Fire safety issues in modern sustainable designs associated with more air-tight building envelopes

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- Airtightness – what's the problem?
- Airtightness over time
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- Consequences of high pressures
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What's the problem?

- Fire = Energy release
- Energy release = Volumetric exp.
- Confined enclosure = Pressurisation

What's the problem?

- Volumetric expansion:

$$q_f = \frac{\left({T_2}/{T_1}\right) - 1}{t_2 - t_1} \cdot V$$

q_f fire-induced flow [m^3/s]
V the volume of the enclosure [m^3]
T_2 temperature at time t_2 in seconds [K]
T_1 temperature at time t_1 in seconds [K]

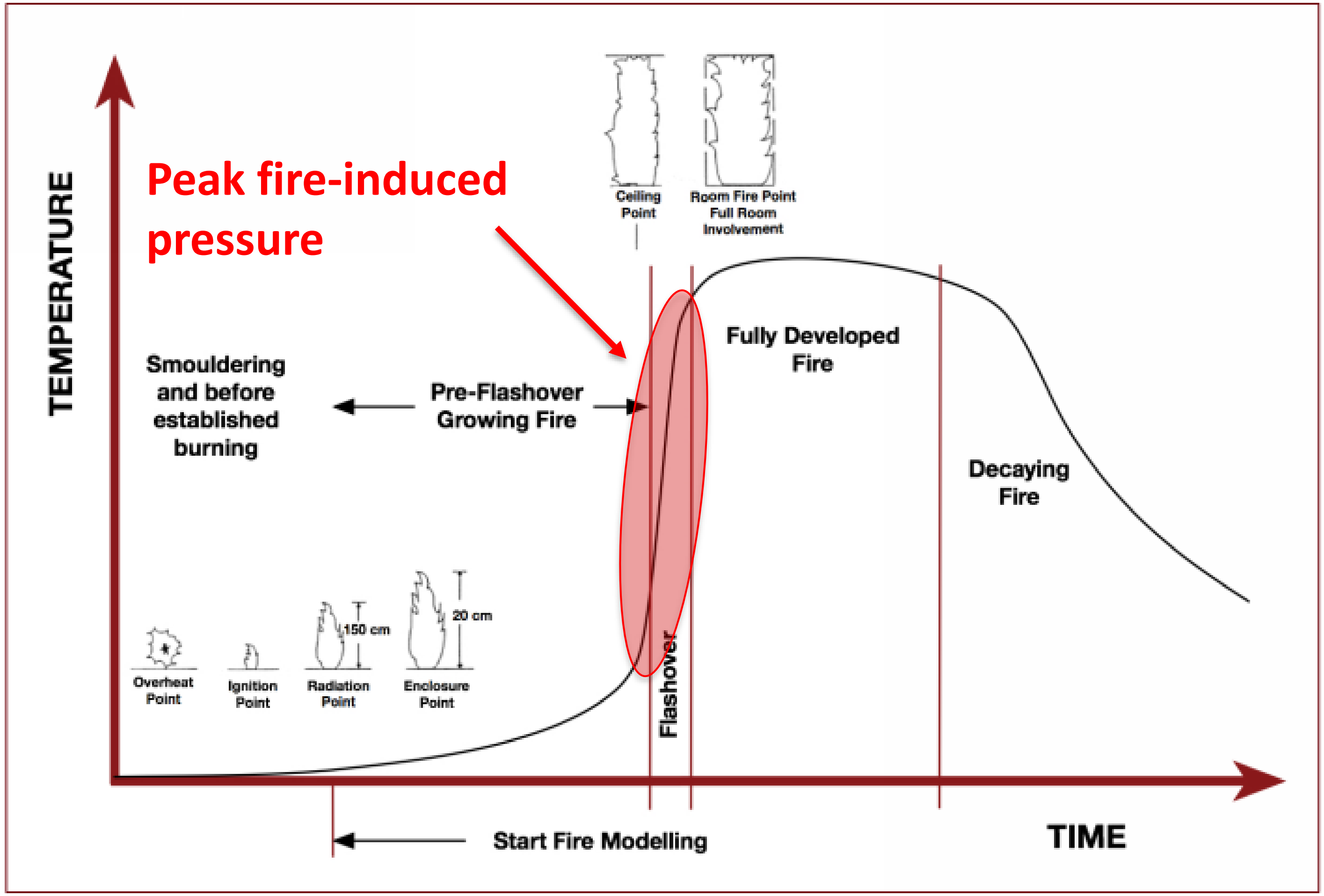
What’s the problem?

- Peak fire-induced pressure:

$$Max\left(\frac{dT}{dt}\right)$$

T	temperature [K]
t	time [s]

What’s the problem?



What's the problem?

Pressurization will cease when:

- A sizeable opening on the façade is created (e.g. window breaks), or
- Oxygen is depleted (circa 10-12 % vol), or
- Successful fire suppression system operation

What's the problem?

- Leakage determines pressurization
- Typical leakage paths:
  - Façade
  - Doors
  - Ducts

What’s the problem?

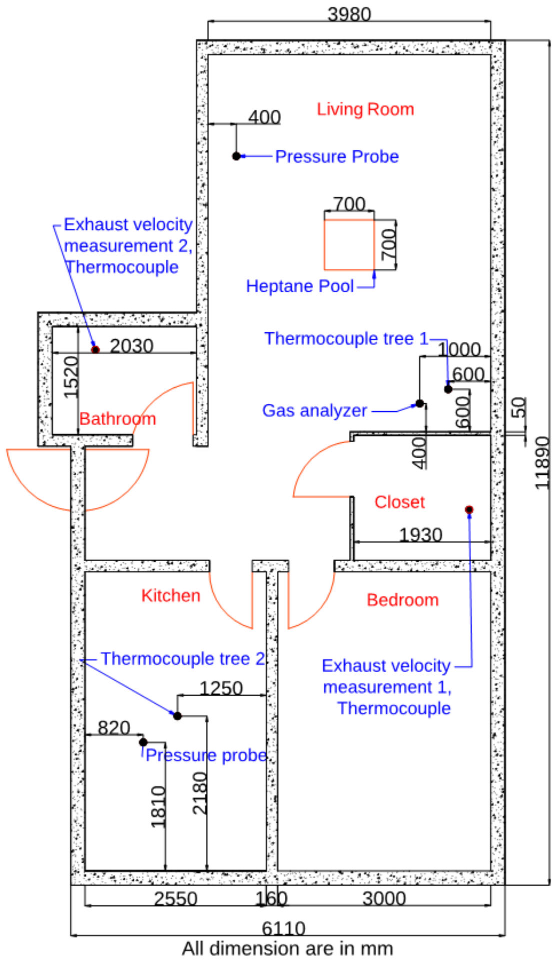
- Fire-induced pressure function of façade airtightness

$$Fire\ induced\ pressure \propto \frac{1}{(Facade\ airtightness)^2}$$

What’s the problem?

- Potential consequences:
  - Smoke spread
  - Excessive door opening forces
  - Integrity failure

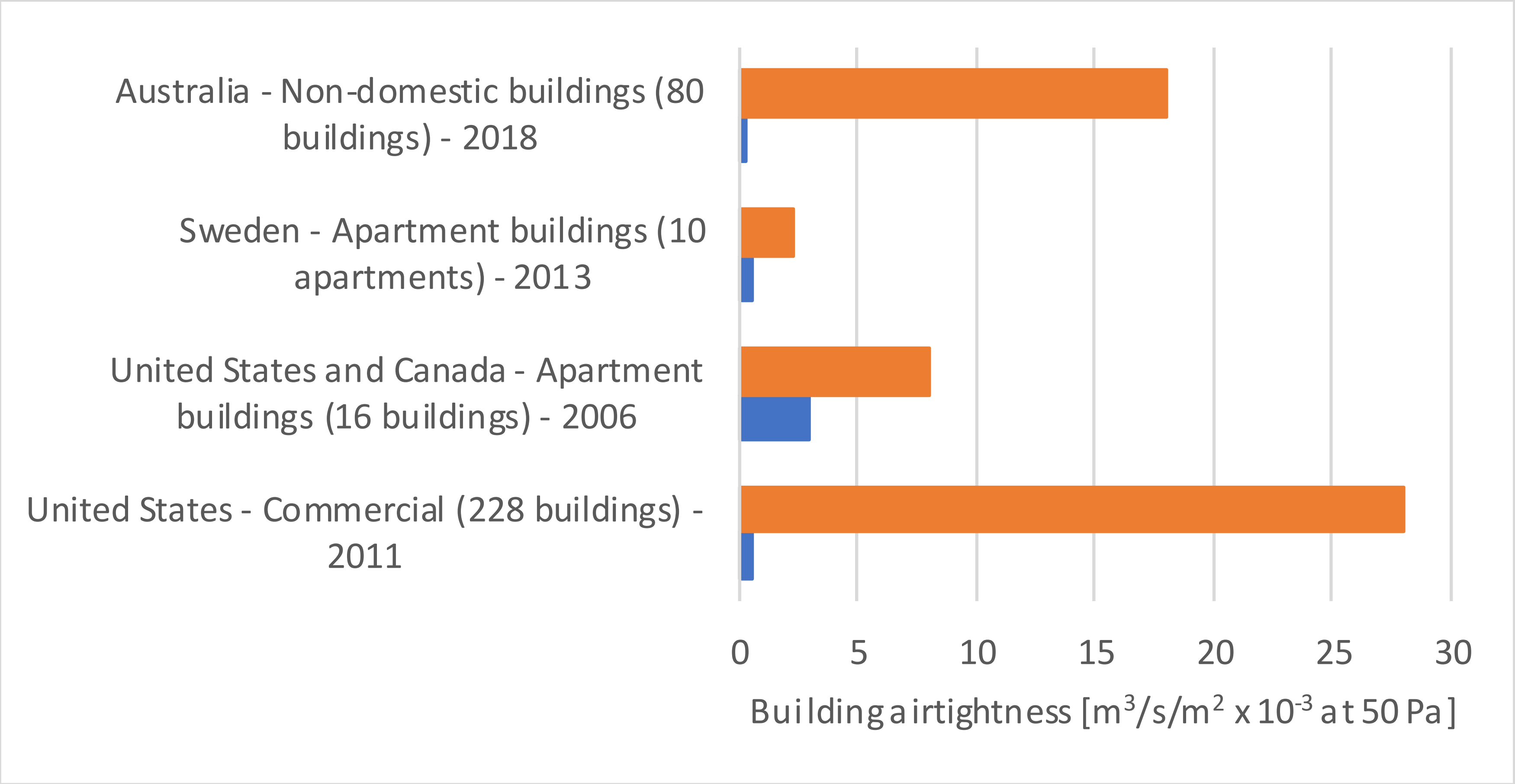
What’s the problem?



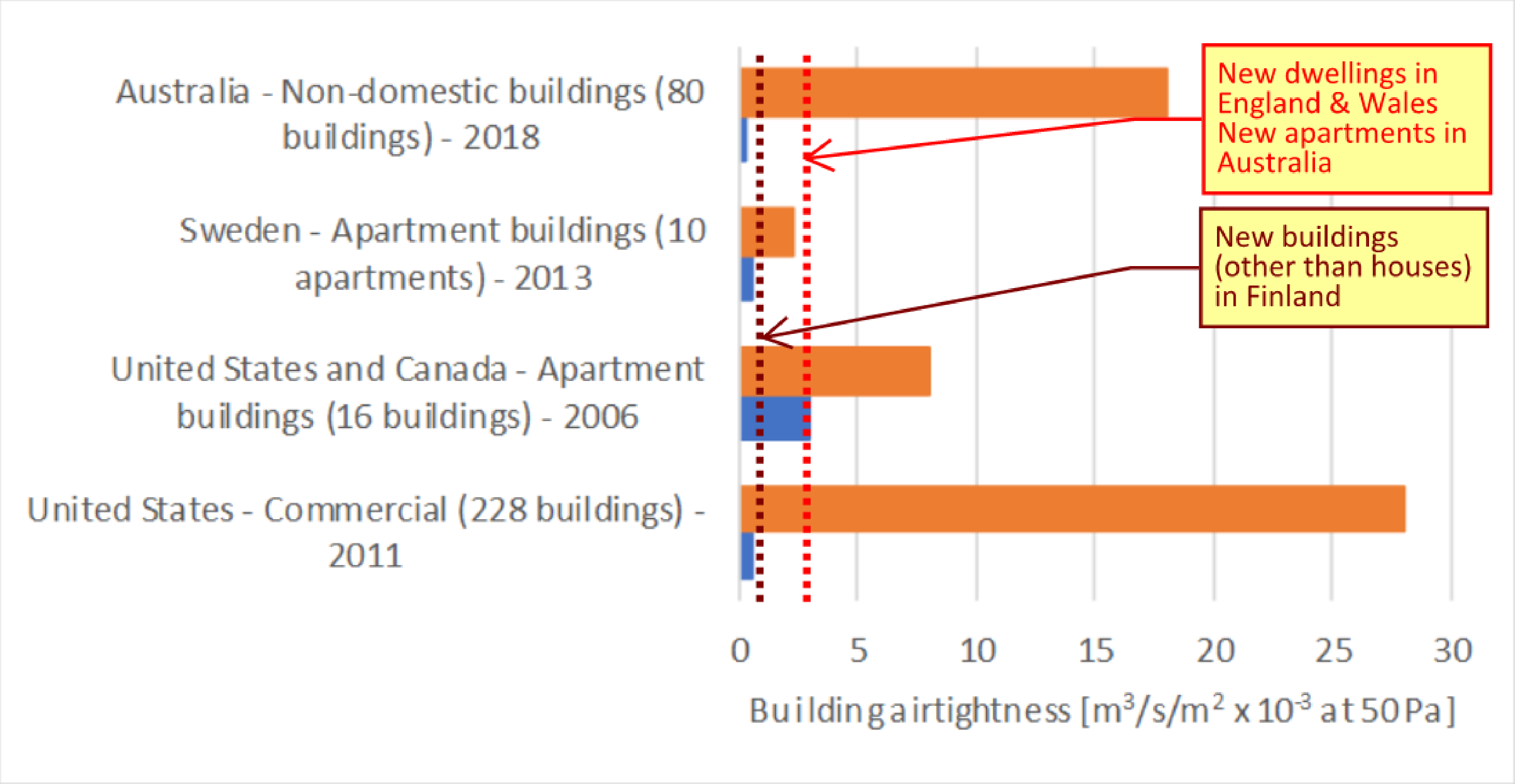
Modern building airtightness

- Building Code Requirements
- Voluntary standards

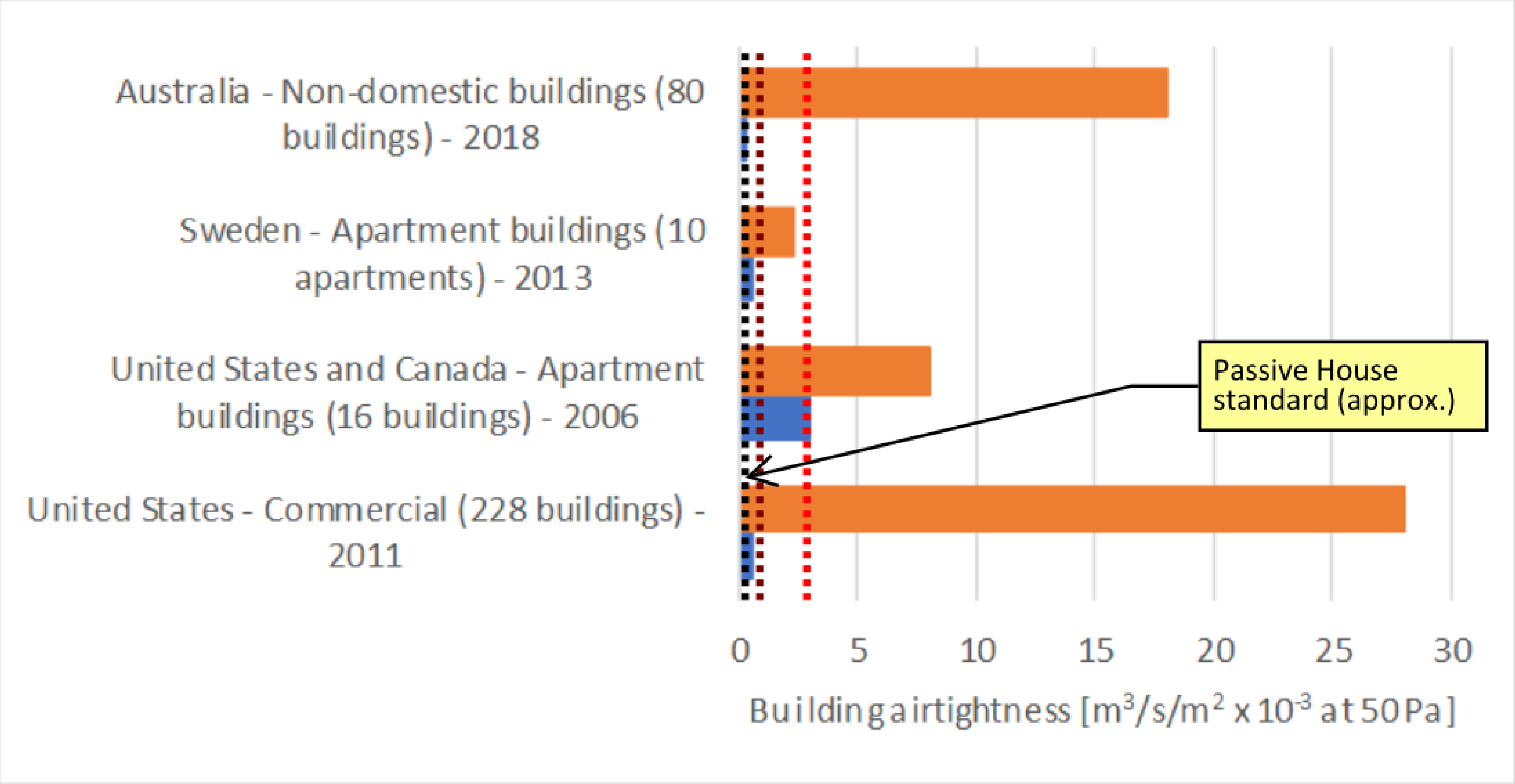
Current stock



Current vs building codes



Passive House standard

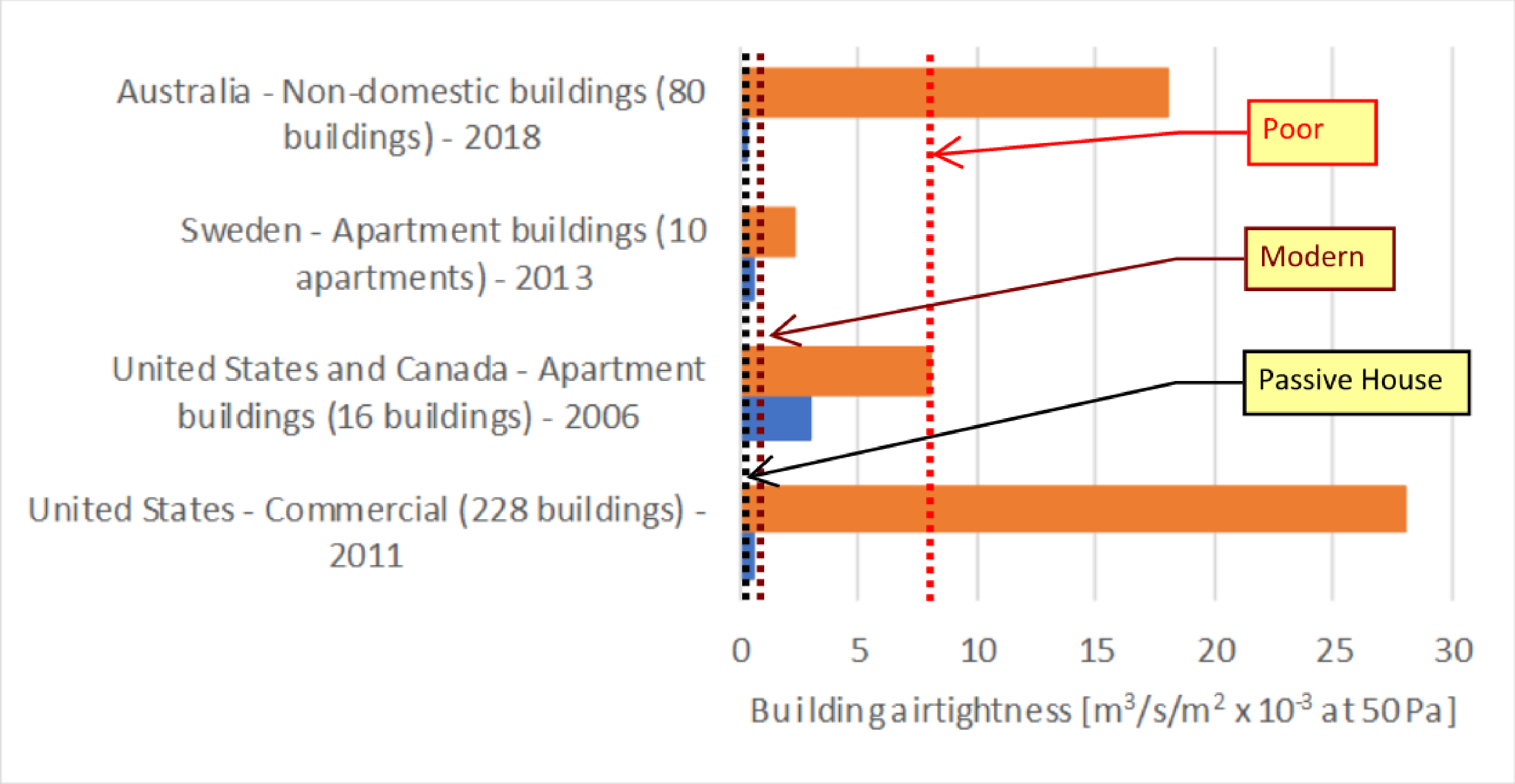


Case study

- Fire compartments
  - 30 & 70 m^2
  - 2.5 m floor to ceiling
  - Single door (e.g. corridor)

- Façade airtightness categories (values at 10^{-3} $m^3/s/m^2$):
  - Poor: 8.00
  - Modern: 0.83
  - Passive House: 0.20

Case study



Australia - Non-domestic buildings (80 buildings) - 2018
Sweden - Apartment buildings (10 apartments) - 2013
United States and Canada - Apartment buildings (16 buildings) - 2006
United States - Commercial (228 buildings) - 2011
Poor
Modern
Passive House
0
5
10
15
20
25
30
Building airtightness [m³/s/m² x 10⁻³ at 50 Pa]

Case study

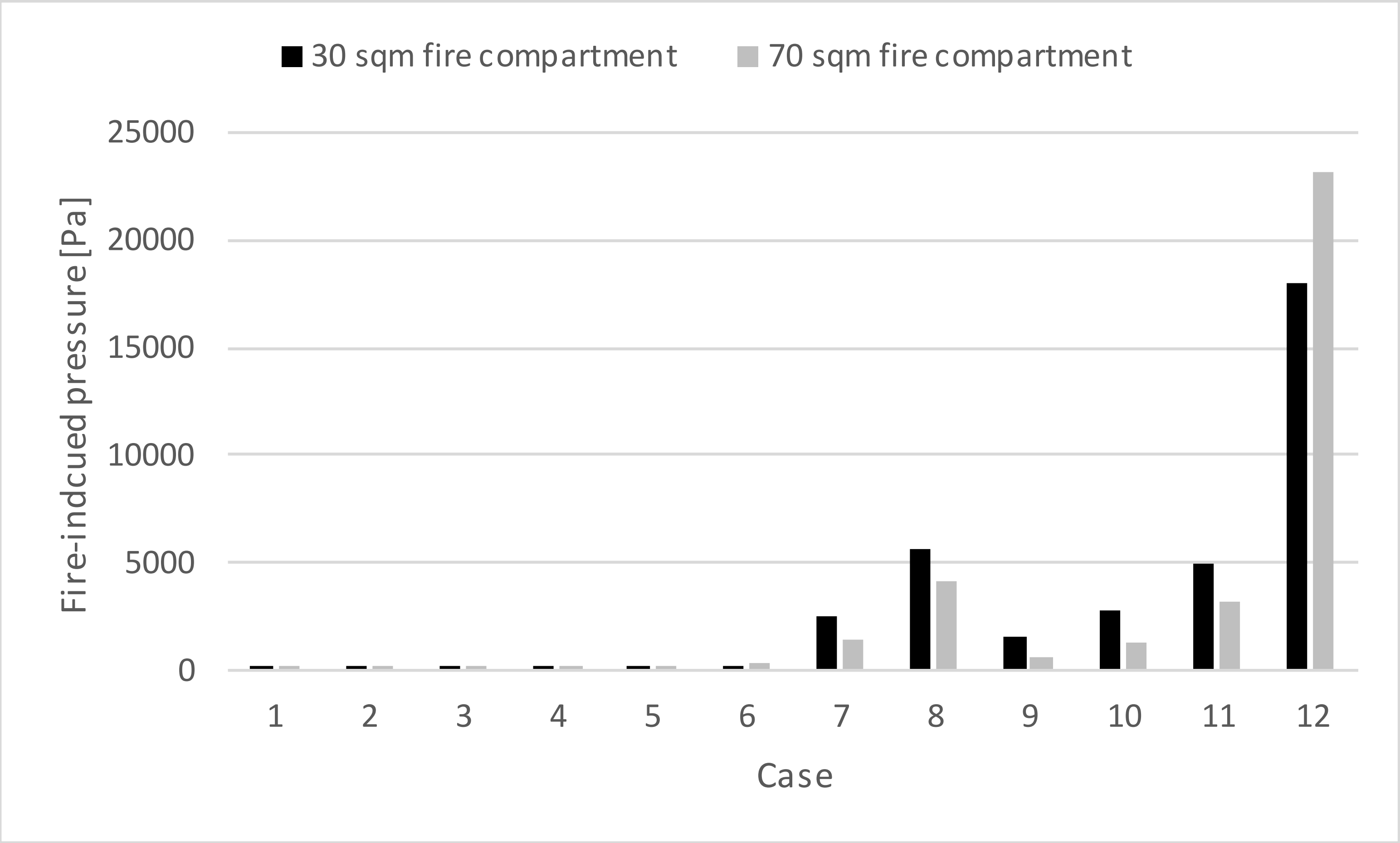
- Smoke seals vs no smoke seals

- Air-handling system (ducts)
  - Motorised fire/smoke dampers, or
  - "Fans in operation" (non-return damper on supply air)
    - Pressure losses - 10 or 30 Pa

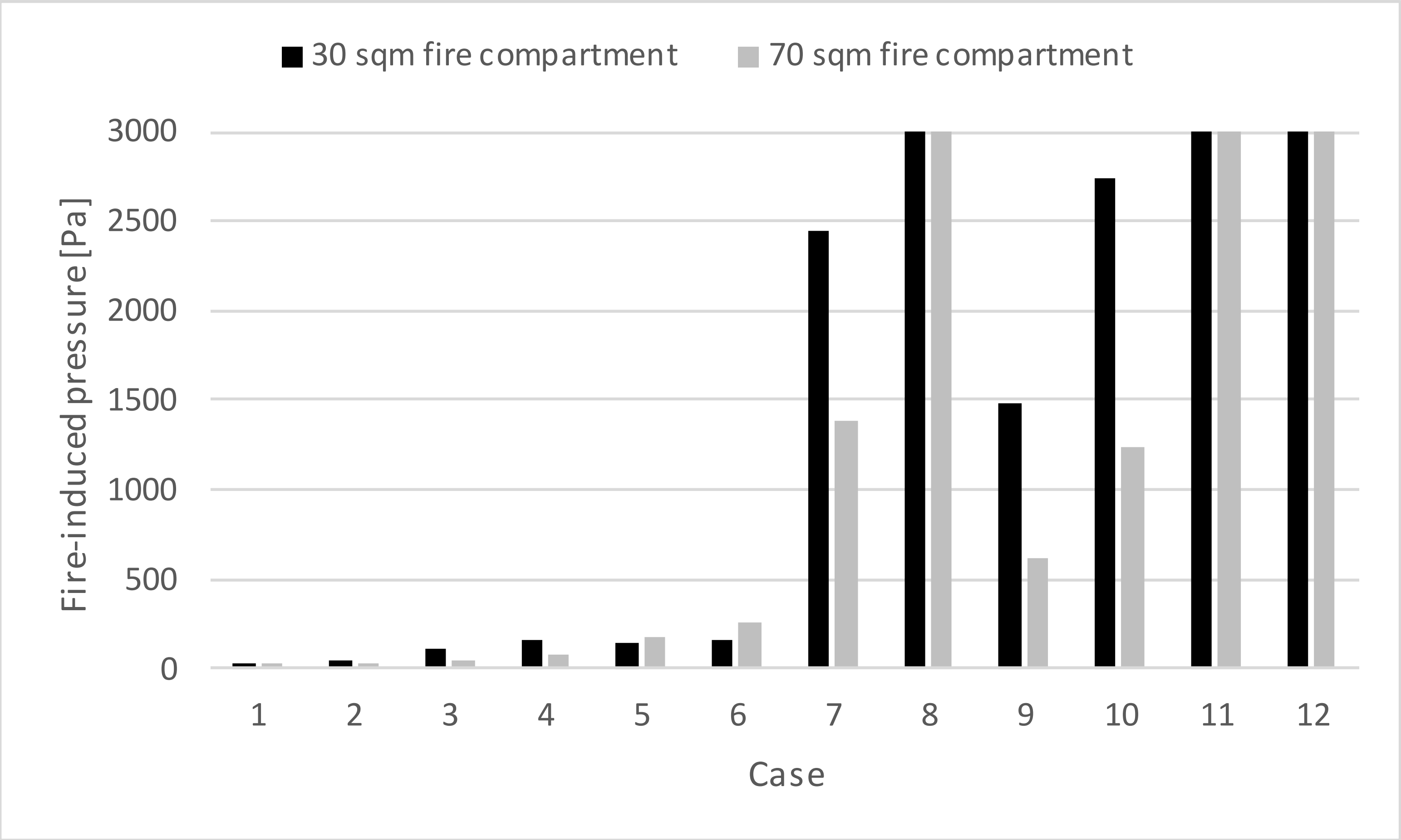
Case study

Case	Air-tightness category	Smoke seals	Pressure losses	Protection method[1]
1	Poor	No	10 Pa	Fans in operation
2	Poor	No	N/A	Fire/Smoke damper
3	Poor	Yes	10 Pa	Fans in operation
4	Poor	Yes	N/A	Fire/Smoke damper
5	Modern	No	30 Pa	Fans in operation
6	Modern	No	N/A	Fire/Smoke damper
7	Modern	Yes	30 Pa	Fans in operation
8	Modern	Yes	N/A	Fire/Smoke damper
9	Passive House	No	30 Pa	Fans in operation
10	Passive House	No	N/A	Fire/Smoke damper
11	Passive House	Yes	30 Pa	Fans in operation
12	Passive House	Yes	N/A	Fire/Smoke damper

Case study - Results



Case study – Results



Case study – Key results

- Poor – Maximum 150 Pa
- Modern & Passive House – Smoke seals major impact
- Motorised fire/smoke dampers contribute to increased pressures

Consequences

- Door opening forces

- Smoke spread
  - Pressurised exits (e.g. stair pressurisation)
  - Pressurised floors (e.g. zone smoke control systems)
  - Ducted air-handling systems

- Integrity failure

Consequences - Door forces

- Door opening force:

$$F_d = F_{dc} + \frac{W \cdot A_d \cdot \Delta p_{door}}{2 \cdot (W - b)}$$

F_d	door opening force [N]
F_{dc}	door closer force [N]
W	door width [m]
A_d	door area [m^2]
b	distance between door handle and edge of door leaf on the latching side [m]
Δp_{door}	pressure differential across door [Pa]

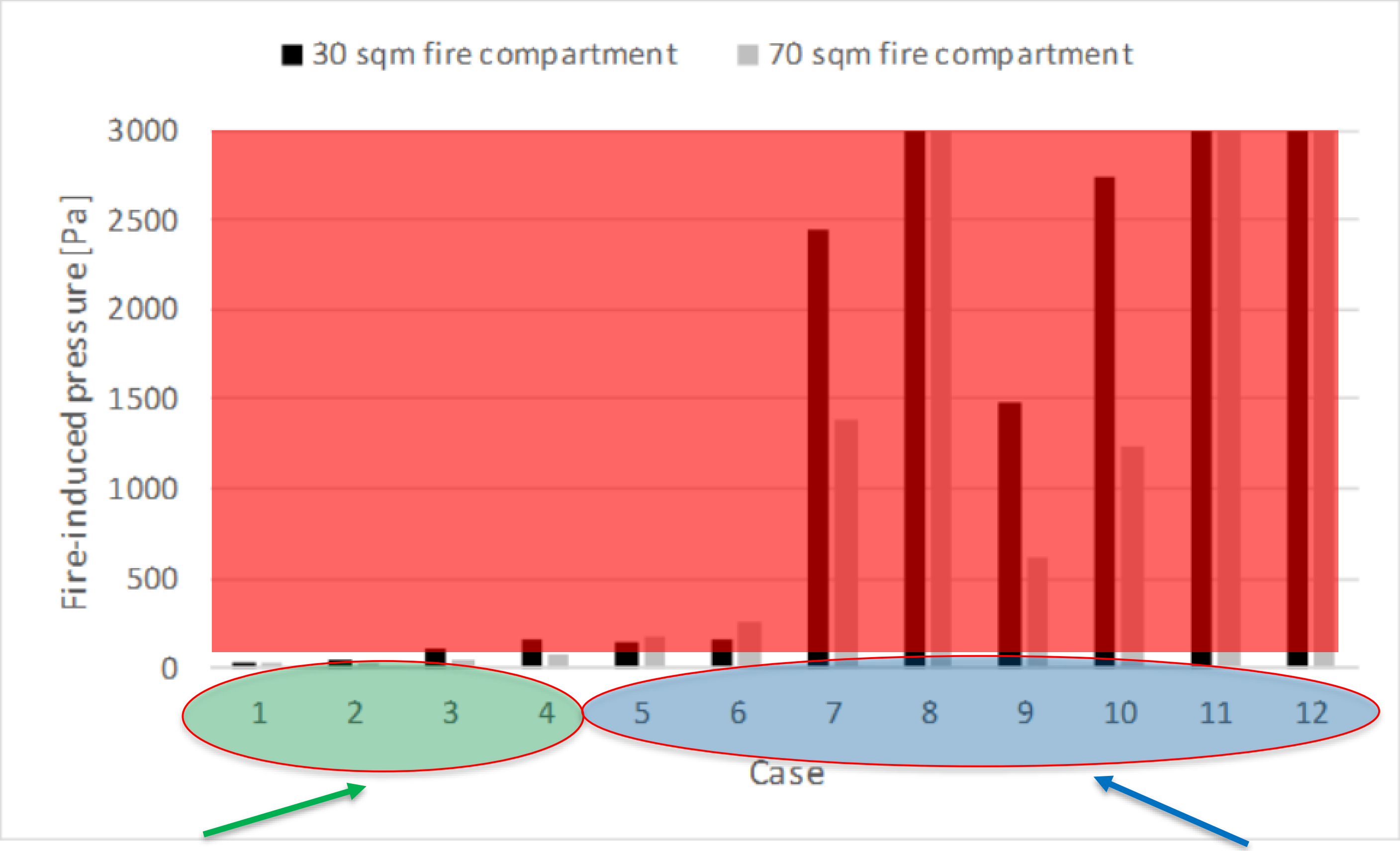
Door forces

- 900 mm wide door:

$$F_d \approx F_{dc} + \Delta p_{door}$$

- Door closer – typically 20-40 N
- 100-130 N typically acceptable in building codes
- Max pressure allowed across door ≈ 100 Pa

Door forces



Poor airtightness = Unlikely to cause issues

Modern/Passive house airtightness = Likely to cause issues

Exit/floor pressurisation

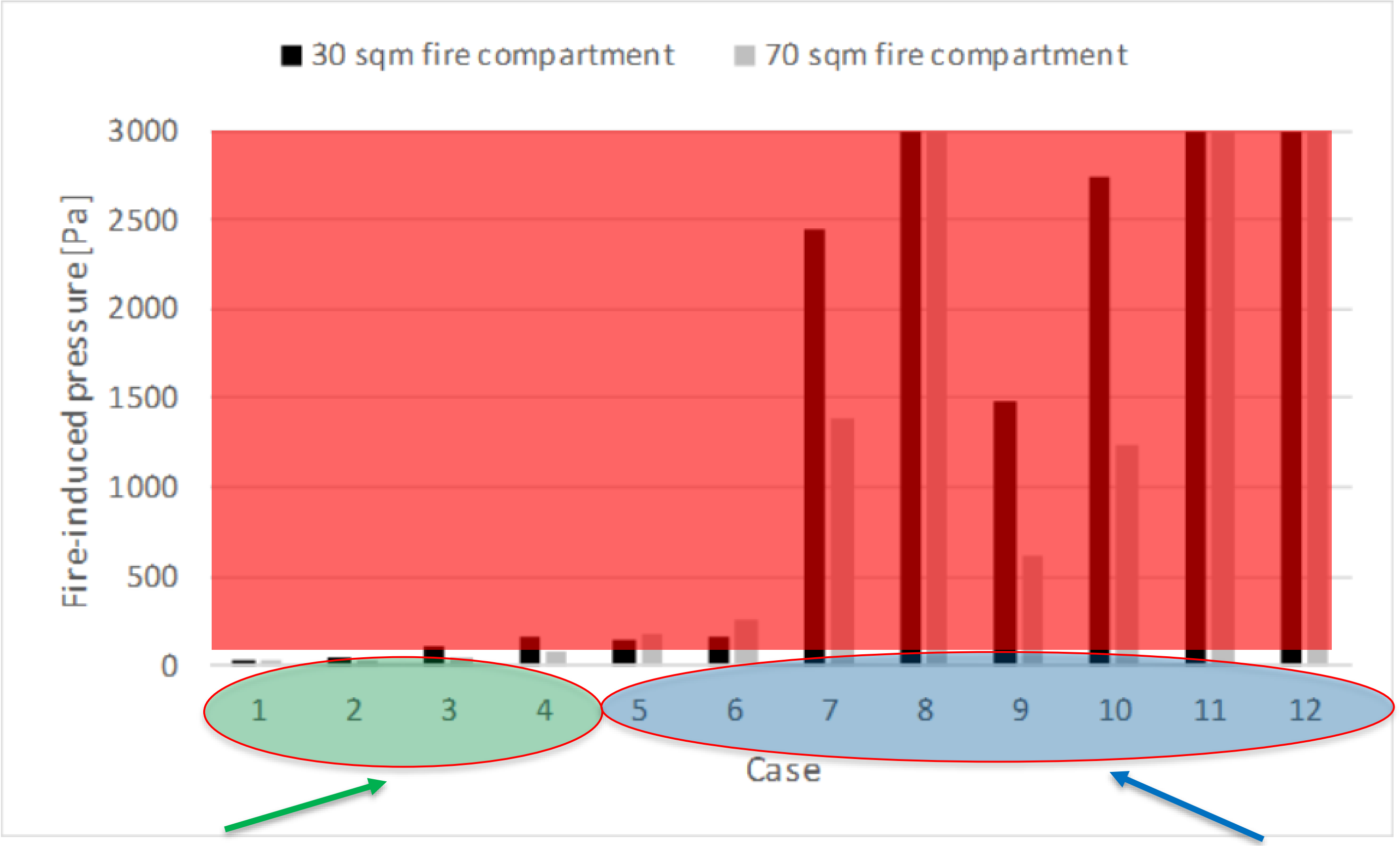
- Intent: Mitigate smoke spread by way of a pressure differential
- Pressure range: Typically 20 – 100 Pa
- Air movement – From higher pressure to lower pressure

Exit/floor pressurisation

$$P_f > P_p = Smoke\ spread$$

P_f	fire-induced pressure [Pa]
P_p	pressure generated by exit/zone pressurisation system [Pa]

Exit/floor pressurisation



Poor airtightness = Unlikely to cause smoke spread

Modern/Passive house airtightness = Smoke spread likely to occur

Air-handling systems

- Only applicable to mechanical ducted systems
- Supply air system most vulnerable to smoke spread:

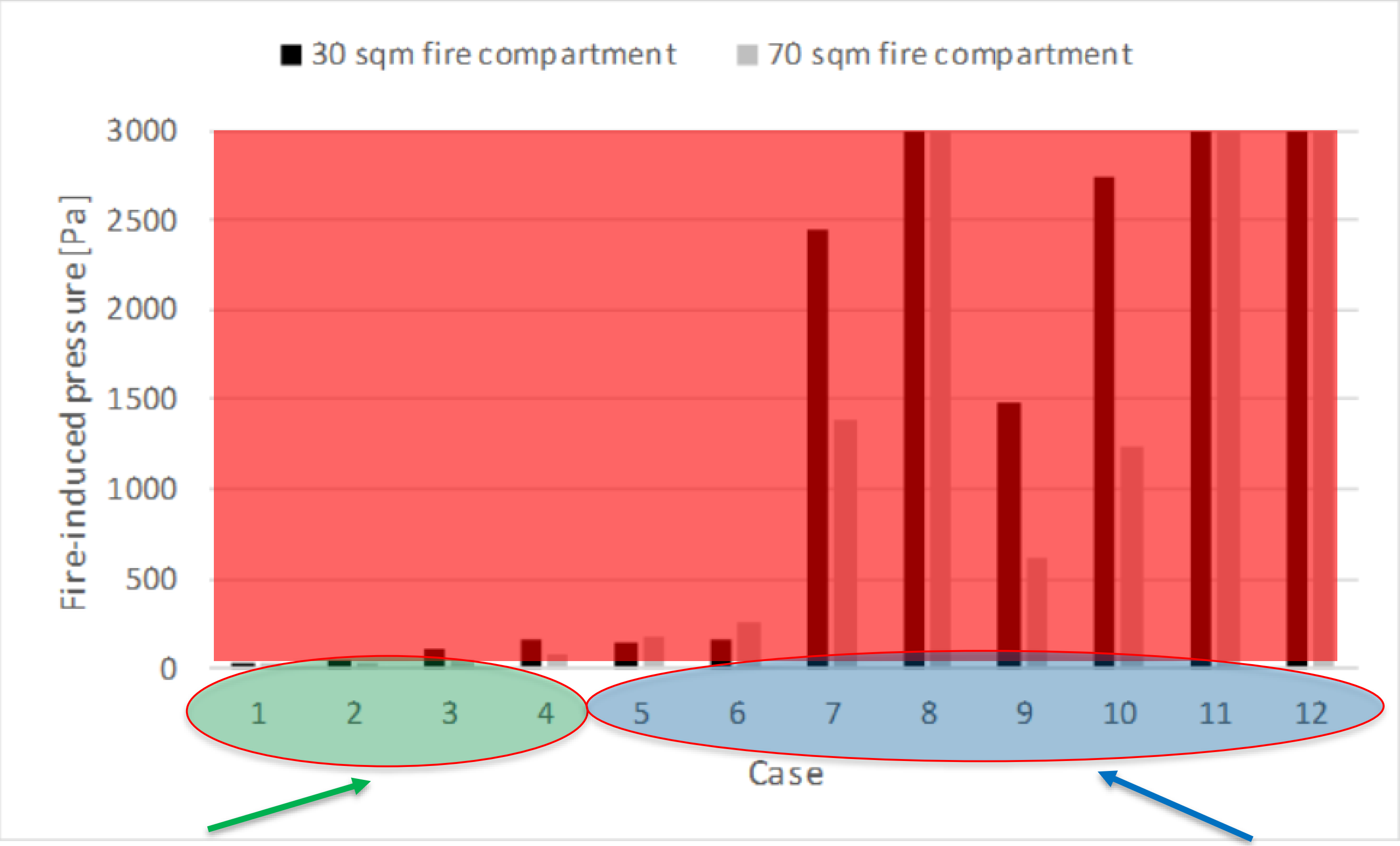
$$P_f > P_{supply} = Smoke\ spread$$

P_f	fire-induced pressure [Pa]
P_{supply}	pressure at main branch to fire compartment [Pa]

- Supply air pressures: Typical 20 – 100 Pa

Air-handling systems

Air-handling systems



Poor airtightness = Unlikely to cause smoke spread

Modern/Passive house airtightness = Smoke spread likely to occur

Integrity failure

- External walls
  - High-rise buildings – must be rated for wind
  - Low/medium-rise buildings – failure from internal pressures?
- Internal walls – failure from increased pressures?
- Smoke/fire dampers – Future pressures exceed current standard requirements

Conclusions

- Issues unlikely in buildings with poor airtightness

- Older building stock would not exhibit any issues

Conclusions

- Significantly higher fire-induced pressures in modern buildings causing:
  - Issues with high door opening forces
  - Smoke spread to exits, between floors & through air-handling systems
  - Potential failure of external & internal walls (and components)

- Building codes should be amended to account for changes in risk

- Practitioners must be aware of the risks

Thanks for listening!

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