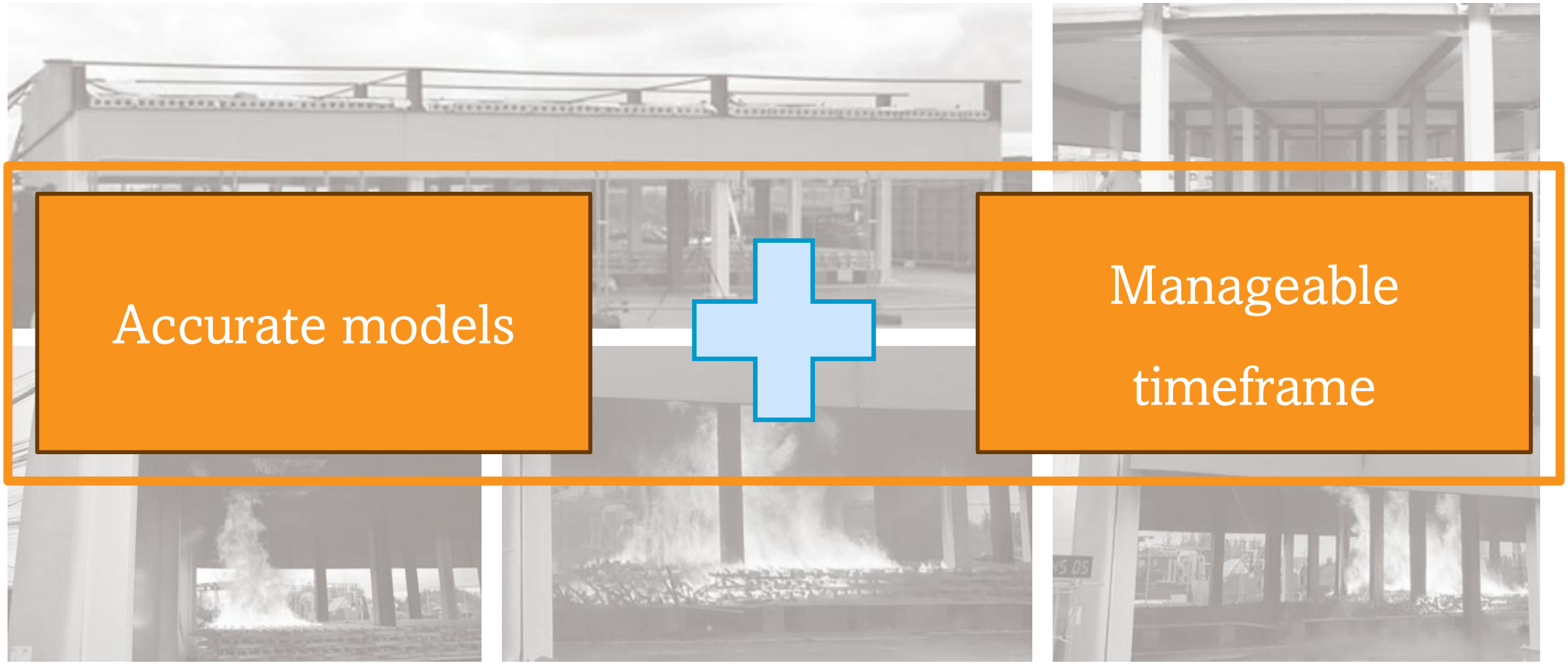
Stantec

Towards a Structured Framework for Incorporating Travelling Fires in Structural Fire Design

How does fire behave in large compartments?

NOT as in a furnace

What do we need?



Agenda

1. Understand what travelling fires are
2. The design methodology with an example
3. Ongoing research

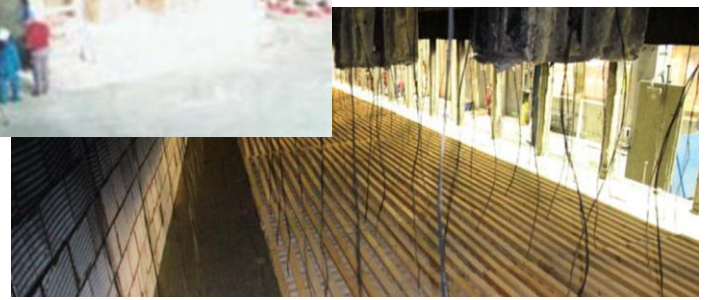
Understanding Travelling Fires

Observing travelling fire behaviour

Tisova

BST 93

Ulster



ETFT

Length > 10 m

Area > 100 m²

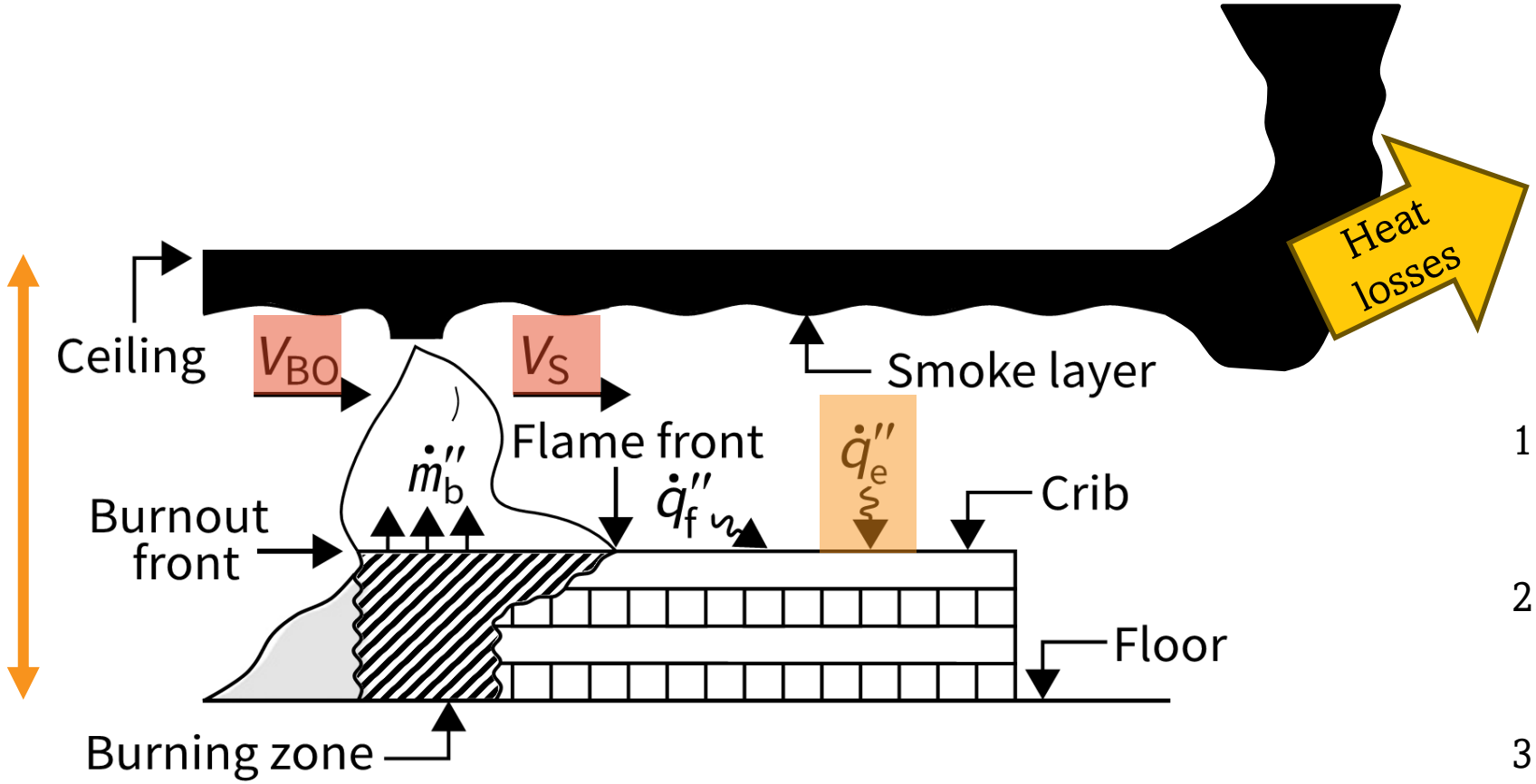
3-4 m ceiling height

250–511 MJ/m²

Open plan layout

Different ventilation

Understanding travelling fire behaviour



1. Fully developed:

$$V_s/V_{BO} \rightarrow \infty$$

2. Growing:

$$V_s/V_{BO} > 1$$

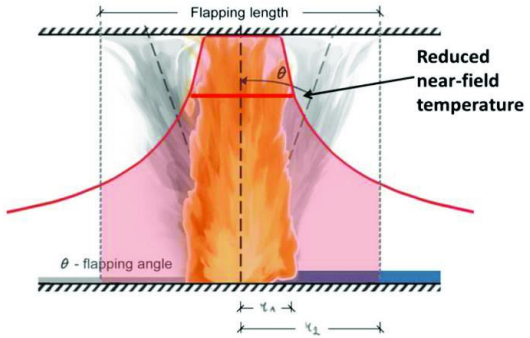
3. Travelling:

$$V_s/V_{BO} \approx 1$$

Gupta et al, 2021

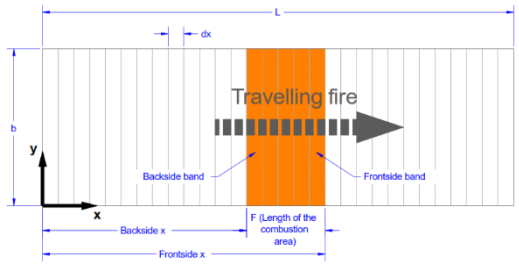
What analytical tools do we have at hand?

Travelling Fire Model (TFM+)



- Temperatures at ceiling height, near and far fields
- iTFM, fTFM
- No smoke layer, ventilation

TRAFIR model



- Heat flux from travelling flame
- Different zones of exposure
- Validated to tests

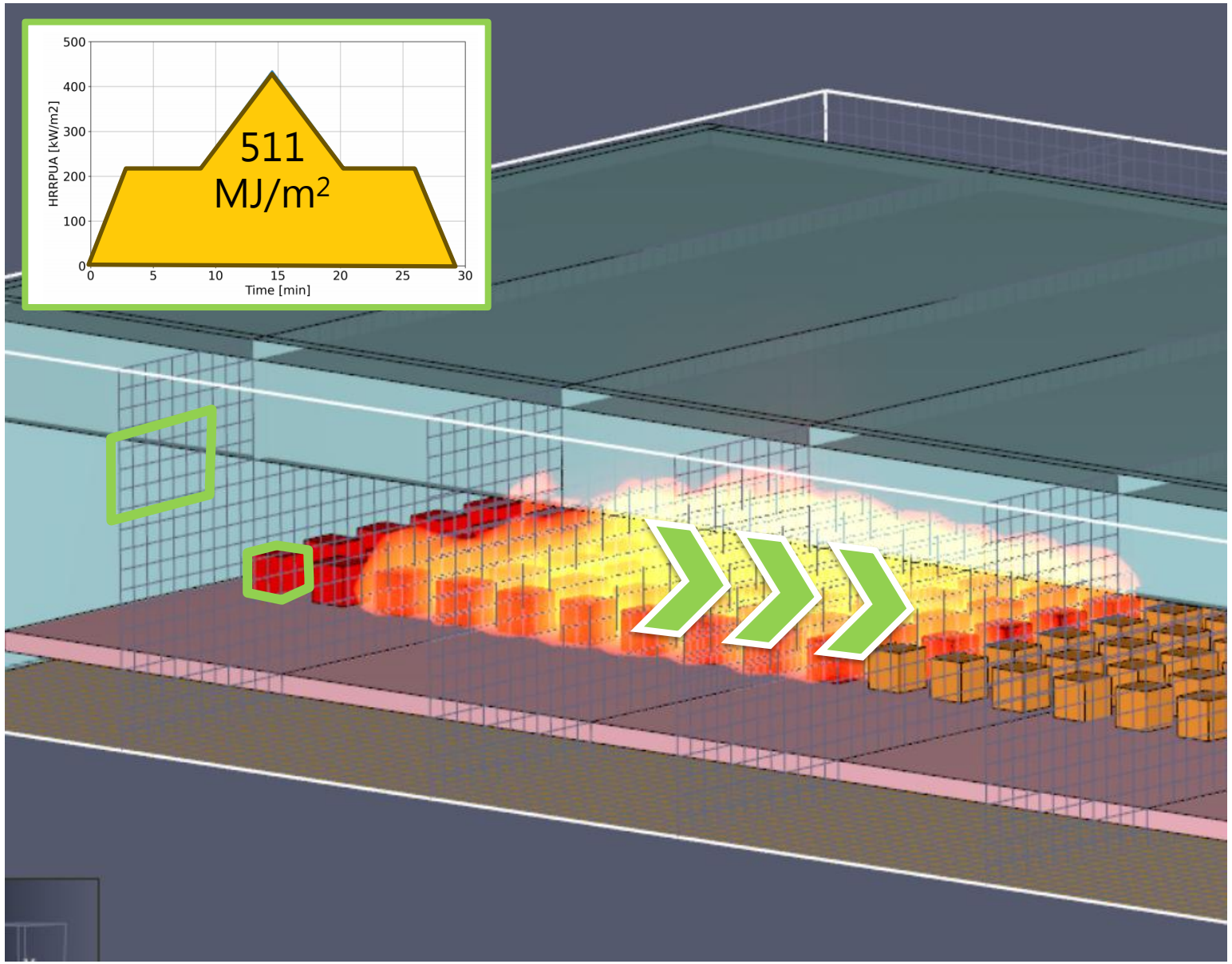
Extended Travelling Fire Method (ETFM)

Flame Extension TFM (fTFM)

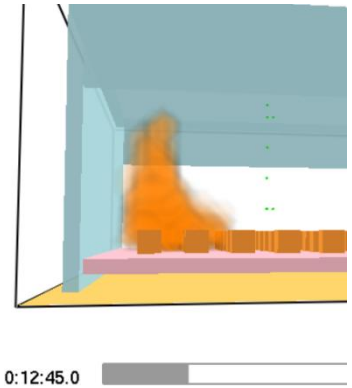
GoZone

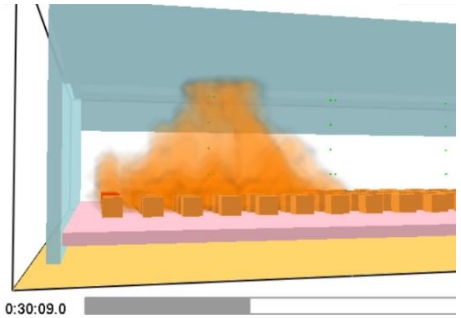
What CFD models do we have at hand?

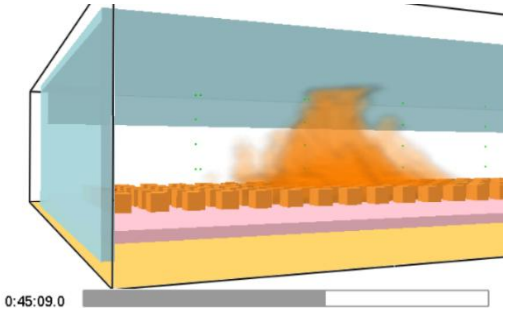
- Simplified fuel load: burning timber cubes 32cm
- Prescribed HRRPUA
- Office building
- Fire spread: 250°C wall temperature, ignition of the entire cube / timer
- 18.24 m × 12.16 m × 3.04 m – 16cm mesh – 170k cells
- 32h in HPC
- Mesh metrics: D*/dx = 10 – 20 + turbulence resolution < 20%
- (Charlier et al, 2021)



CFD model captures travelling behaviour



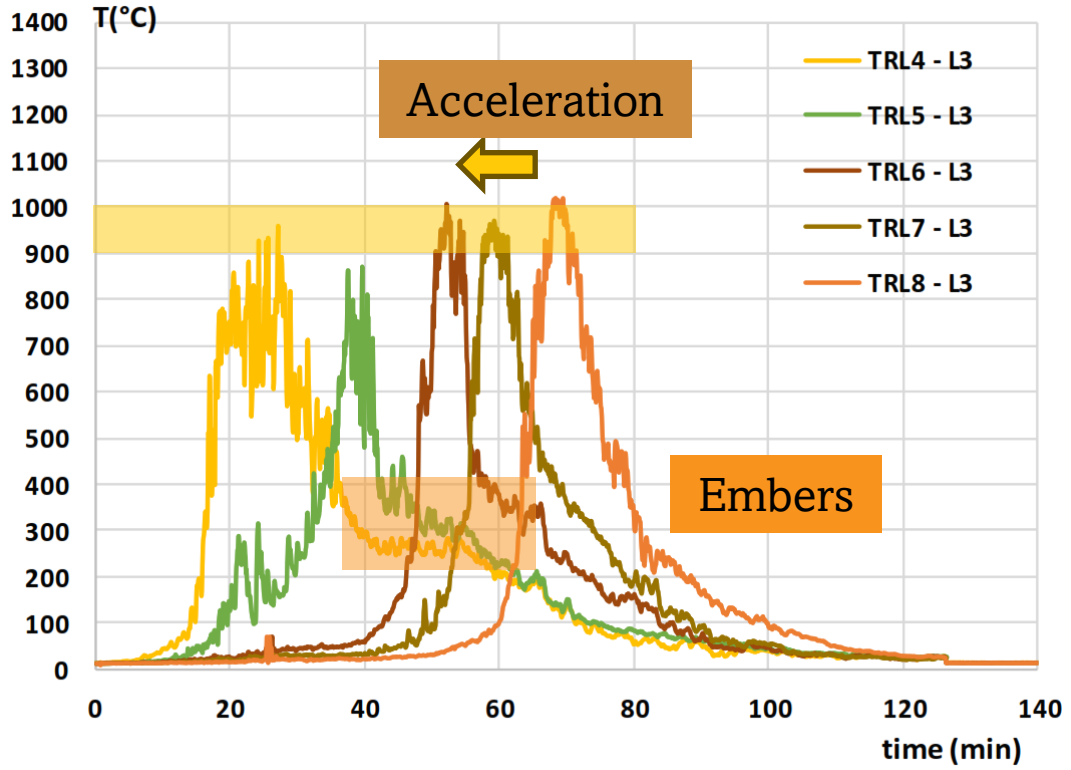


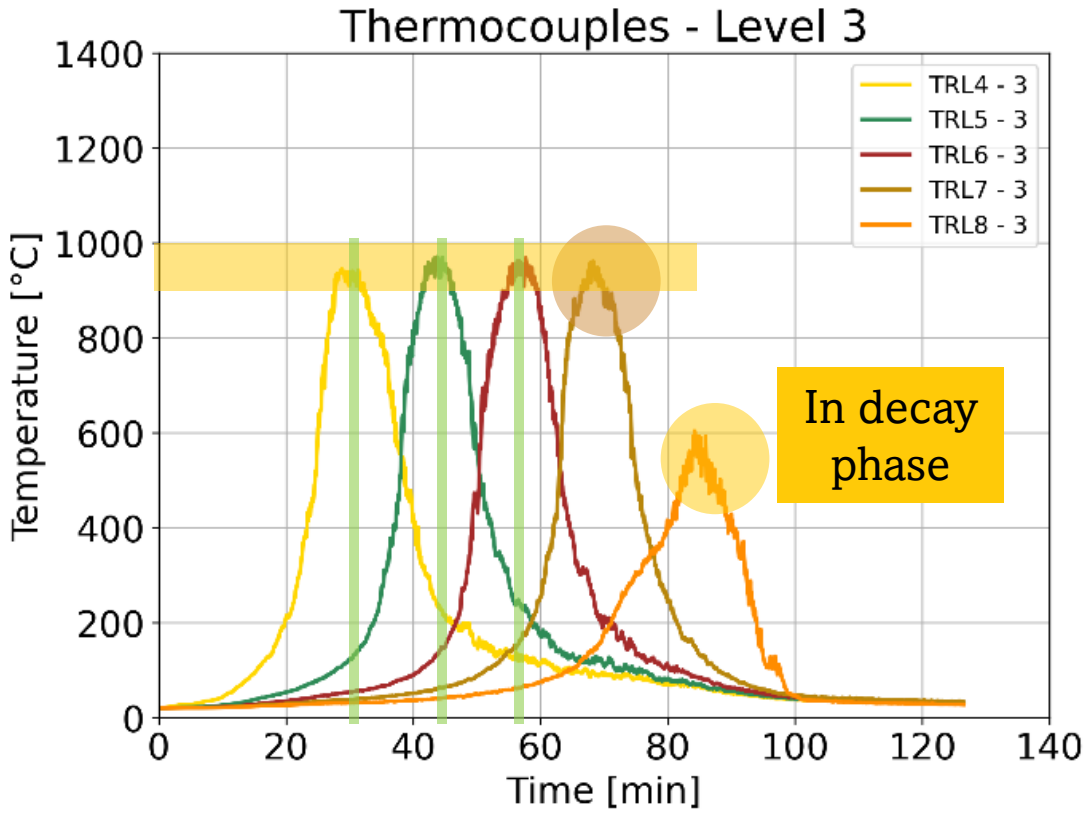


Test observations

FDS model

Some discrepancies

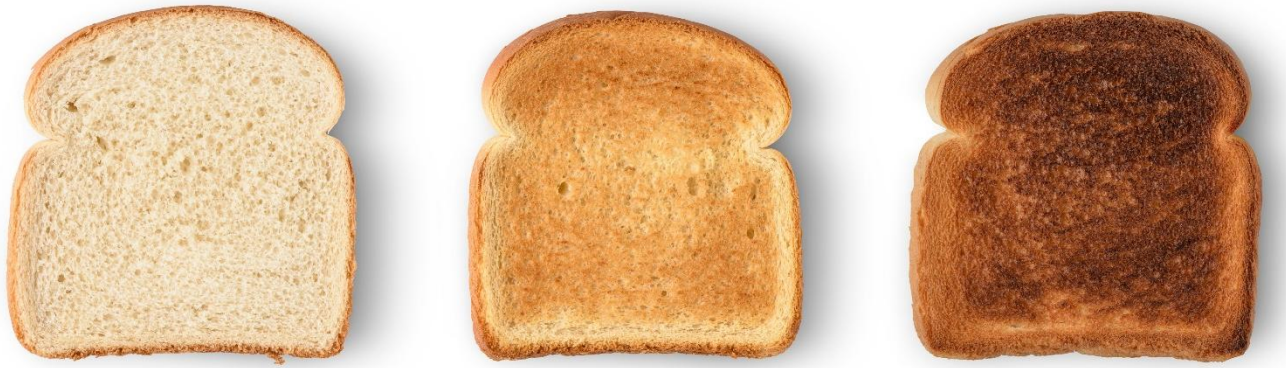


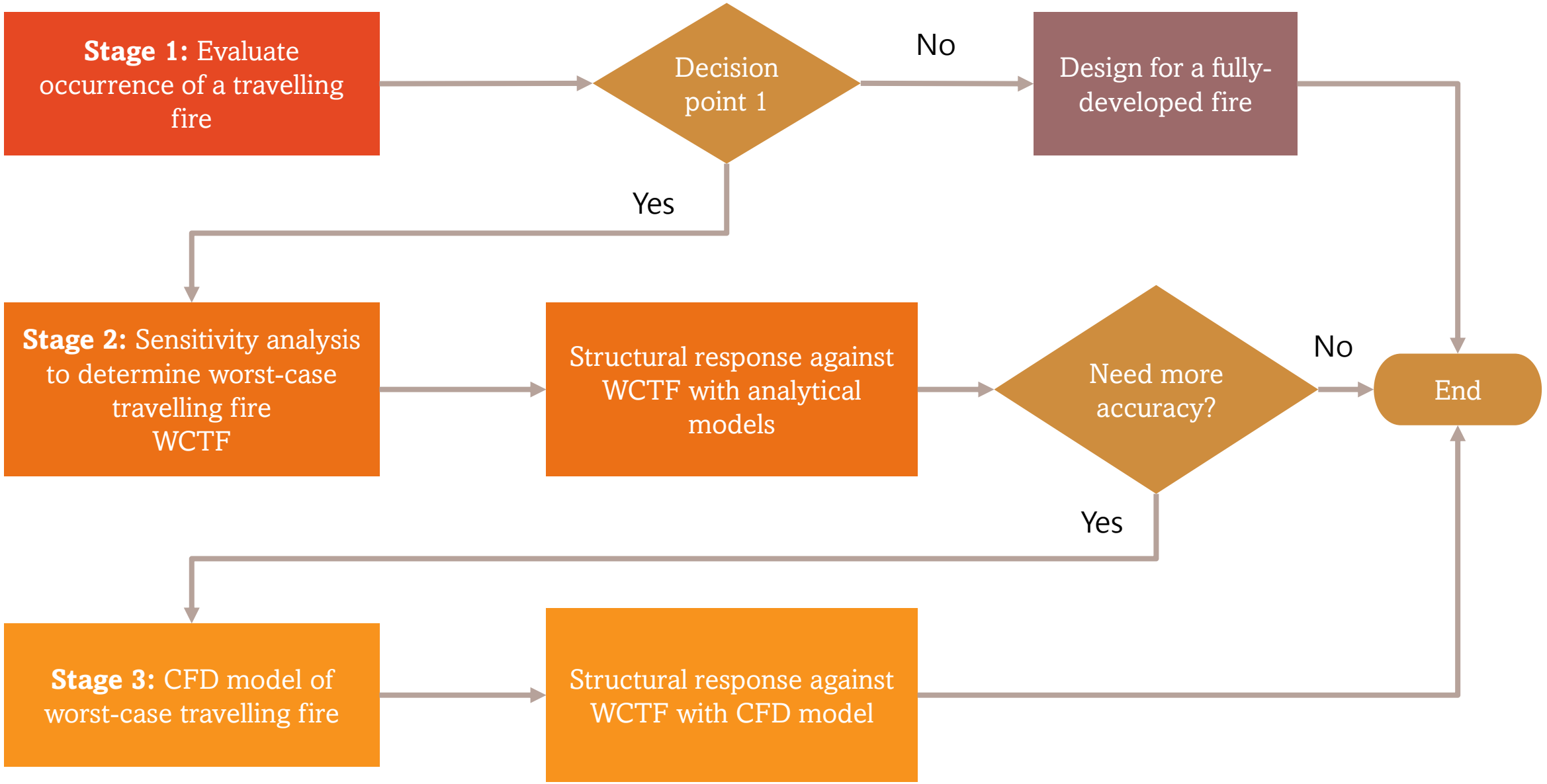


Test observations

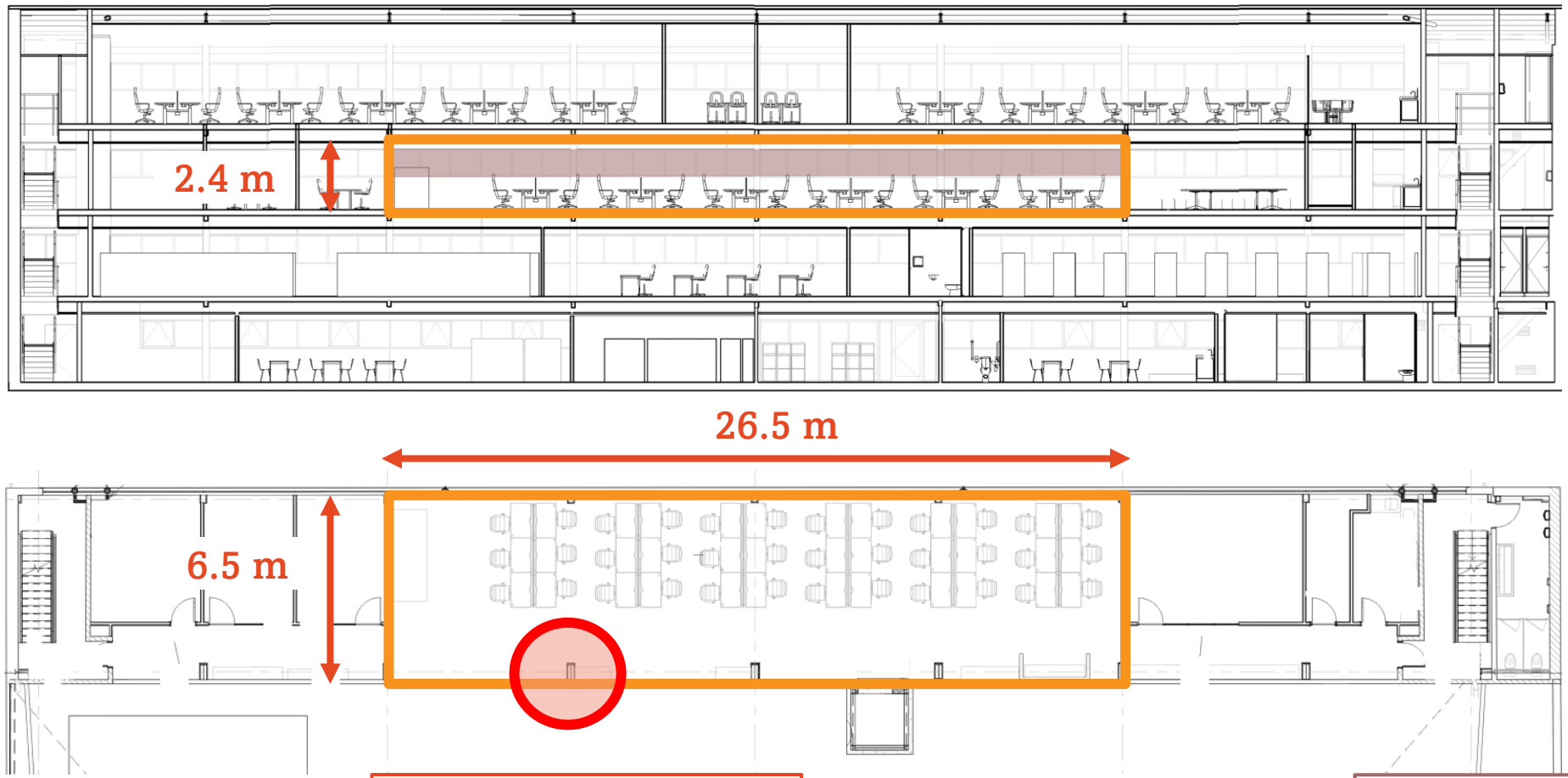
FDS model

Design framework applied to a design example




Stage 1: Evaluate occurrence of a travelling fire
Decision point 1
No
Design for a fully-developed fire
Yes
Stage 2: Sensitivity analysis to determine worst-case travelling fire WCTF
Structural response against WCTF with analytical models
Need more accuracy?
No
End
Yes
Stage 3: CFD model of worst-case travelling fire
Structural response against WCTF with CFD model

Design example

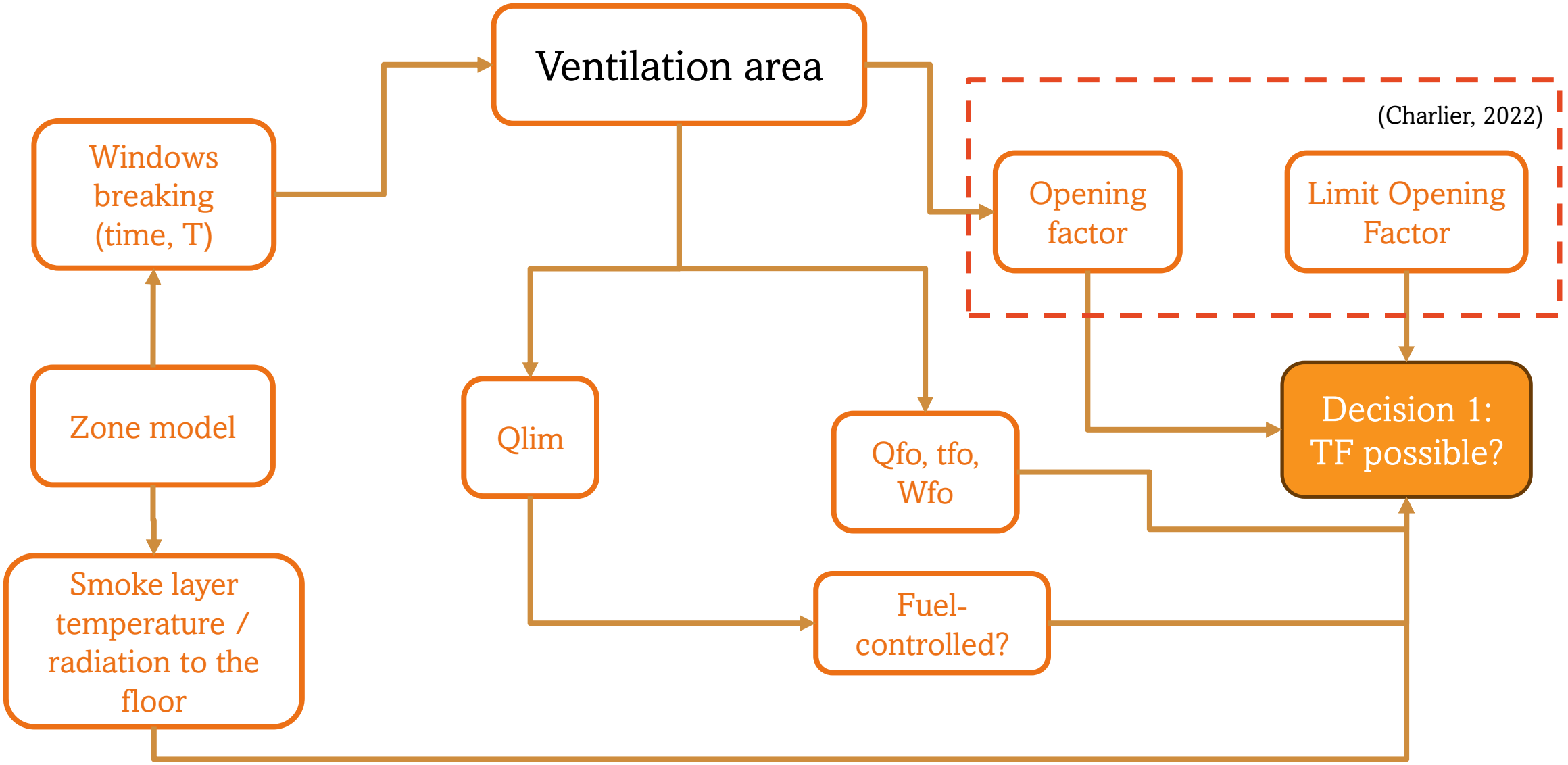


Office fire load

Unprotected steel column

0.9 x 26.5 m windows at both sides

Ventilation area: the main variable for screening



Insights from parametric study by M. Charlier, 2022

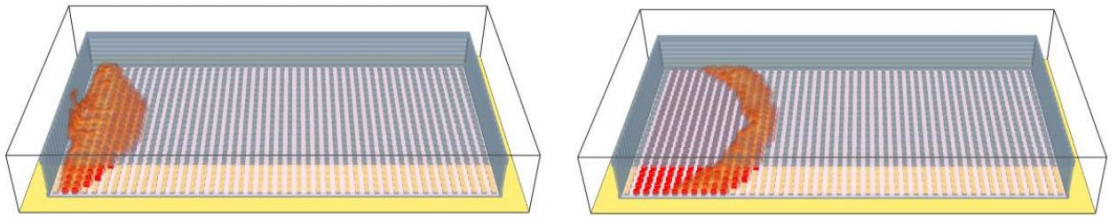


Figure 176: Scenario #A3s – progression of the flaming zone at (a) 31 minutes ; (b) 74 minutes

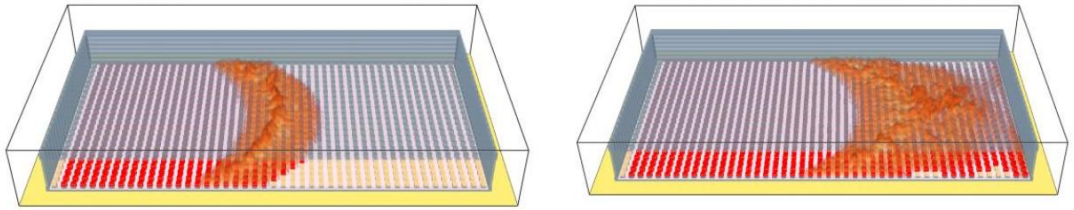
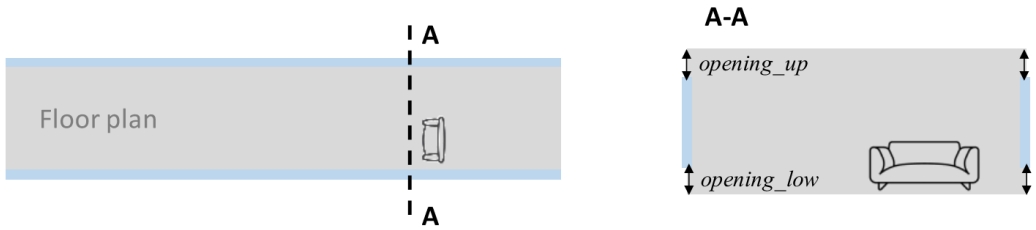


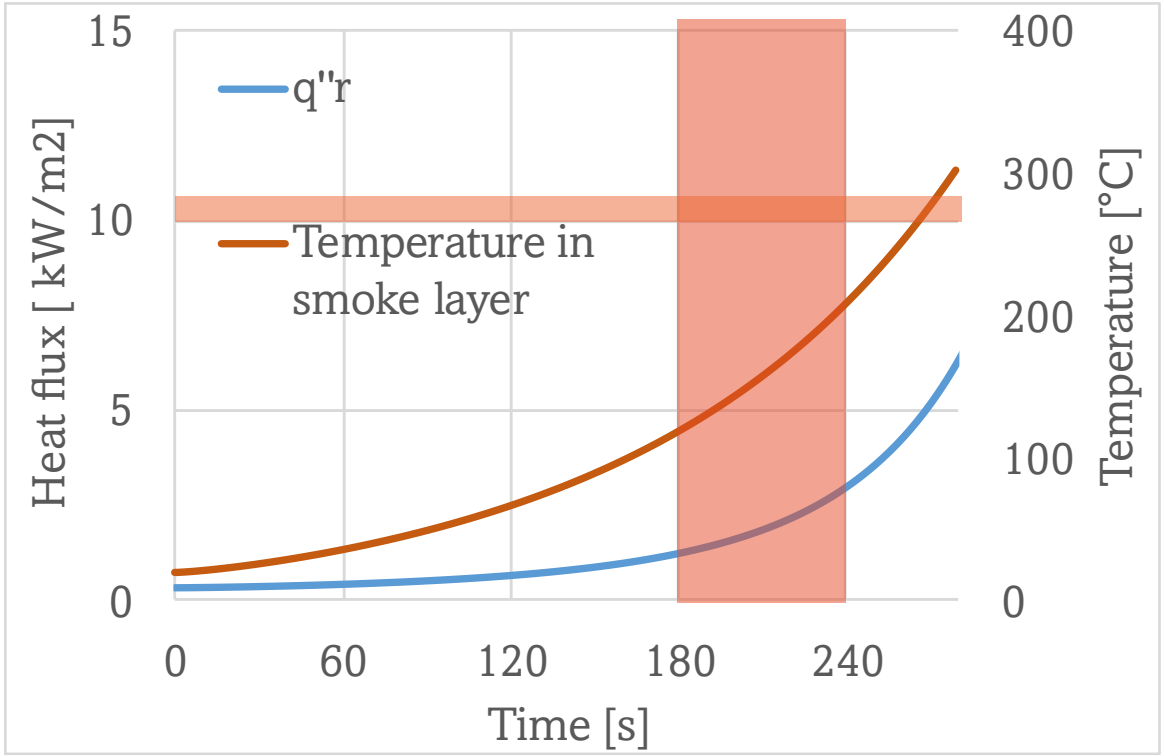
Figure 177: Scenario #A3s – progression of the flaming zone at (a) 125 minutes ; (b) 148 minutes



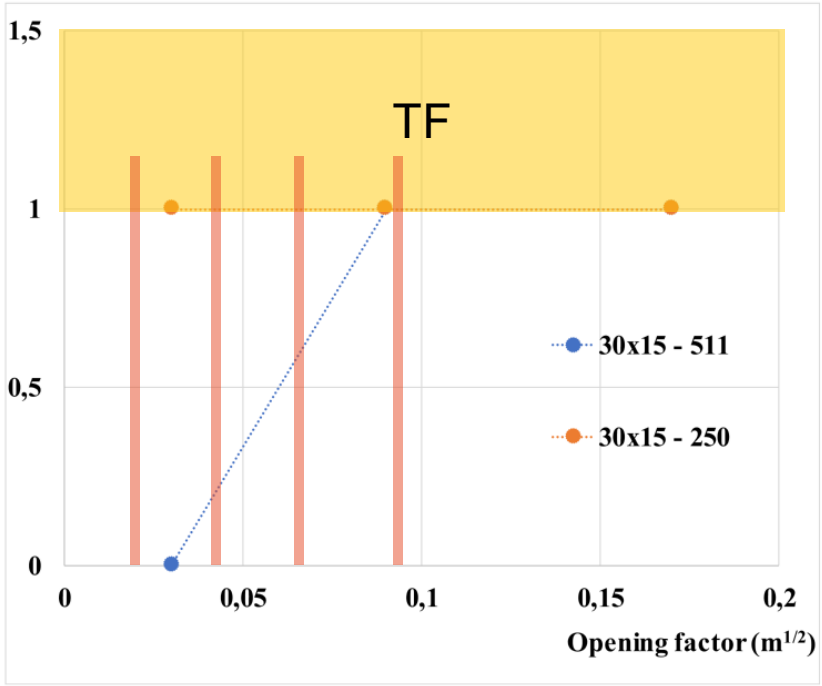
- CFD simulations
- 250, 511, 730 MJ/m^2
- Height of openings 25%, 50%, 75% of compartment height
- 30 m x 15 m; 70 m x 25 m
- Ceiling height: 3 m, 8 m
- Global fire behaviour: growing, travelling, fully developed.
- Flame width as function of time.
- Travelling speeds.
- Limit Opening Factor.

Zone model predicts windows breaking and no flashover

- Axisymmetric plume
- Considering different ventilation areas
- Graph for no ventilation
- Radiation to floor from upper smoke layer < 10kW/m^2
- Glass breaking at 100-150°C (SFPE) @ 3-4min
- Zone model can be extended after windows break



Limit Opening Factor as one decision parameter



Reference compartment

(Charlier, 2022)

Scenario	All windows open	75% open	50% open	25% open
Ventilation area (m^2)	45.9	34.4	22.95	11.475
Opening Factor ($m^{1/2}$)	0.09	0.067	0.045	0.022
OF > LOF?	Yes	Not conclusive	Not conclusive	Not conclusive

QFO analysis is useful for decision, with caveats

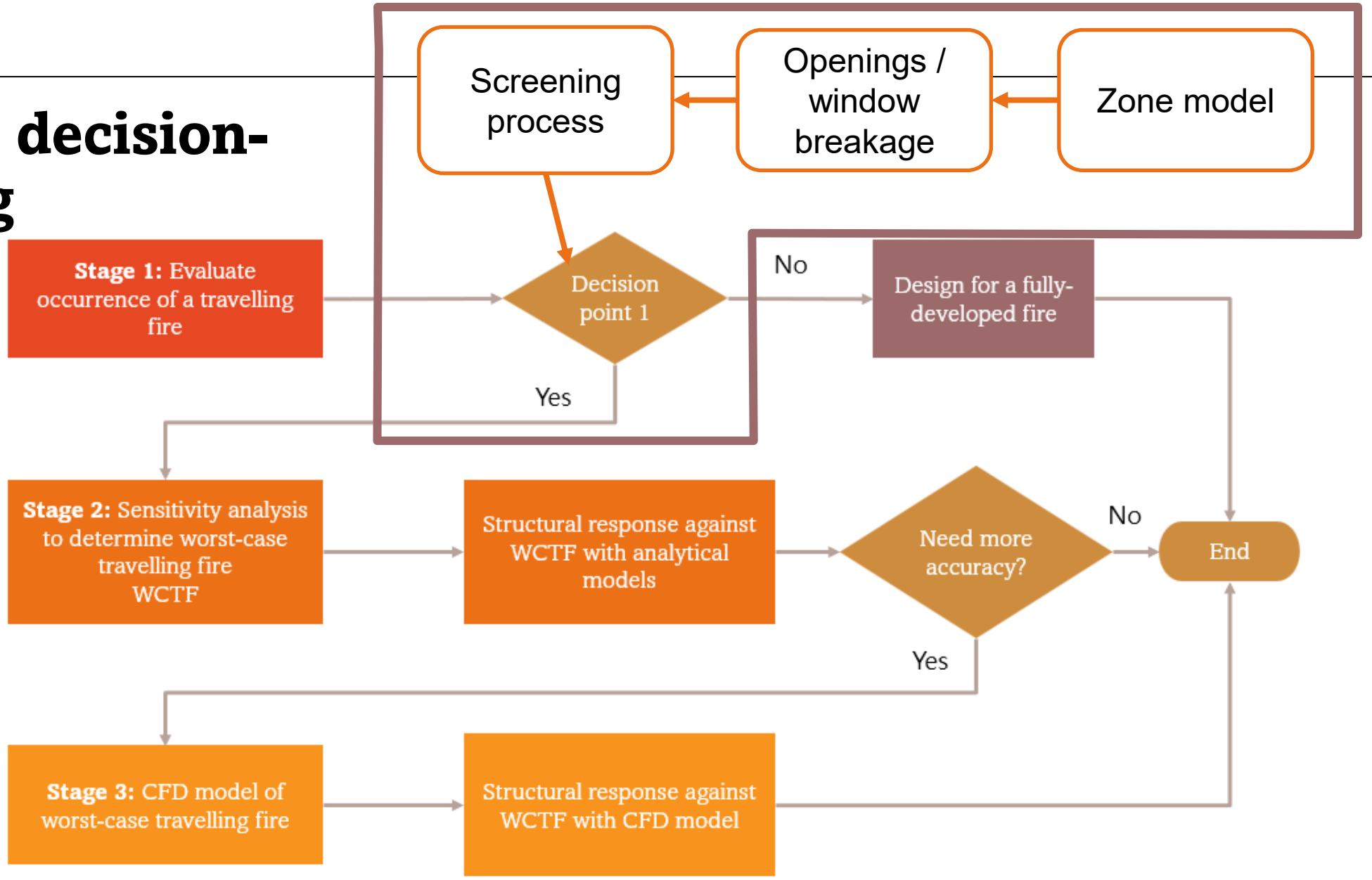
- Based on McCaffrey, Quintiere and Harkleroad.
- FO criteria: upper layer 500-600°C.
- Energy balance of compartment fire.
- Heat transfer to enclosure simplified as heat transfer coefficient.
- Regression of experiments, so probably small compartments.

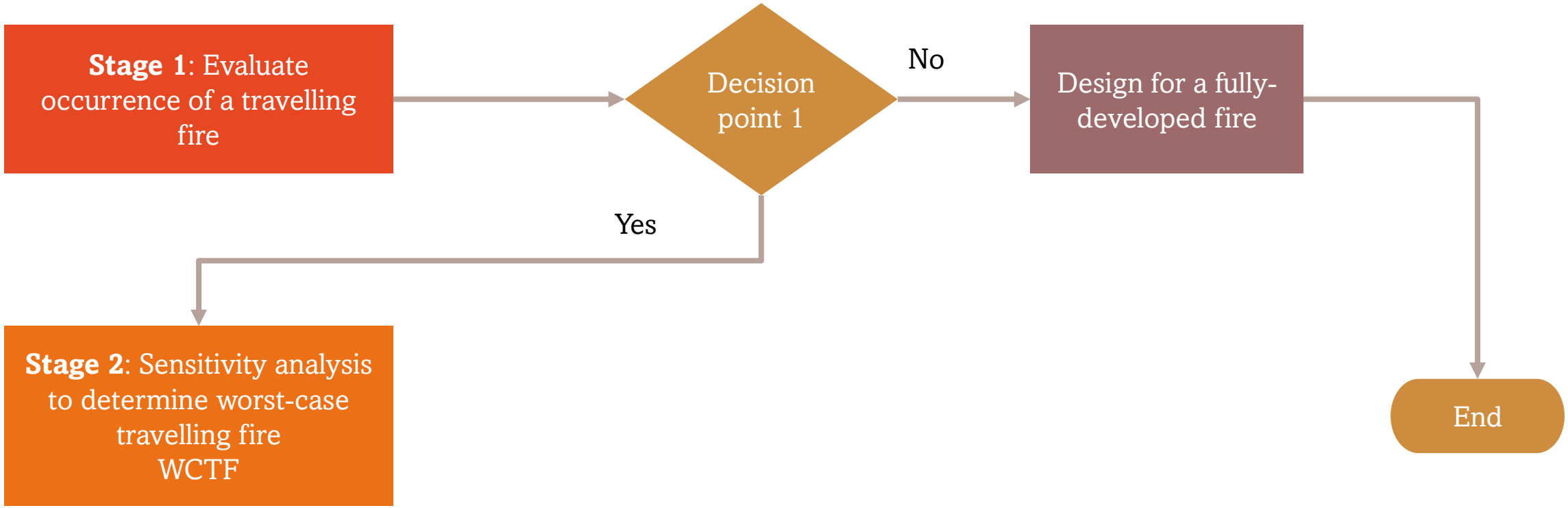
Scenario	All windows open	75% open	50% open	25% open
Ventilation area (m^2)	45.9	34.4	22.95	11.475
QFO (kW)	19 500	17 000	13 800	10 000
Time for QFO (min)	22	20	18	16
tFO < travelling time? (Charlier, 2022)	Yes	Yes	Yes	Yes
Flame width for flashover (m)	12	10.35	8.5	6
WFO > realistic flame width? (Charlier, 2022)	Yes	Yes	No	No
Likely scenario?	Travelling fire	Travelling fire	Not conclusive	Not conclusive

Screening with varying ventilation area: TF possible

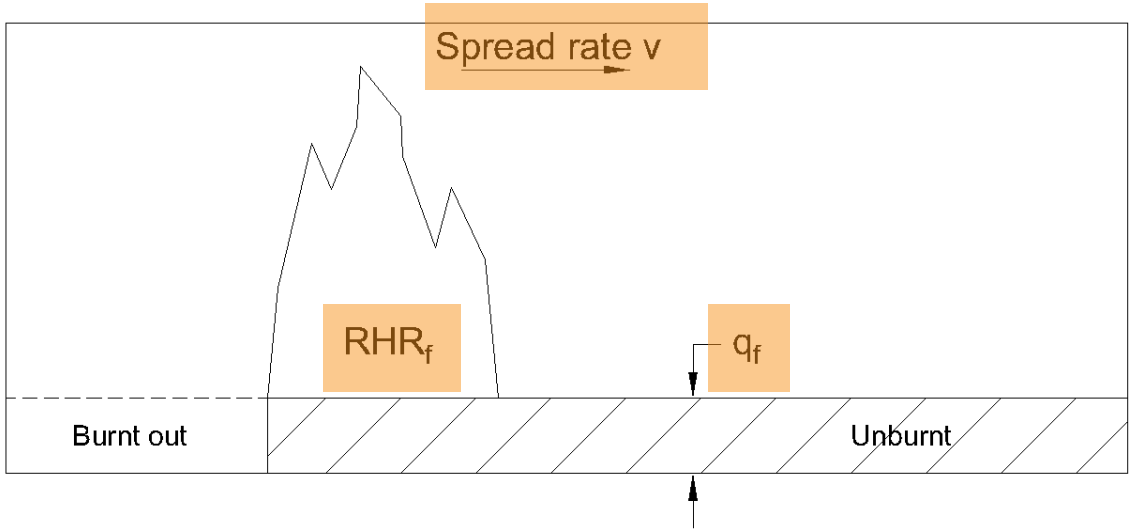
Scenario	All windows open	75% open	50% open	25% open
OF > LOF?	Yes	Not conclusive	Not conclusive	Not conclusive
tFO < travelling time? (Charlier, 2022)	Yes	Yes	Yes	Yes
WFO > realistic flame width? (Charlier, 2022)	No	No	Yes	Yes
Criteria enough for flashover?	No	No	No	No
Fuel-controlled fire?	Yes	Yes	Yes	Possibly
Outcome?	Travelling fire	Travelling fire	Travelling fire	Travelling fire and fully developed

Robust decision-making



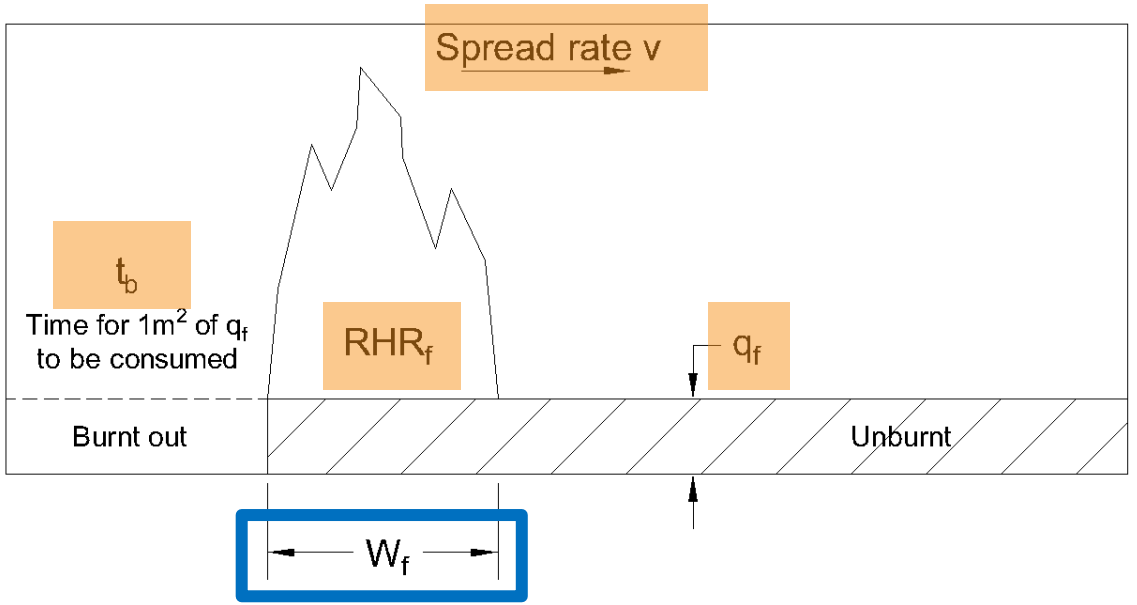

Stage 1: Evaluate occurrence of a travelling fire
Decision point 1
No
Design for a fully-developed fire
Yes
Stage 2: Sensitivity analysis to determine worst-case travelling fire WCTF
End

Stage 2: Sensitivity analysis to determine worst-case travelling fire
WCTF



Heat release rate per unit area RHR_f		Fuel load density q_f	Travelling speed v
EN1991-1-2 Annex E 250 kW/m^2	Test data 400 kW/m^2	EN1991-1-2 Annex E Avg = 420 MJ/m^2 80% = 511 MJ/m^2	Charlier, 2022 Parametric study 2 – 9 mm/s

Stage 2: Sensitivity analysis to determine worst-case travelling fire WCTF



Select a combination of parameters

$$t_b = \frac{q_f}{RHR_f} = 1680\ s$$

$$W_f = v \cdot t_b = 3.36\ m$$

Consistent with Wf in Charlier, 2022?

No

Discard scenario

Yes

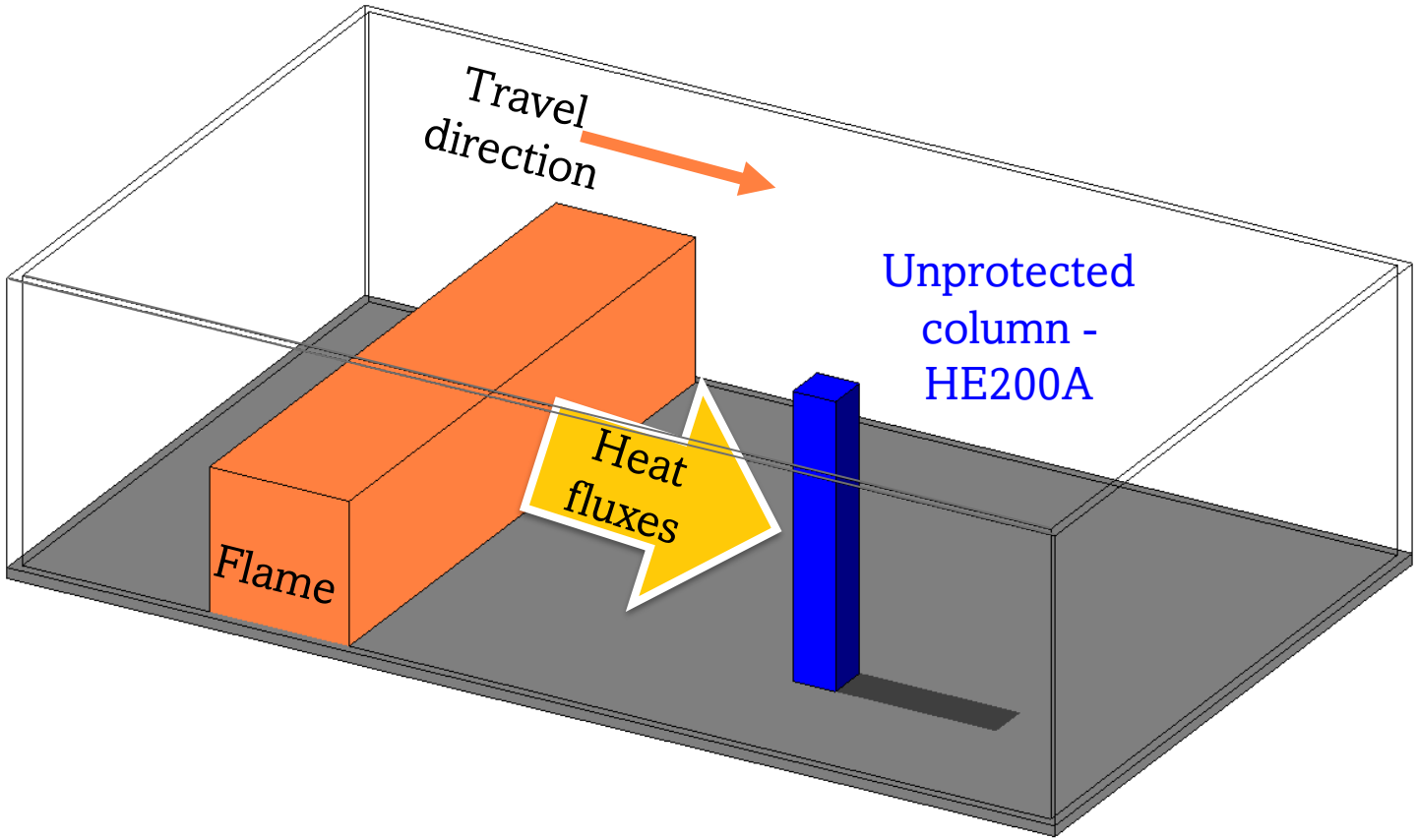
Include scenario for structural evaluation

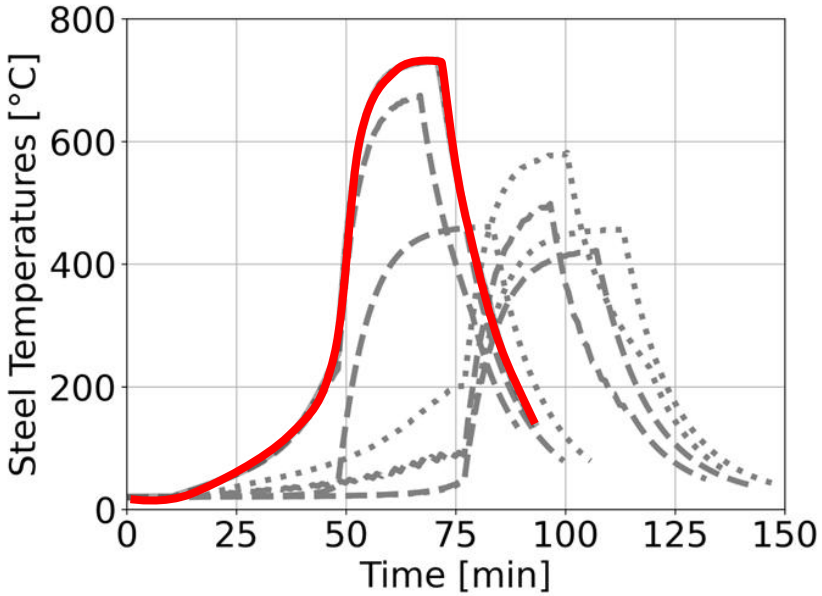
Stage 2: Sensitivity analysis to determine worst-case travelling fire
WCTF

→

Structural response
TRAFIR model

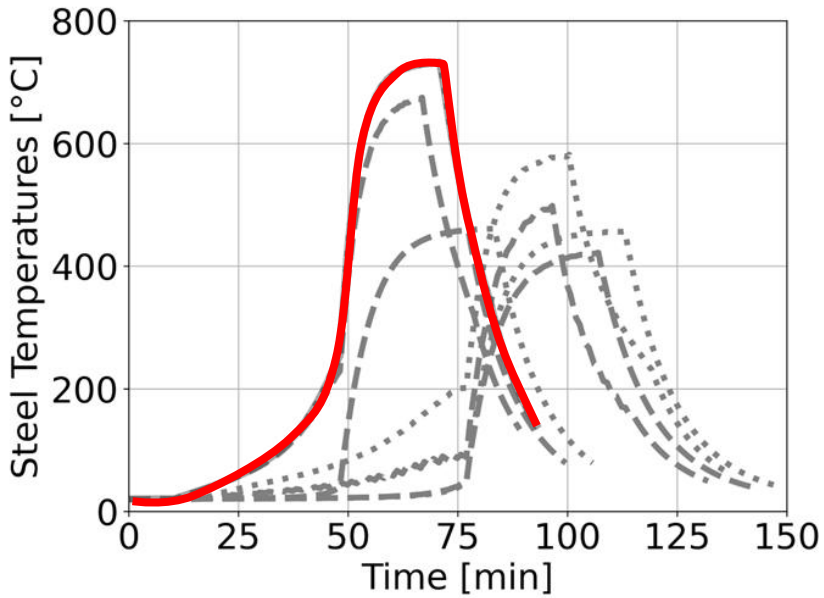
- EC1 and EC3 equations
- Section factor of 211mm^{-1}
- Steel properties EN 1993-1-2
- T @ 2.5m height

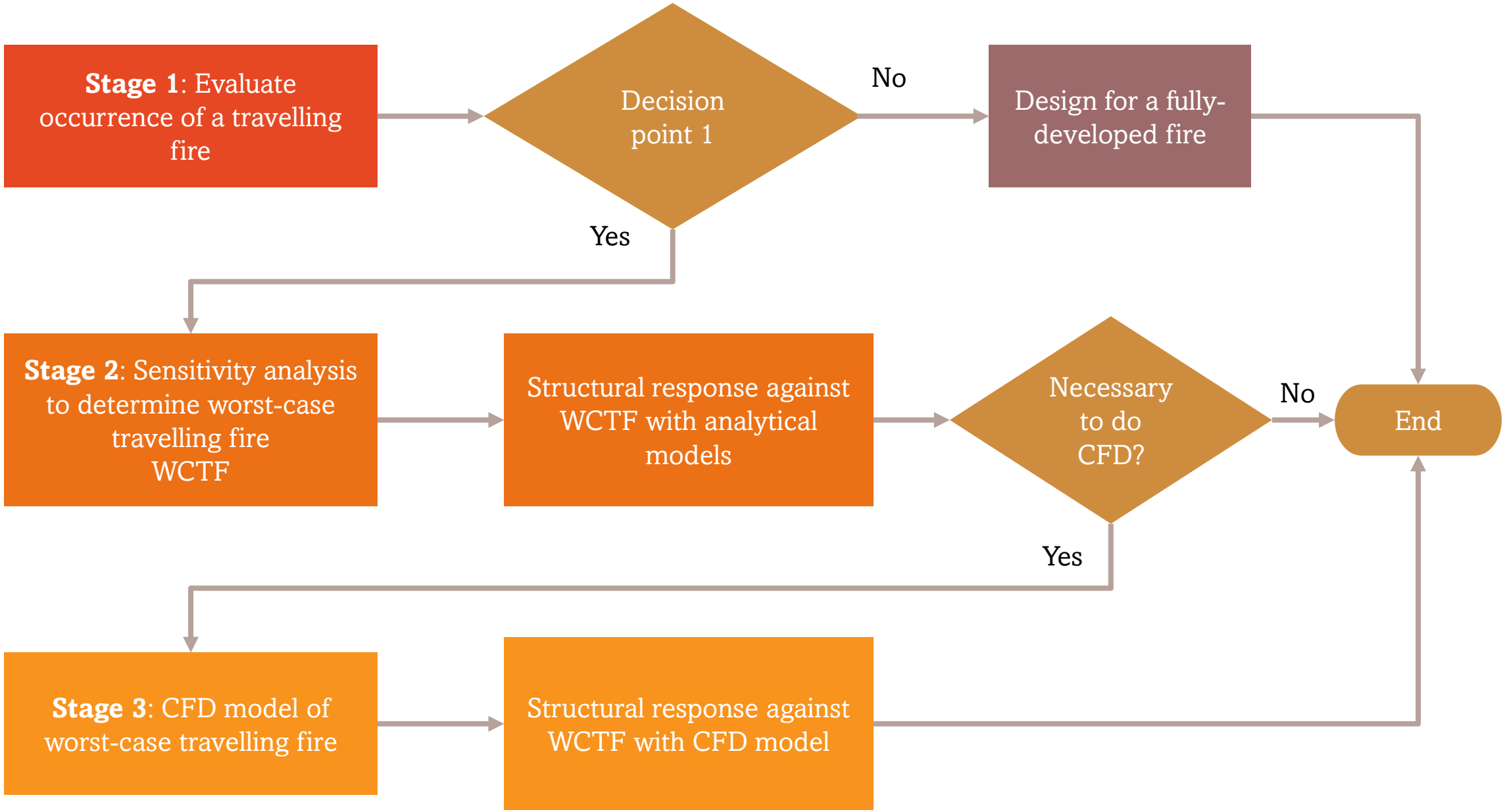




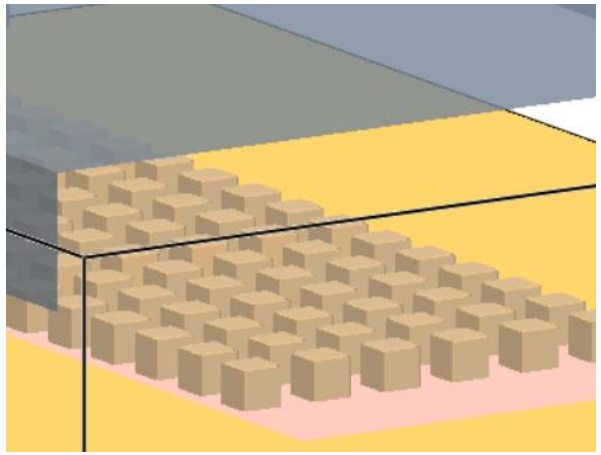
Stage 2: Sensitivity analysis to determine worst-case travelling fire WCTF → Structural response TRAFIR model → Worst-case travelling fire WCTF

q_f [MJ/m^2]	RHR_f [kW/m2]	v [mm/s]
511	400	3.5




Stage 1: Evaluate occurrence of a travelling fire
Decision point 1
No
Design for a fully-developed fire
Yes
Stage 2: Sensitivity analysis to determine worst-case travelling fire WCTF
Structural response against WCTF with analytical models
Necessary to do CFD?
No
End
Yes
Stage 3: CFD model of worst-case travelling fire
Structural response against WCTF with CFD model

Limitation of fire spread model



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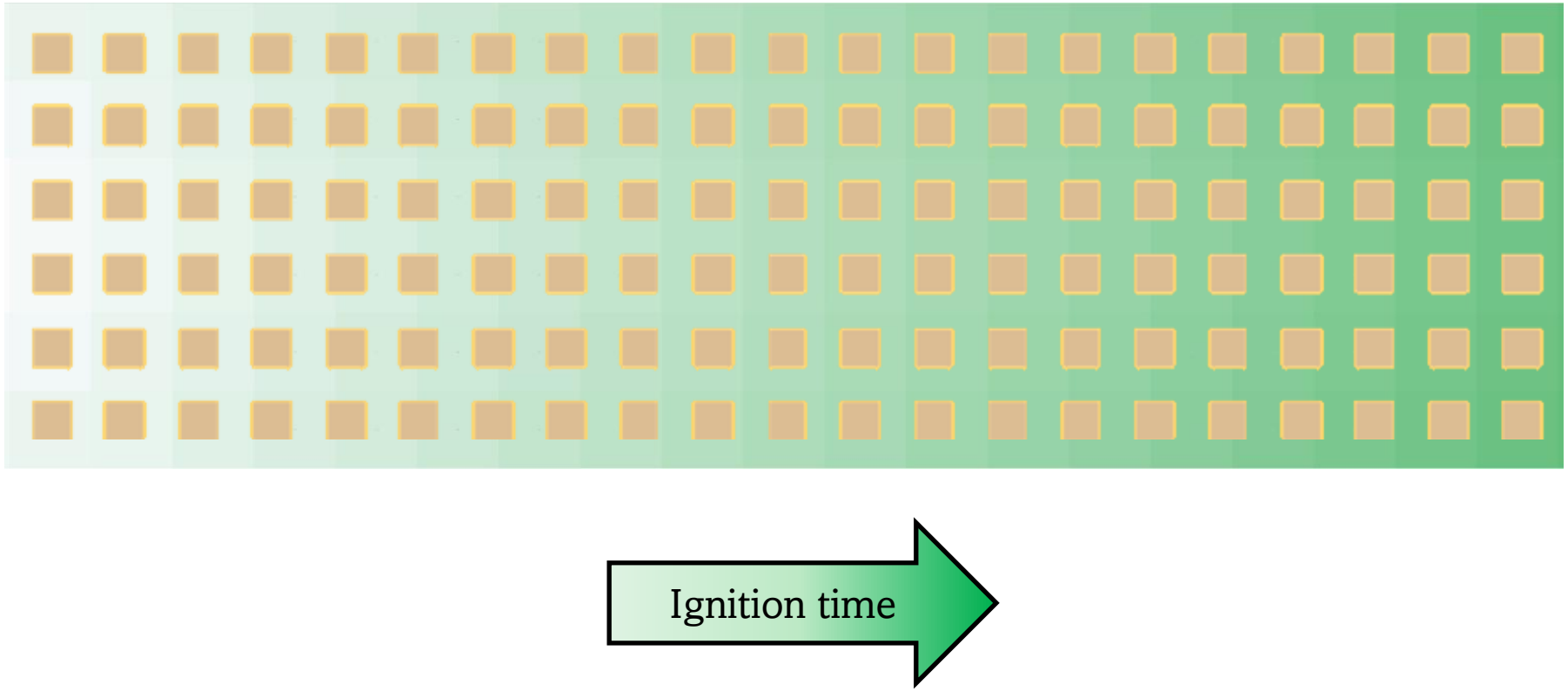
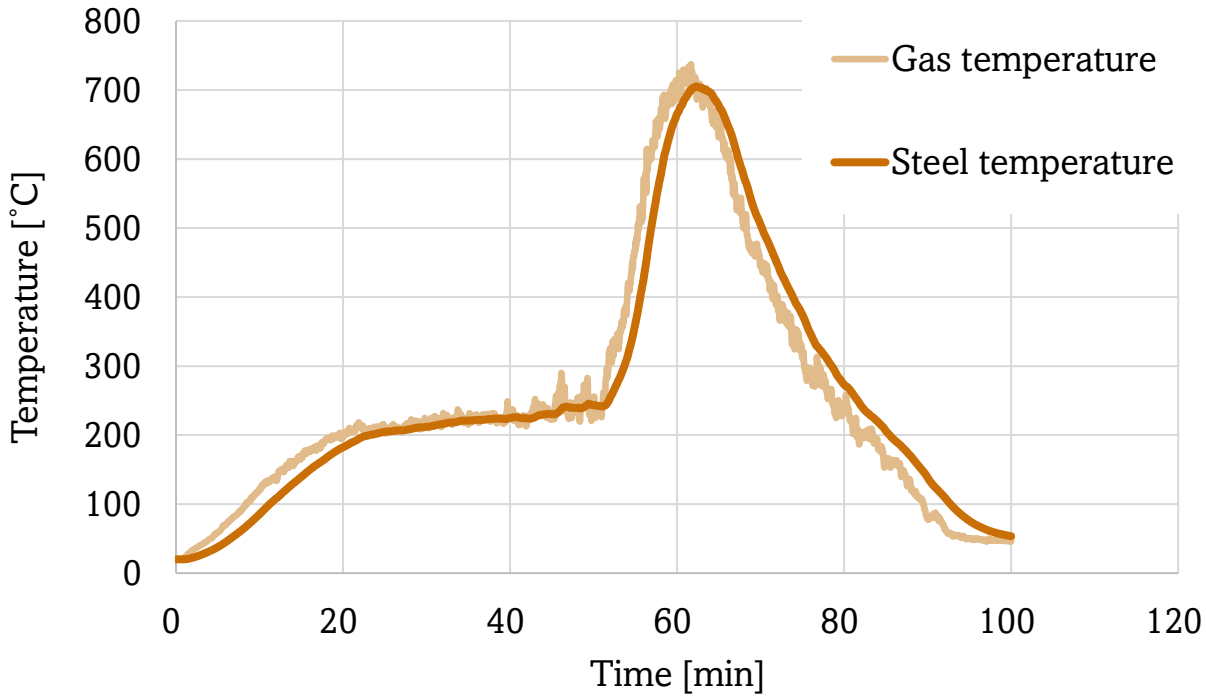
Simplification and uncertainty

Stage 3: CFD model of Worst-Case Travelling Fire → Fire spread model → Prescribed travel speed using timer control logic

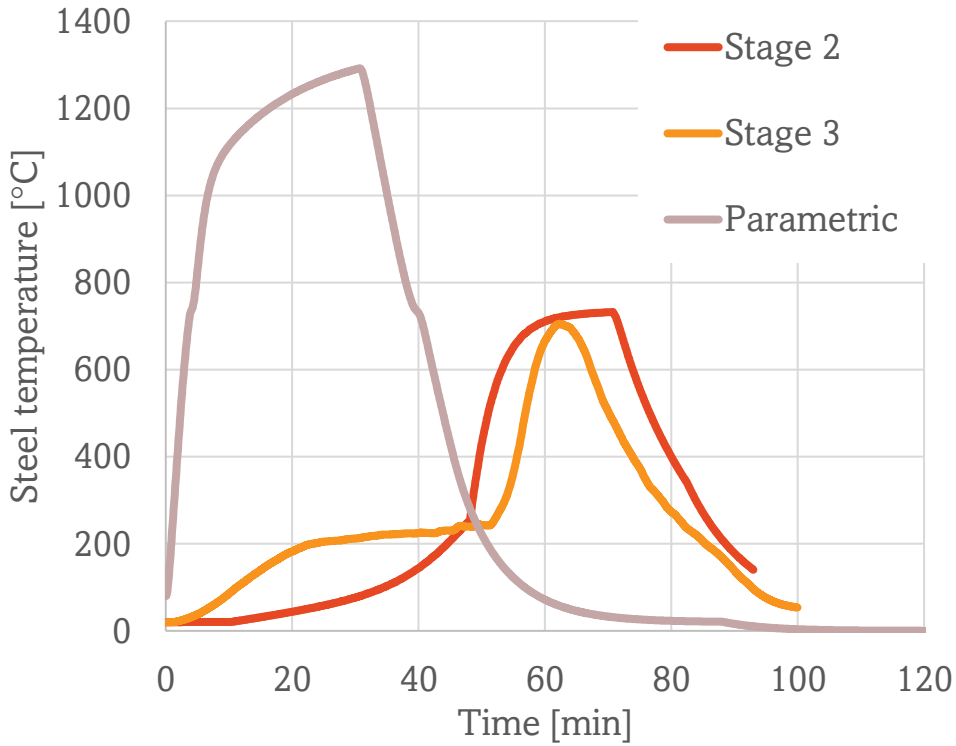


Stage 3: CFD model of Worst-Case Travelling Fire → Fire spread model → Prescribed travel speed using timer control logic → Structural response



Outcome of the design process

- Stage 1: TF more likely than fully-developed fire even with different ventilation conditions.
- Stage 2: WCTF characterised rapidly by analytical models.
- Stage 3: more data availability about fire exposure for more detailed analyses.
- Comparison with parametric exposure reveals design scenario for structure.



Research aimed to industry

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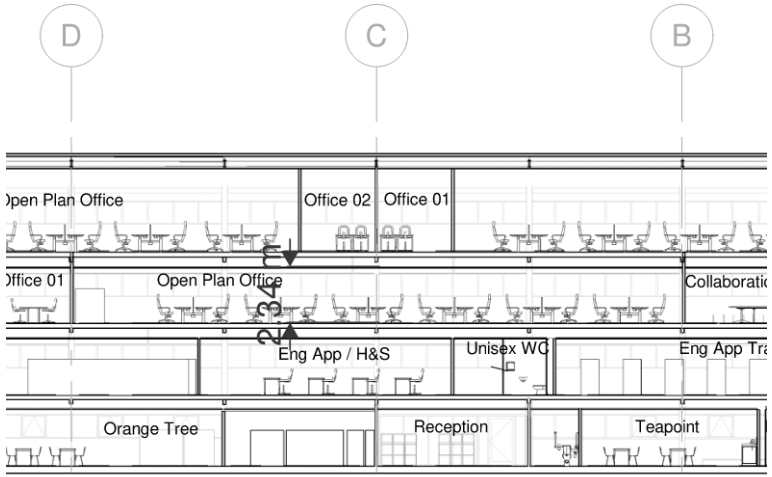
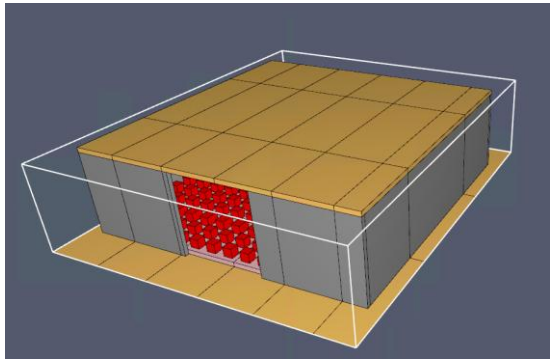
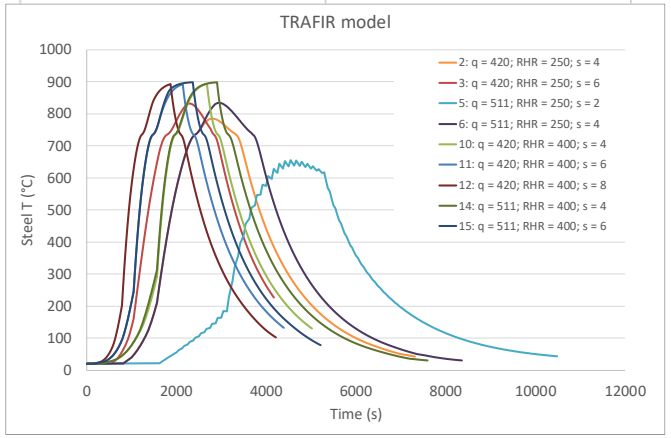
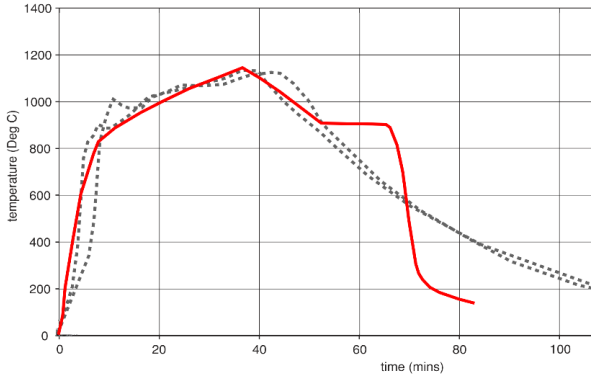
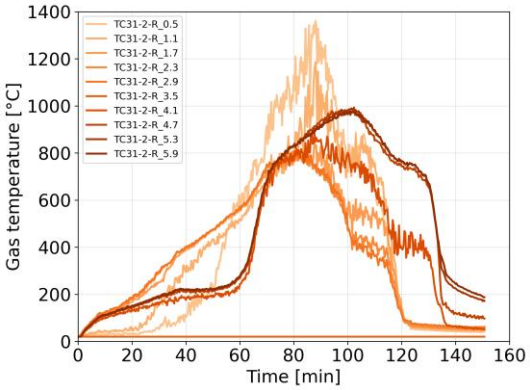








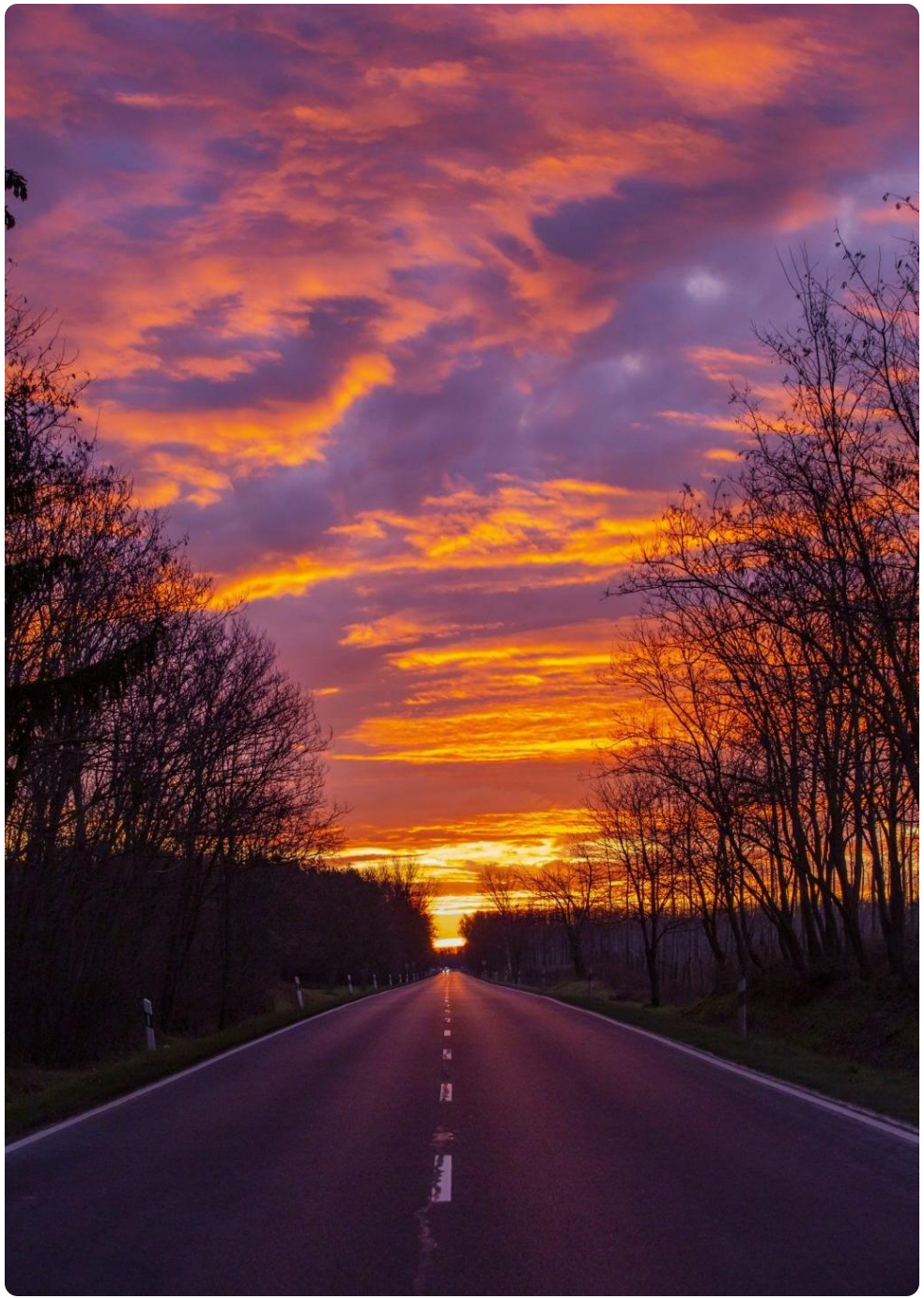


Ongoing research

STRUCTURES IN FIRE FORUM

STRUCTURES IN FIRE FORUM – 10TH APRIL 2026

THE DIAMOND, 32 LEAVYGREAVE RD, BROOMHALL, SHEFFIELD S3 7RD



Conclusions

- Travelling fires behaviour has been observed in various tests, geometry and ventilation conditions are important parameters.
- Flexible framework that incorporates analytical and computational models in the performance-based design of buildings.
- 3-stages for increasing understanding and make better-informed decisions.
- Travelling fires is an ongoing research topic and this framework will benefit from more insights and approaches.
- Adoption in performance-based design relies on understanding the assumptions and limitations of each travelling fire models used.

Stantec

The Institution of Fire Engineers
Scotland Branch

Thank you