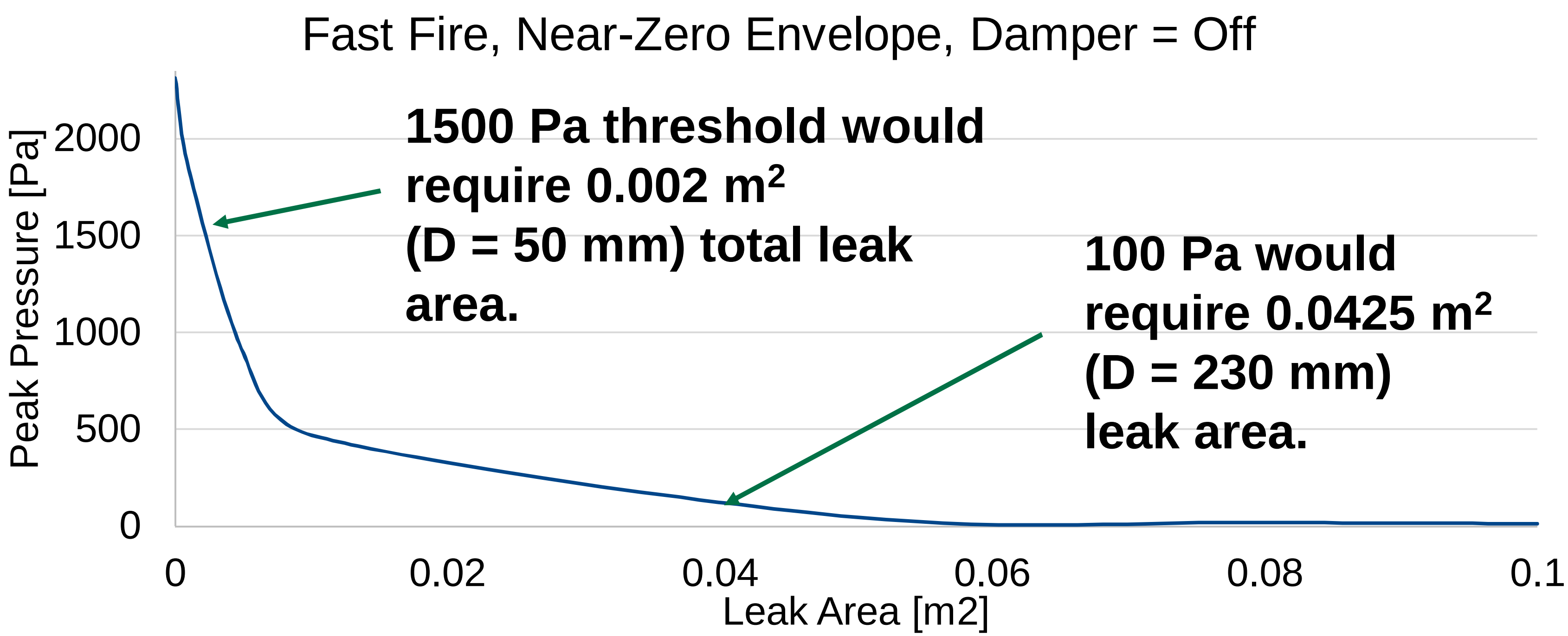


(a) Fan = Off, Dampers = Off (b) Fan = On, Dampers = Off (c) Fan = On, Dampers = Inlet

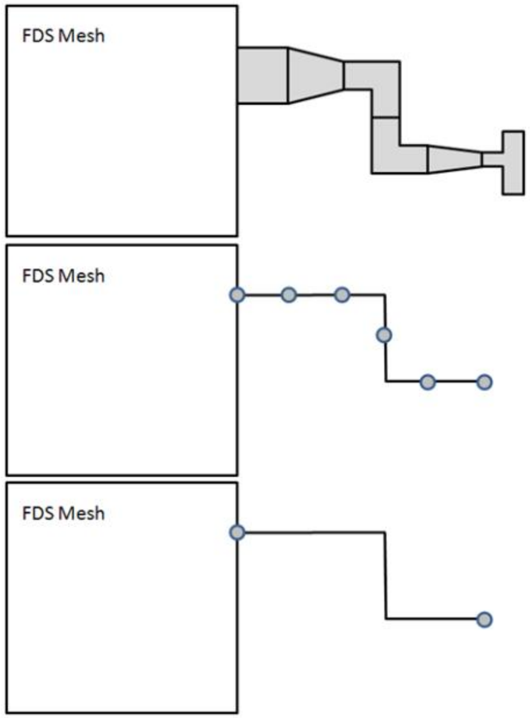
Smoke spreading: visibility



Pressure management



Issues with the HVAC system modelling



1. **Real systems are too complex for ”engineering” the model.**
2. **Fan units are much more than just a fan. Pressure losses of the fan unit can dominate.**
3. **Real systems are always tuned and balanced for normal mode of operation. We can do the same for the FDS model, but a better tool would help.**