multiparametric CFD analyses to understand the key variables in car park smoke control

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- MSc FSE at Main School of Fire Service in Warsaw
- PhD Civ. Eng. at ITB Warsaw, for the research on the role of building architecture in the design of smoke control systems
- with ITB since 2010: Deputy Head of Fire Research Department, fire researcher, CFD engineer and smoke control consultant
- 2019 NFPA Bigglestone Award for work on wind and fire coupled modelling
- VP of Polish SFPE Chapter

My research areas: CFD in FSE, smoke control wind and fire, visibility in smoke, travelling fires, façade fires

car park fires

- Diverse in architecture;
- Similar in principles, systems and operational characteristics;
- Forefront of innovation - in car-park and vehicle technology;
- Large fire load coupled with favourable ventilation conditions, and possibly significant human presence when in heavy use;
- Commonly built under | next to | above other structures;

car park fires

- If uncontrolled may reach a point of growth, where effective firefighting operations are not possible, potentially leading to structural failure

Liverpool (2017)

car park fires

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- If uncontrolled may reach a point of growth, where effective firefighting operations are not possible, potentially leading to structural failure

Moscow (2017)

car park fires

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- If uncontrolled may reach a point of growth, where effective firefighting operations are not possible, potentially leading to structural failure

Cork (2019)

car park fires

- If uncontrolled may reach a point of growth, where effective firefighting operations are not possible, potentially leading to structural failure

Stavanger (2020)

car park smoke control

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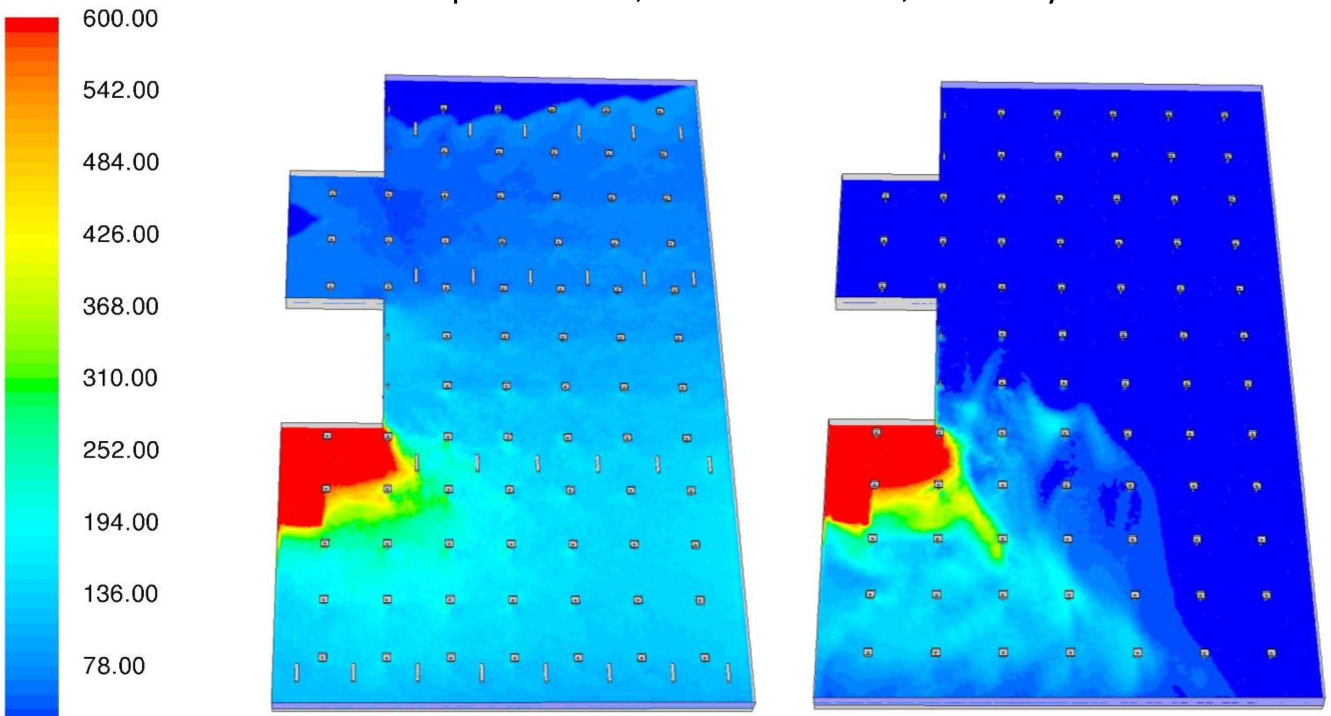
- will not prevent or contain fire, but may significantly change the conditions in the protected venue by reducing the exposure of users and the structure to heat and smoke;
- obligatory in multiple law systems (eg. in Poland);
- designed for life safety (evacuation), firefighter operations or both;

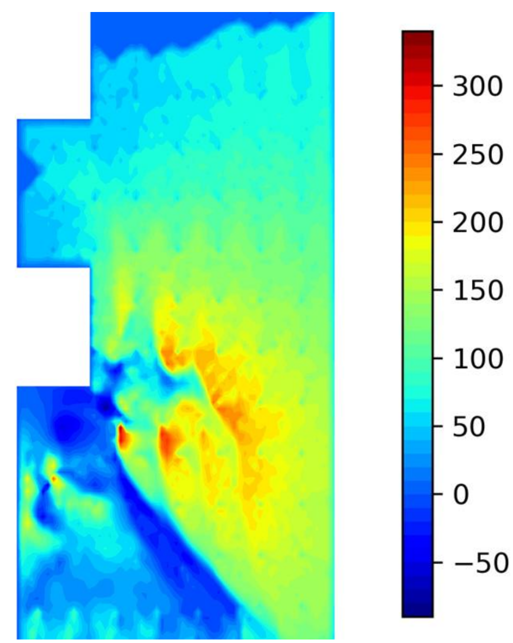
Temperature, 20 MW fire, steady-state



No smoke control

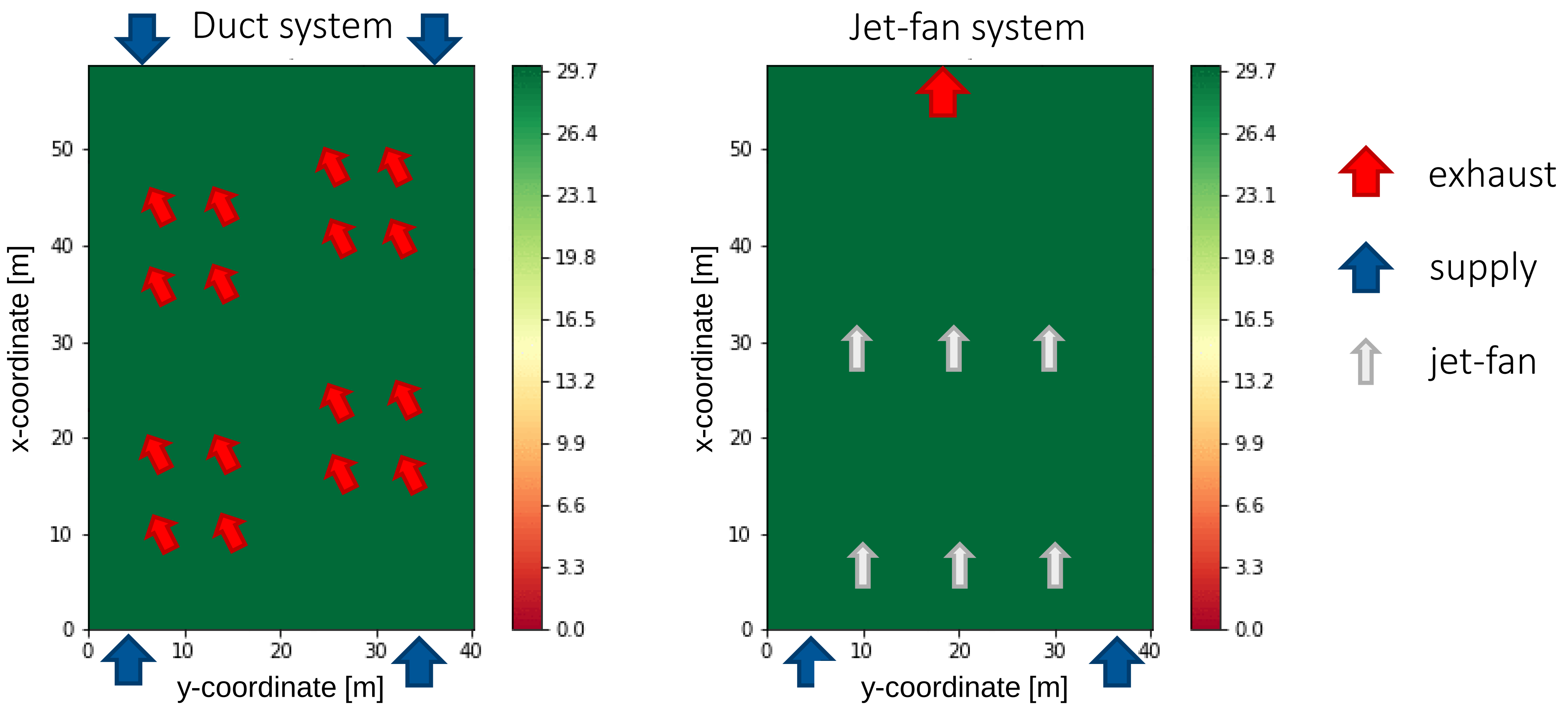
Jet-fan system

Difference between two simulations



car park smoke control

- Two main technologies – duct smoke exhaust systems and ductless jet-fan systems.
- Different ideas of operation, different strengths and weakness.
- In many cases used interchangeably (even if they shouldn't…)



Car park smoke control system **should be** designed with aid of CFD modelling.

Car park fire scenarios show repeatability of fuel load, ignition sources and fire spread scenarios, passive and active fire protection systems etc. However, the impact of minuscule architectural details (location of vents, shape of the CP, beams, columns etc.) is significant, and the flow-field in each car park is unique.

Car parks may have **similar** design fire scenarios and characteristics, but are very **diverse** in fire outcomes.

previous research on CP-SC

CFD modelling has proven useful in systematic studies on various aspects and characteristics of the car park smoke control systems.

JET-FAN SYSTEMS IN CAR PARKS DESIGN METHODS: AN OVERVIEW AND ASSESSMENT OF PERFORMANCE

SFPE EUROPE

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Ocena wpływu aranżacji garażu na wynik symulacji CFD rozprzestrzeniania się dymu i ciepła

The Influence of the Arrangement of Passenger Cars in Indoor Car Parks on CFD Calculations

Оценка влияния устройства подземного паркинга на результаты CFD-моделирования распространения дыма и тепла

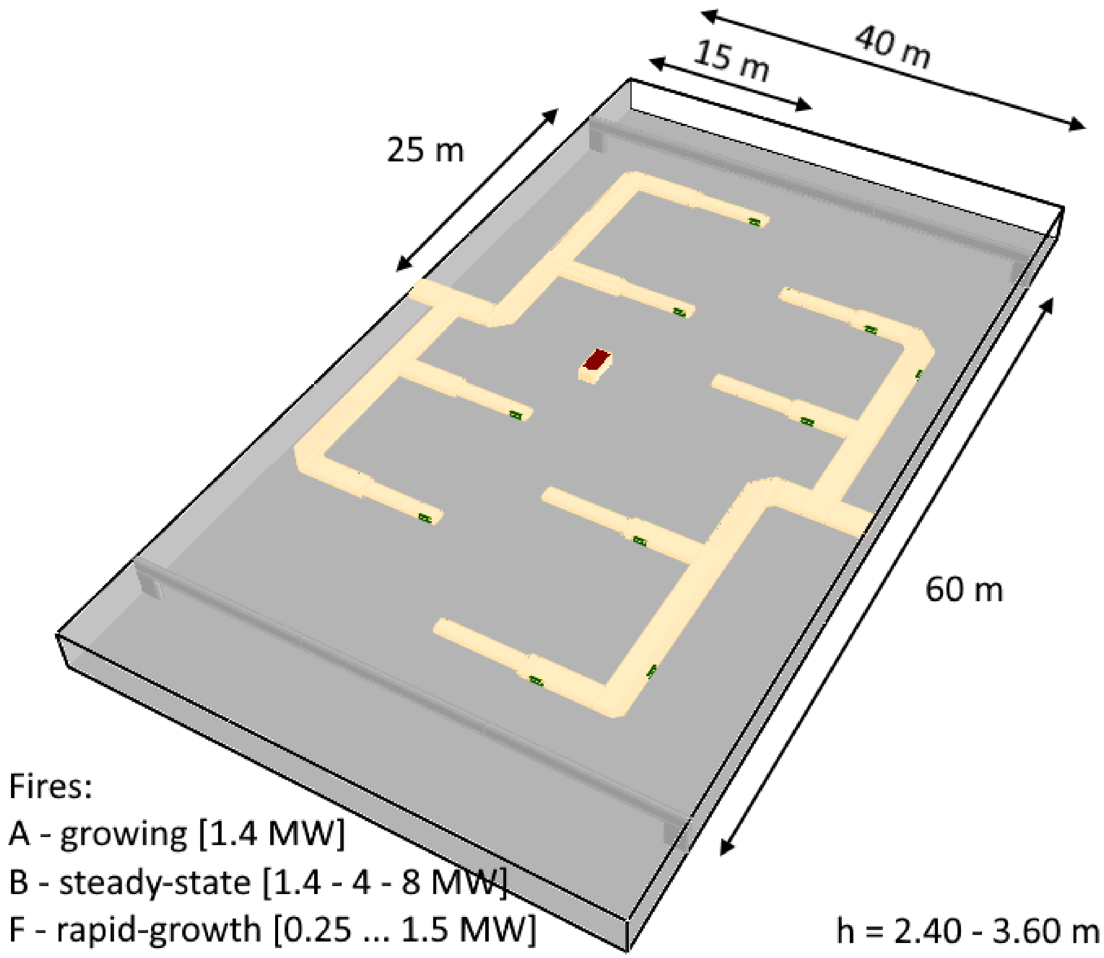
Multiparametric study on performance of jet-fan based systems in two different car parks. Looking into exhaust capacity of the system against fires with variety of sizes, and into fans with different thrust

https://www.sfpe.org/page/Issue9Feature3/Jet-Fan-Systems-in-Car-Parks-Design-Methods-an-Overview-and-Assessment.htm

How obstacles influence the results of car park CFD? We have performed probabilistic analyses with various 'car-load' levels in three different car parks to estimate the differences between 'full', 'partially-full' and 'empty' car parks.

https://panel.sft.cnbop.pl/storage/ba77bcb7-0f79-4b14-a595-e36f60c7e3b0

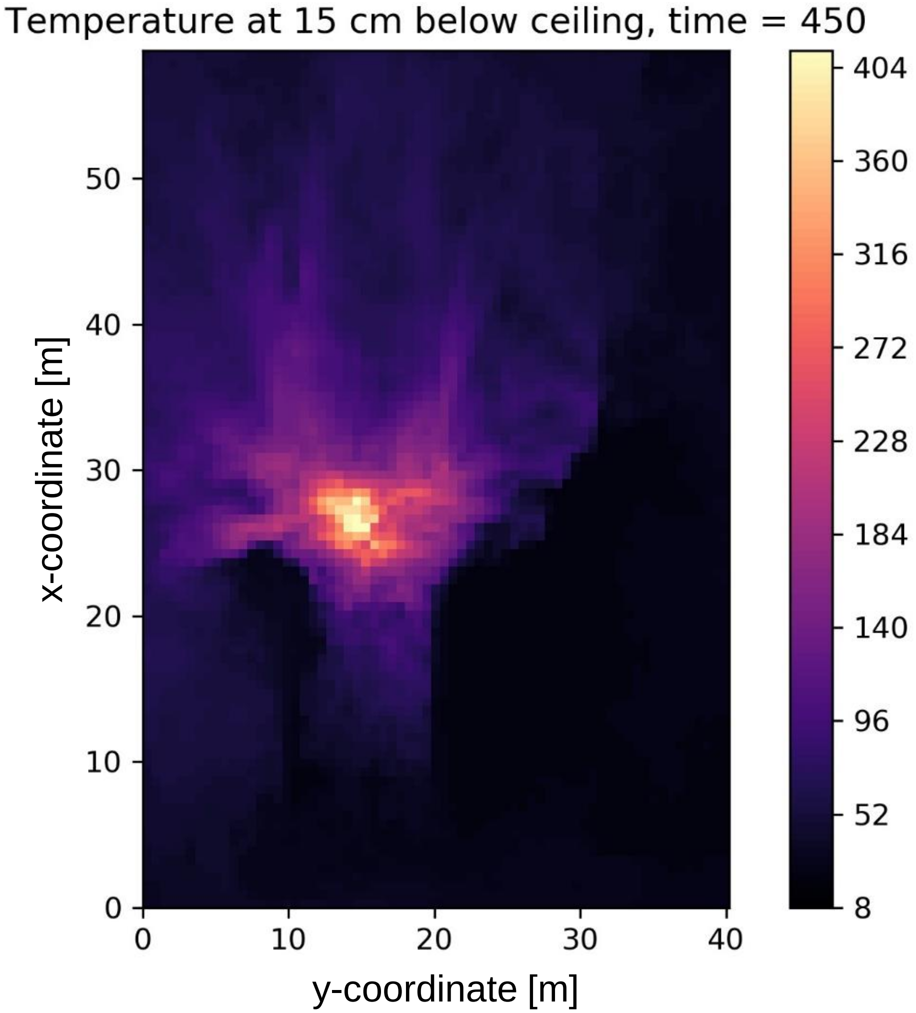
current project



aims of NZP-127 research project on car park ventilation systems

- to use FDS to study outcomes of a wide range of fires in car parks with various heights, equipped with smoke control systems with various characteristics;
- to identify key variables influencing the performance of car park ventilation systems;
- to develop framework for case-preparation, performance of simulation and automated data processing to allow for drawing conclusions from a large body of results

current project



main model characteristics:

- 15 cm mesh, approx. 2.5M elements per simulation
- total of 480 CFD simulations performed
- on average 162 CPU·hours per simulation
- approx. 78 000 CPU·hours used for the whole project
- automated Python scripts for case generation
- initial geometry and DEVC/HVAC definition in PyroSim
- Data acquisition with arrays of DEVC

```
&DEVC ID='TMP_XY_1860_60_180',  QUANTITY='TEMPERATURE', XYZ=18.600000,0.600000,1.800000/
&DEVC ID='TMP_XY_1920_60_180',  QUANTITY='TEMPERATURE', XYZ=19.200000,0.600000,1.800000/
&DEVC ID='TMP_XY_1980_60_180',  QUANTITY='TEMPERATURE', XYZ=19.800000,0.600000,1.800000/
&DEVC ID='TMP_XY_2040_60_180',  QUANTITY='TEMPERATURE', XYZ=20.400000,0.600000,1.800000/
```

- automated Python scripts for data curation, and postprocessing

variables

- architectural
- fire related
- smoke control systems

variables

- architectural
  - **height of the car park**

    (2.40 m | 2.70 m | 3.00 m | 3.30 m | 3.60 m)
  - area of the car park

    ($2400\ m^2$)
  - shape of the car park

    (rectangular, 3:2 ratio)
  - how full is the car park?

    (empty)

variables

- architectural
- fire related

  - **design fire**
    - Probabilistic | deterministic fire development
  - **standardized fires (eg. TNO) | t^2 fires | rapid fires**
    - HRRPUA

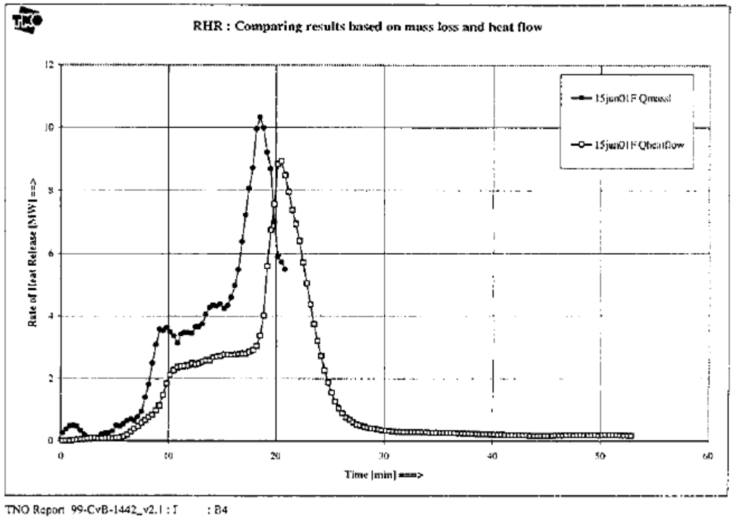
      (500 kW/m²)
    - source growth rate | growth mode

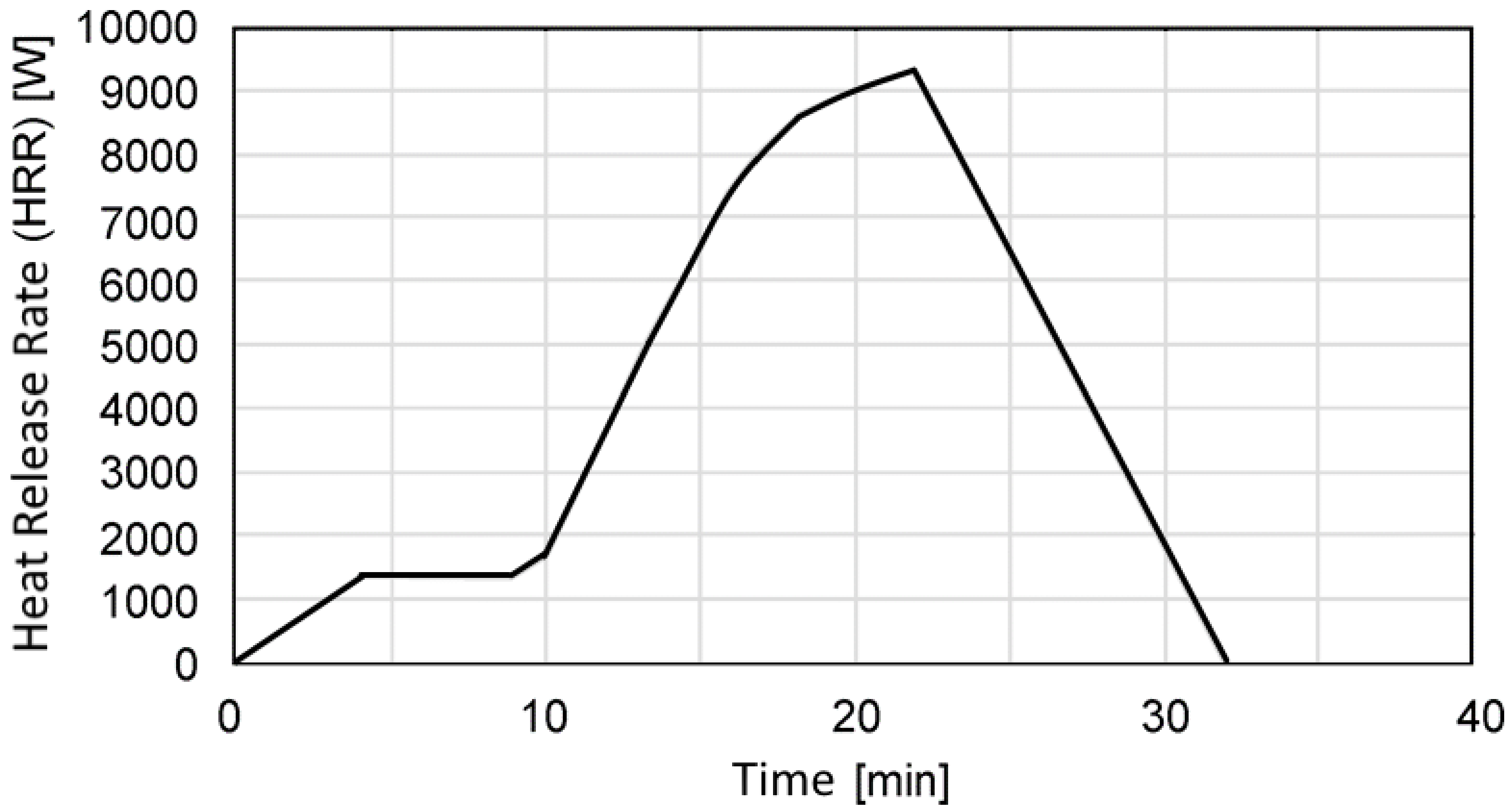
      (constant HRRPUA)
    - Emissions

      (y_soot = 0.1 g/g | y_co = 0.07 g/g | HoC = 25 MJ/kg)

variables

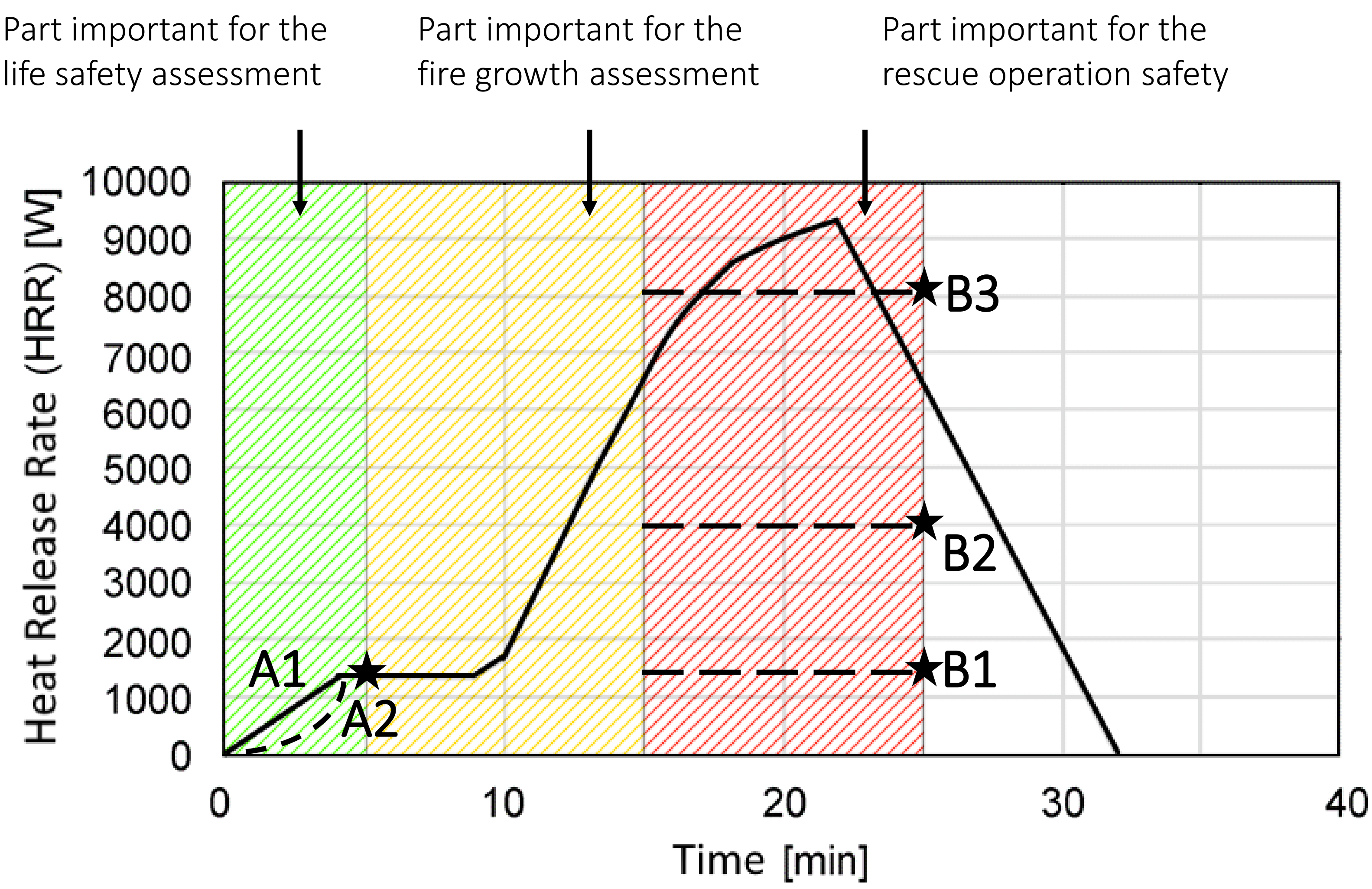
- architectural
- fire related





variables

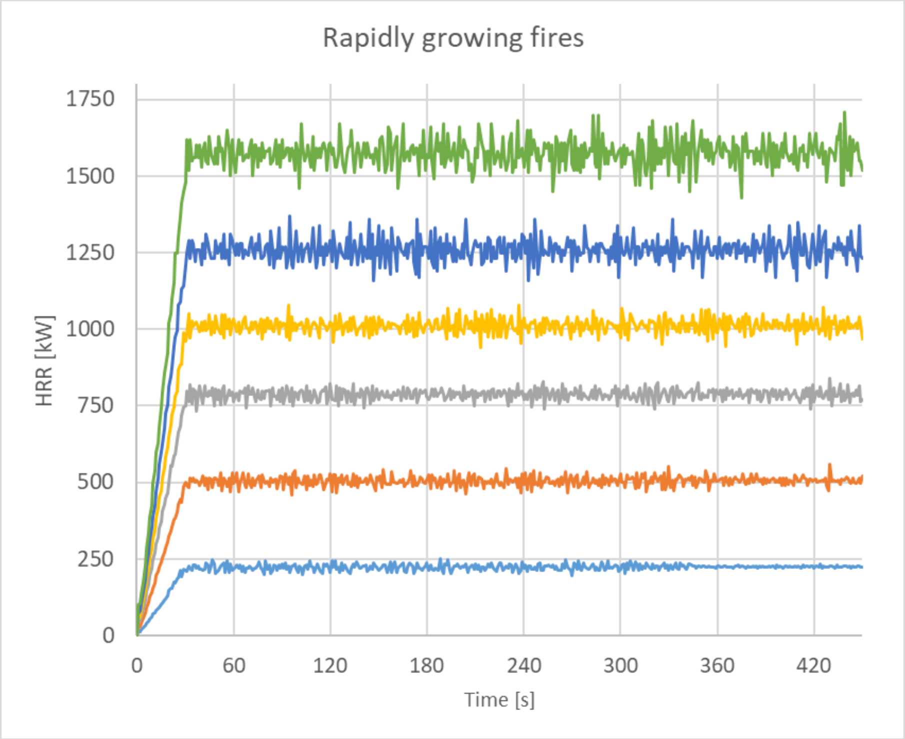
- architectural
- fire related



variables

- architectural
- fire related

We do not know what how to make a credible design fire for an EV vehicle, thus for the purpose of this research a class of 'rapidly growing fires' was developed, to investigated some of challenges related to almost instantaneous fires of vehicles.



variables

- architectural
- fire related
- smoke control systems

- **duct systems**
- **exhaust capacity**

(17 m³/s | 34 m³/s | 50 m³/s)

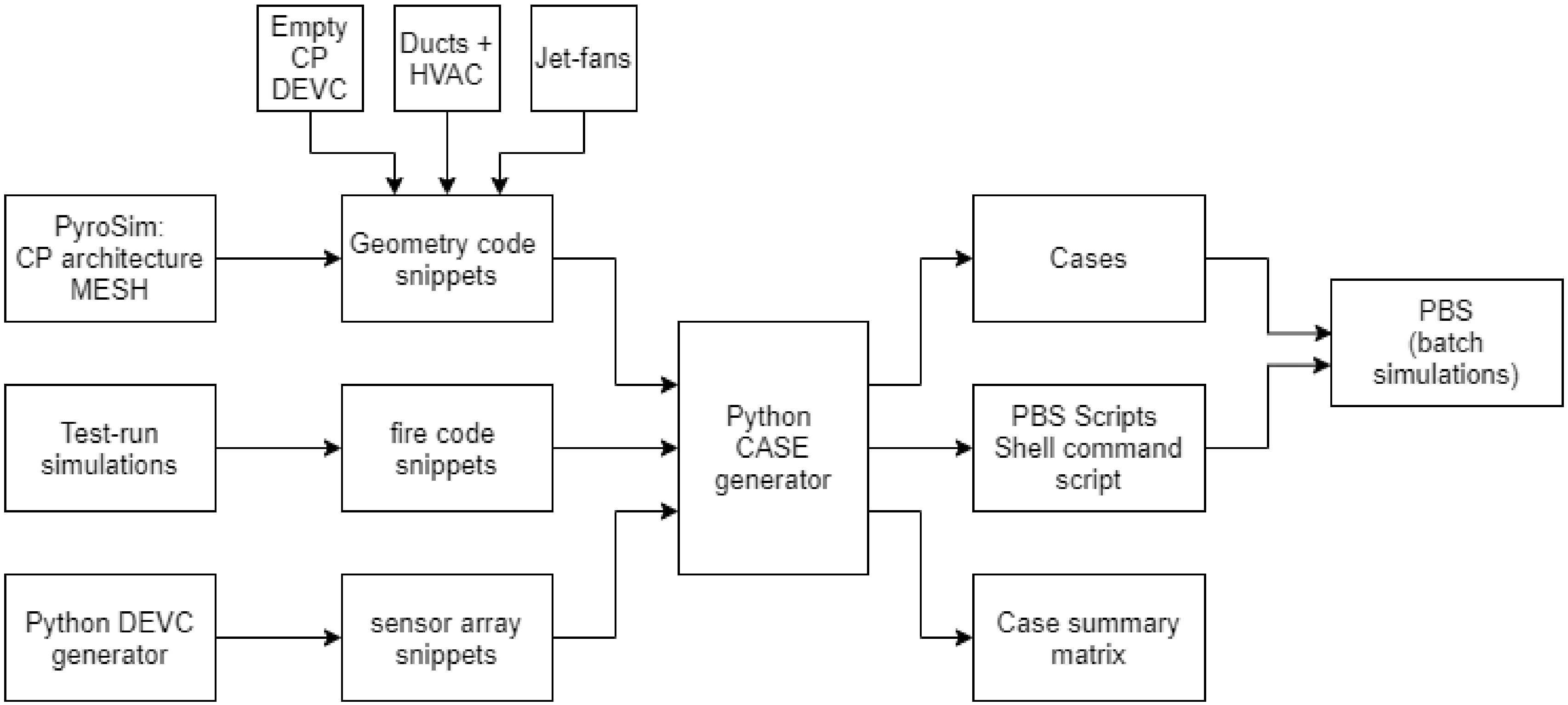
- number of exhaust points
- exh. point location
- exh. velocity
- air-supply strategy

- **jet-fan systems**
- **open vs closed CP**
- **exhaust capacity**

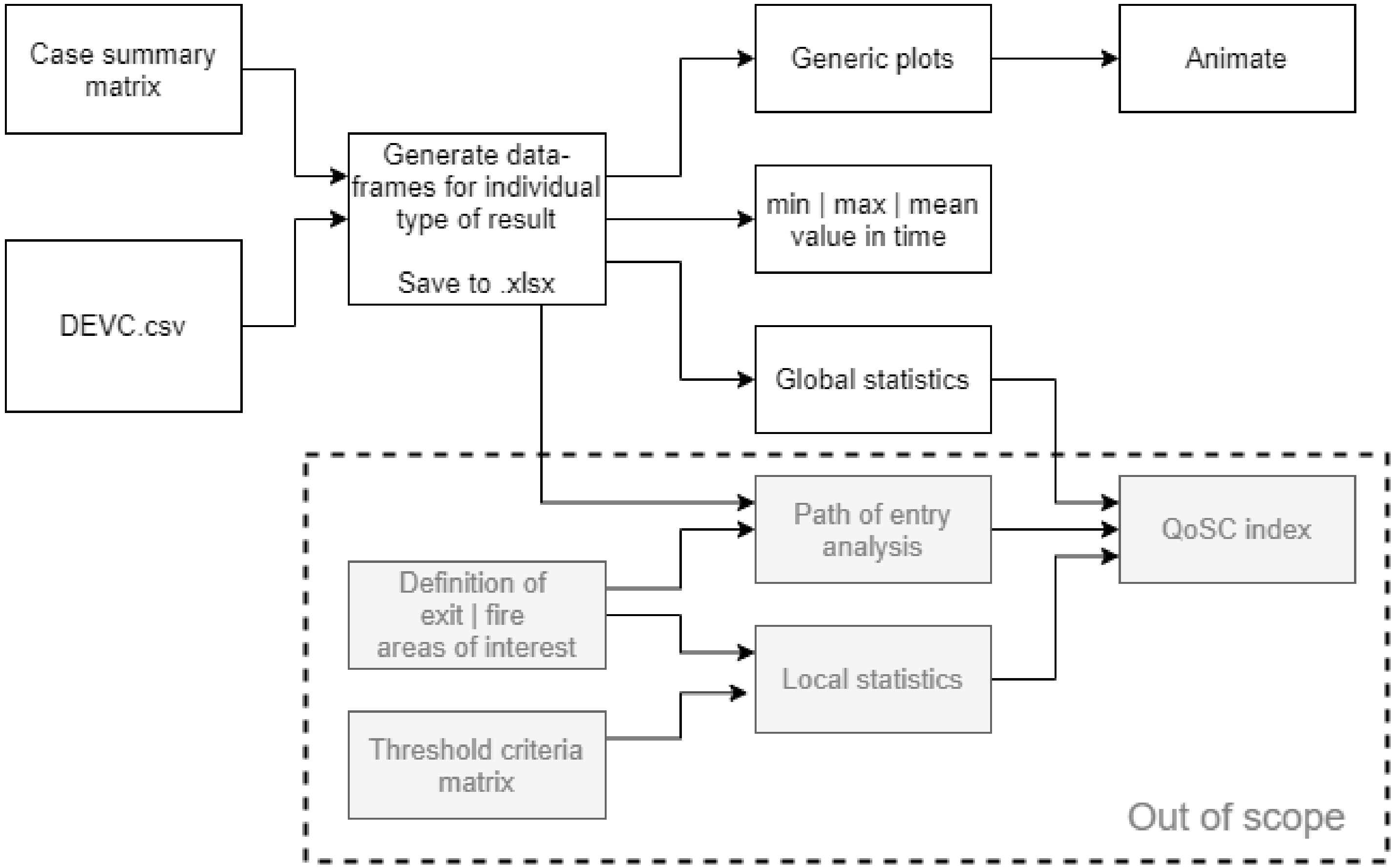
(44 m³/s | 66 m³/s | 88 m³/s)

- number of jet-fans
- thrust of jet-fans
- air-supply strategy

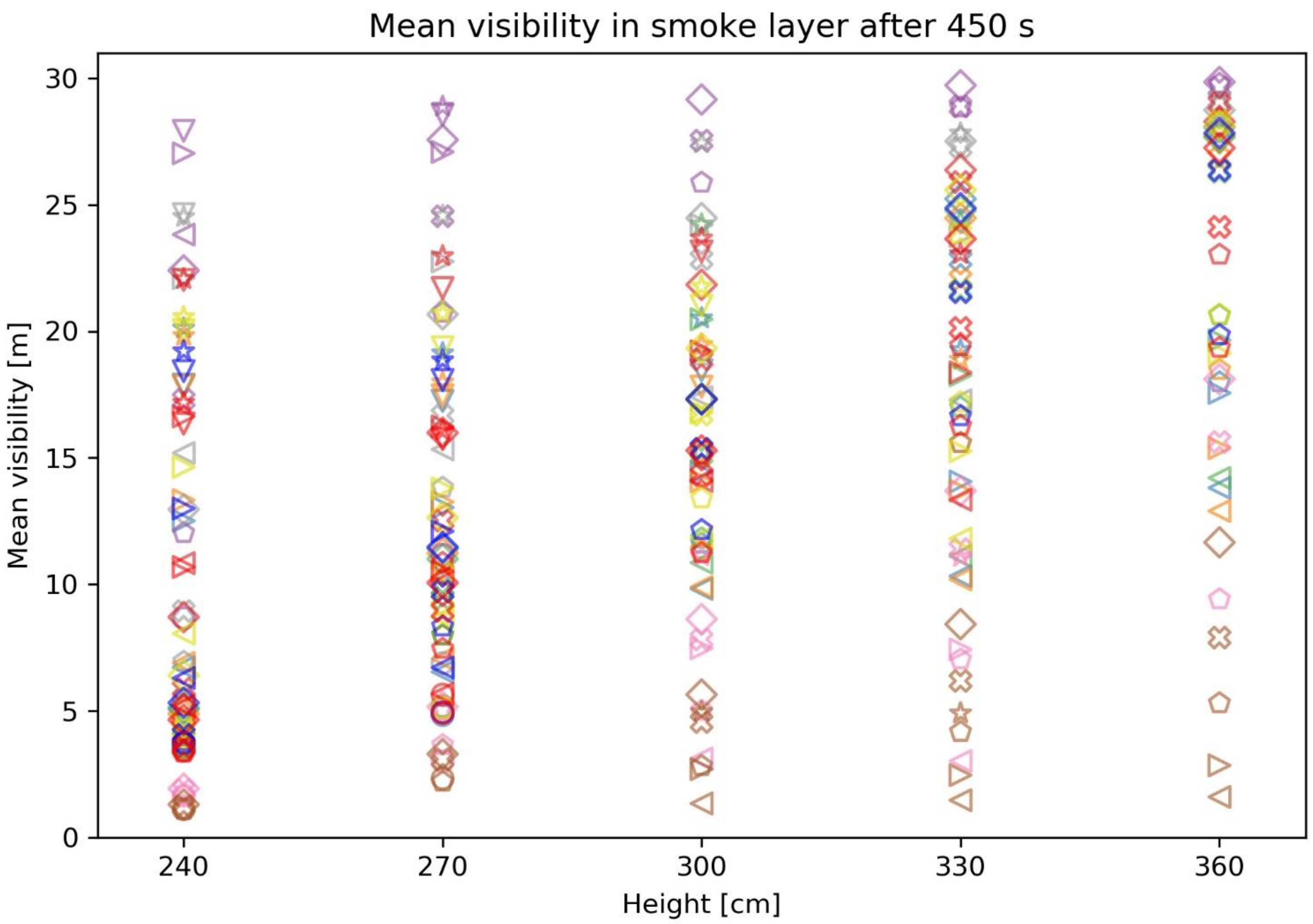
workflow – pre-processing



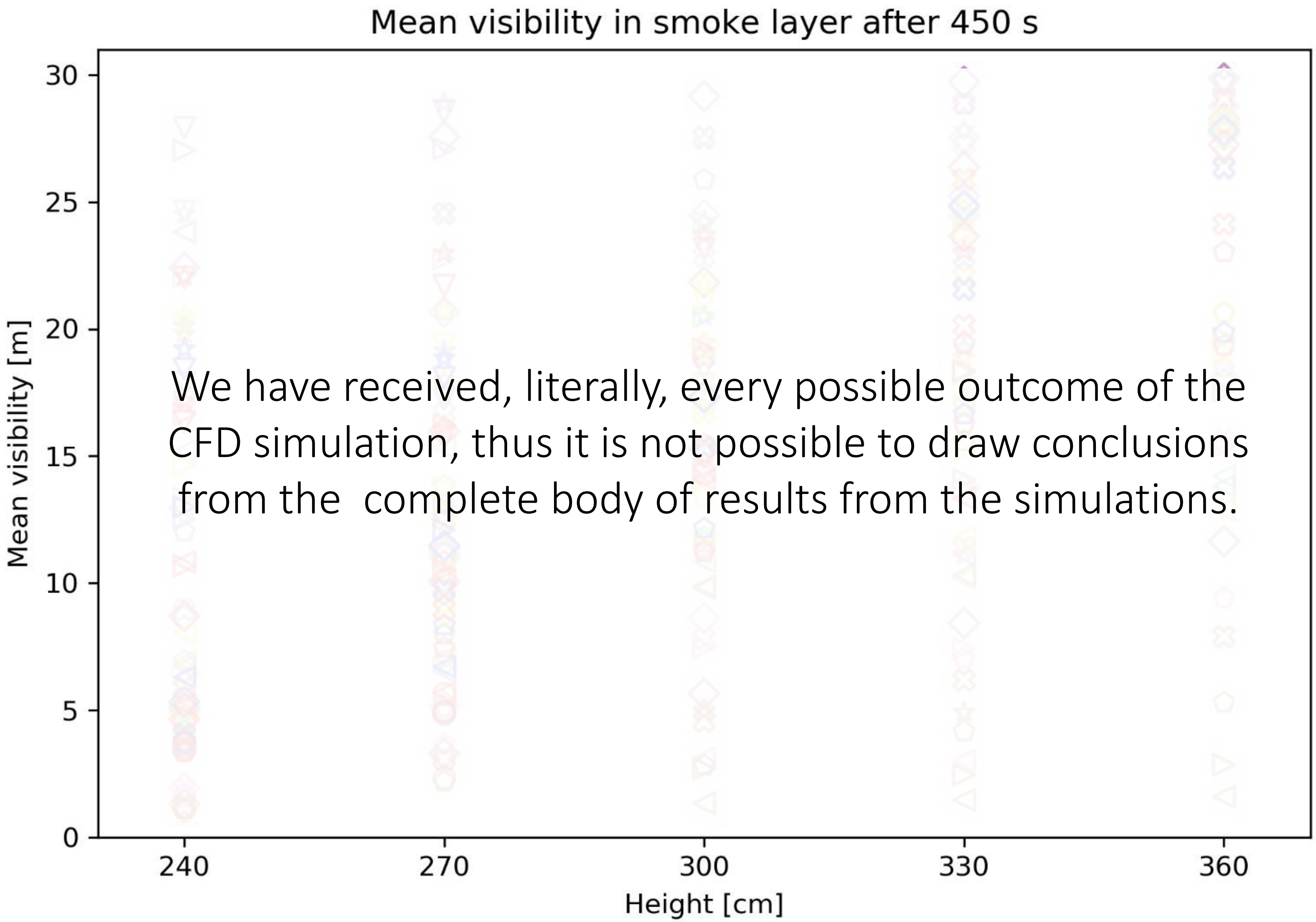
workflow – post-processing



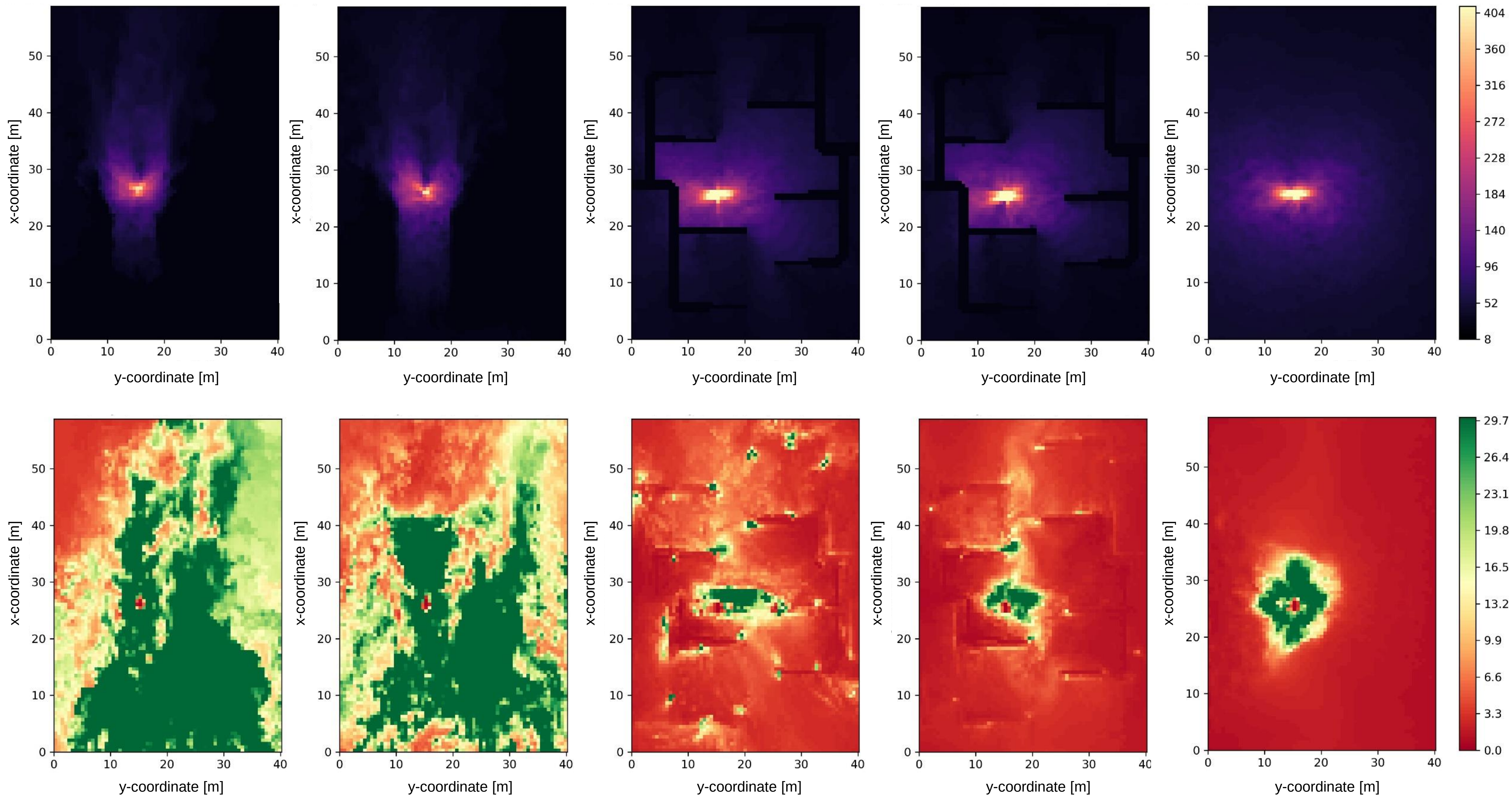
results


Mean visibility in smoke layer after 450 s
Mean visibility [m]
Height [cm]
0
5
10
15
20
25
30
240
270
300
330
360

results


Mean visibility in smoke layer after 450 s
Mean visibility [m]
0
5
10
15
20
25
30
240
270
300
330
360
Height [cm]
We have received, literally, every possible outcome of the CFD simulation, thus it is not possible to draw conclusions from the complete body of results from the simulations.

results – large variability



Jet-fans (88 m³/s)

y-coordinate [m]

Jet-fans (44 m³/s)

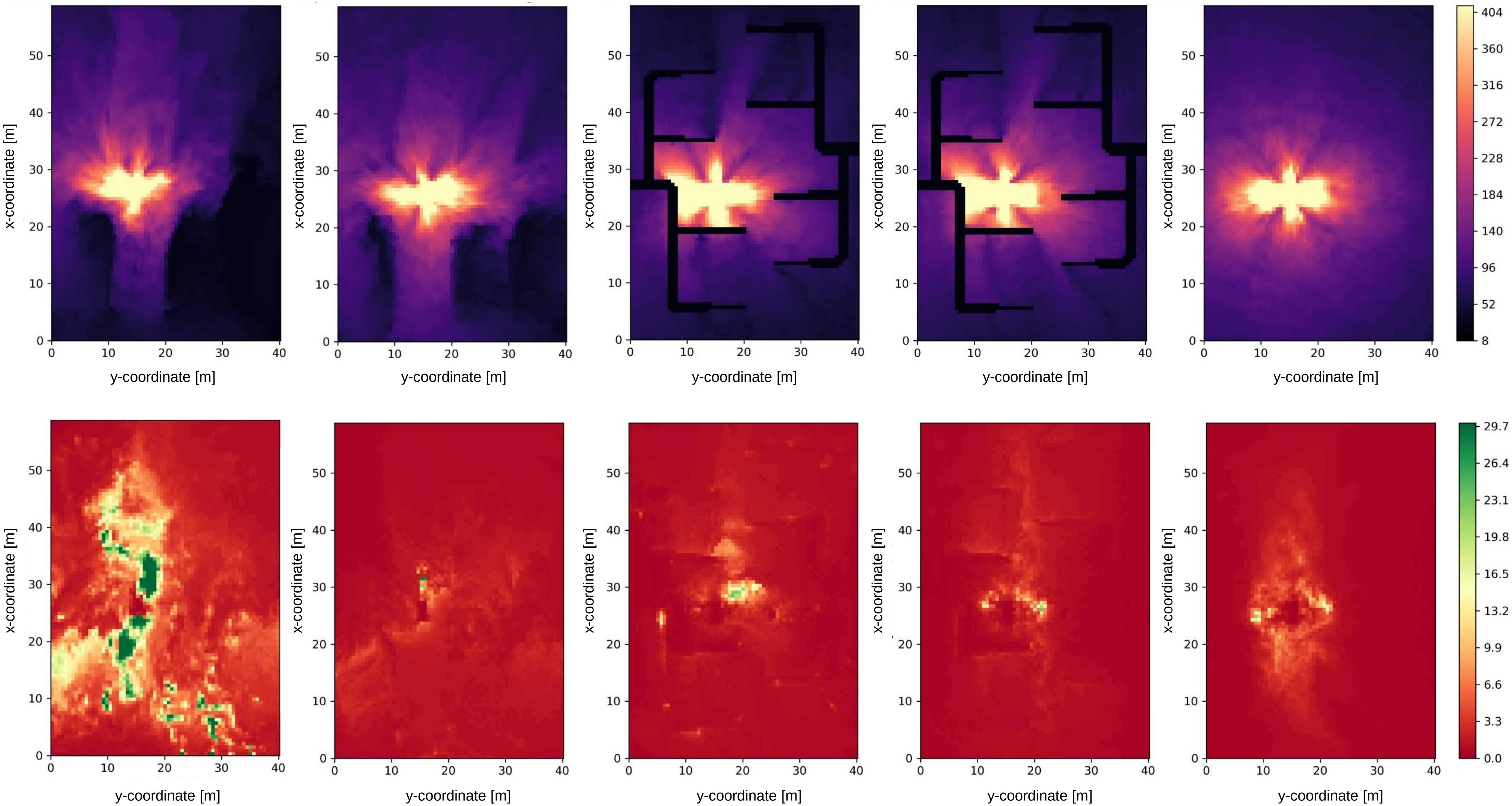
Ducts (50 m³/s)

Ducts (17 m³/s)

No vent

H = 2.40 m, HRR = 1.40 MW (const.), t = 450 s

results – large variability



Jet-fans (88 m³/s)

Jet-fans (44 m³/s)

Ducts (50 m³/s)

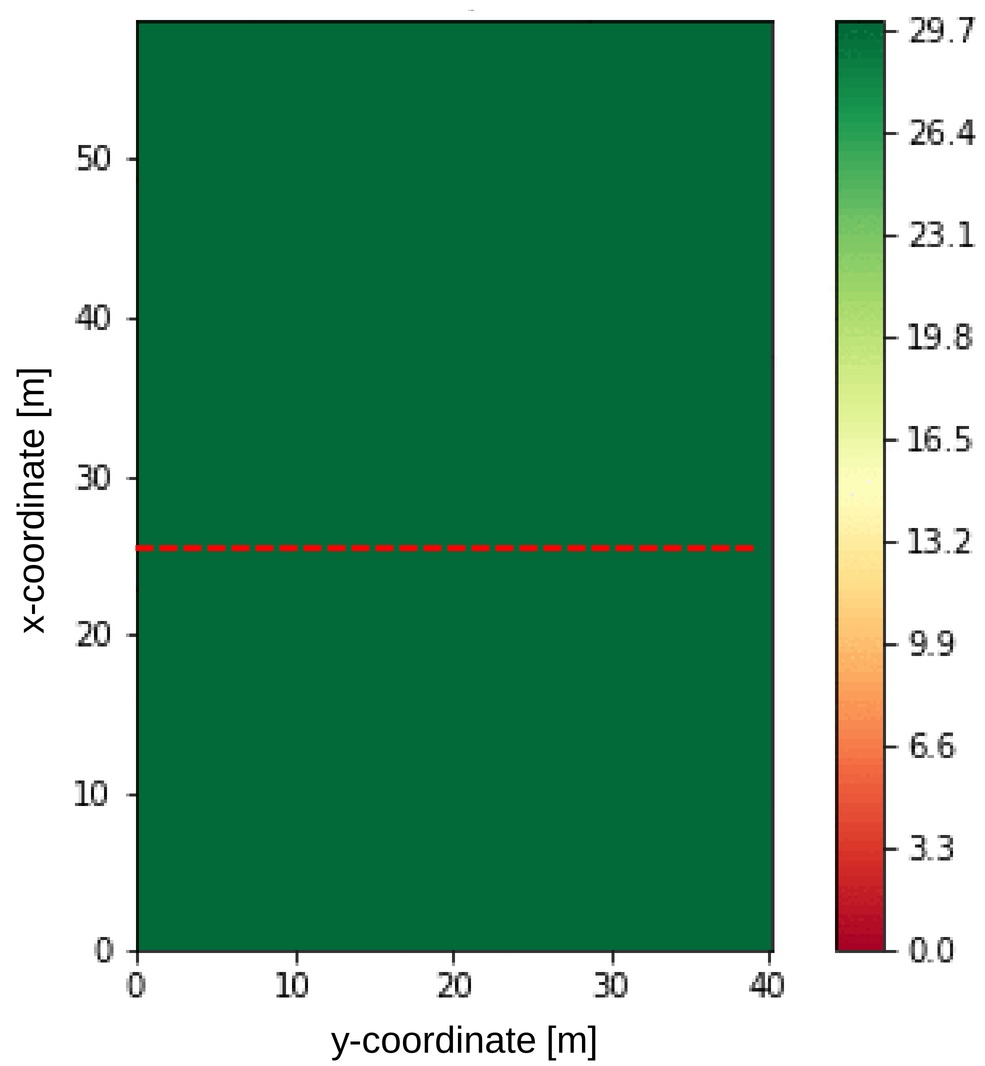
Ducts (17 m³/s)

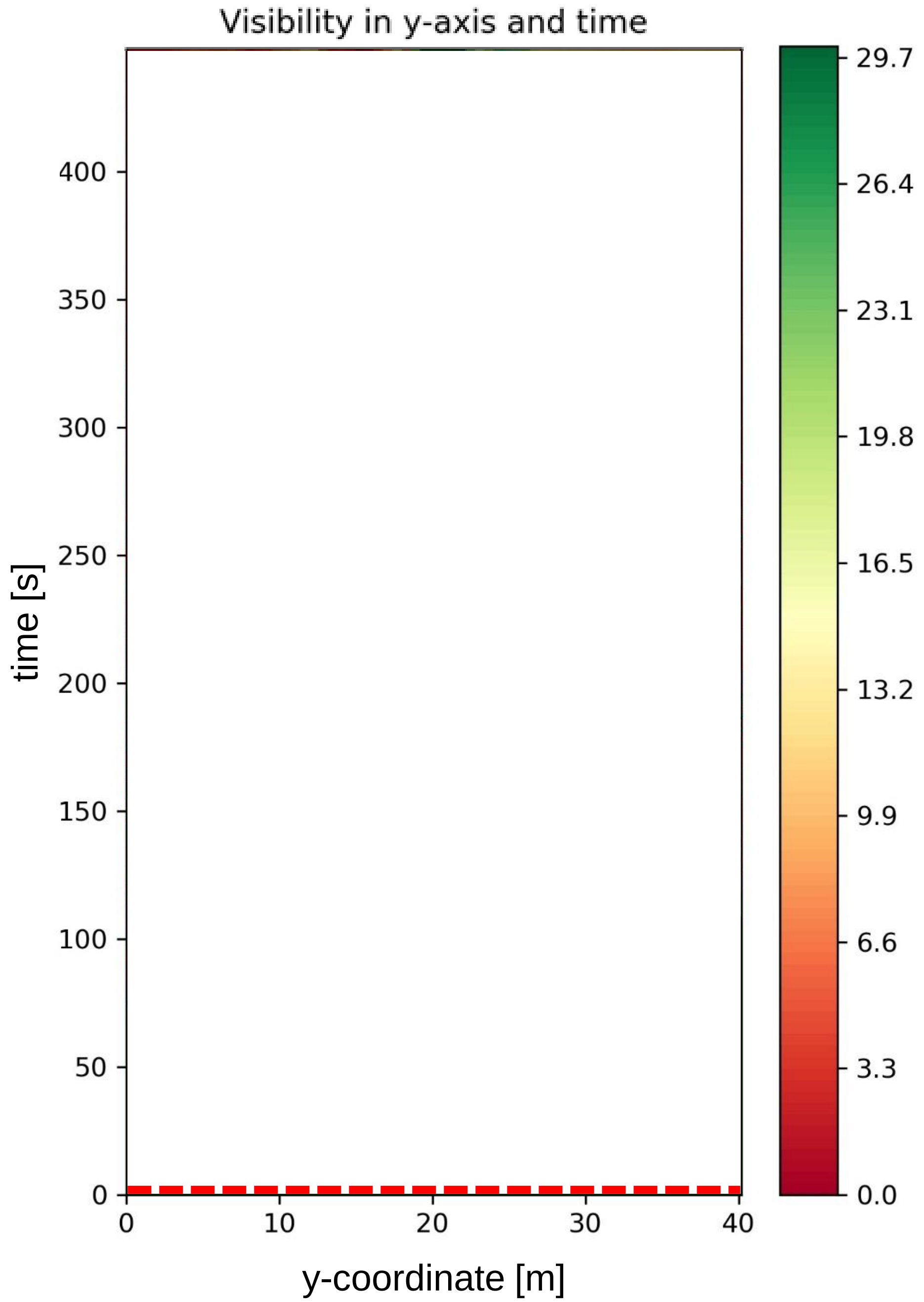
No vent

H = 2.40 m, HRR = 8.00 MW (const.)

results – value in XZ line in time

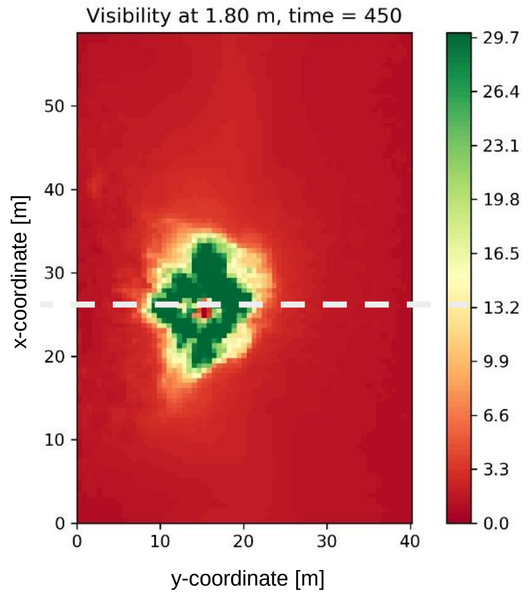
If you save the values along a line of sensors for every time step in simulation, you can present the time evolution of that value on a 2D plot.

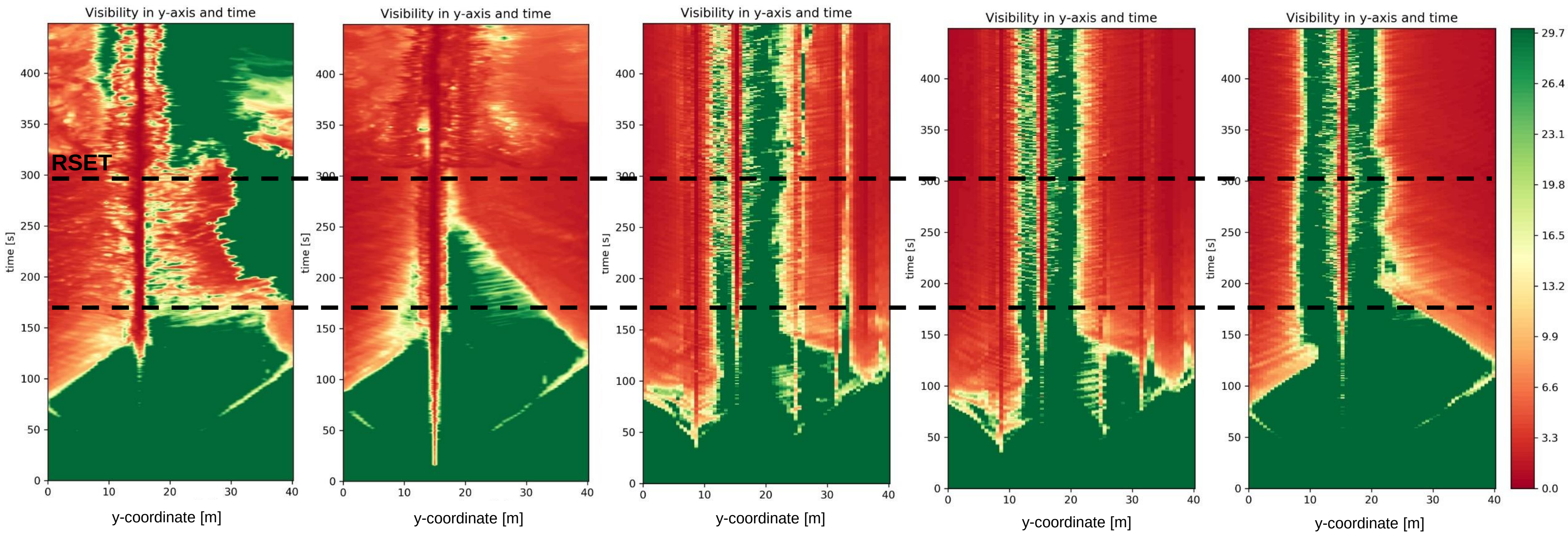




results – low height

In car parks with low height ceiling (2.40 m) we have observed **no favourable outcomes** in RSET no matter the scenario of operation investigated



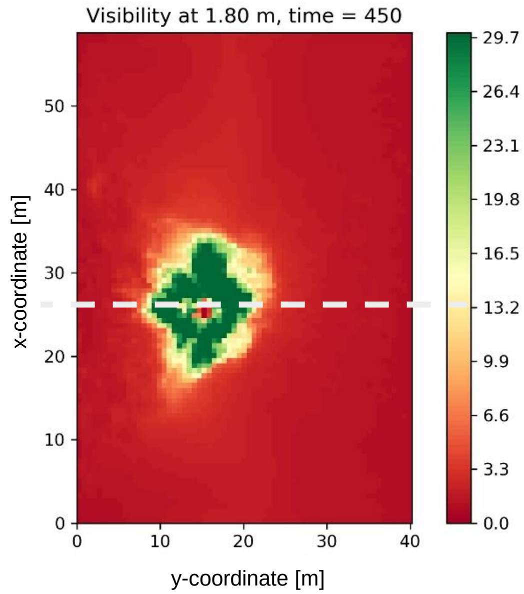


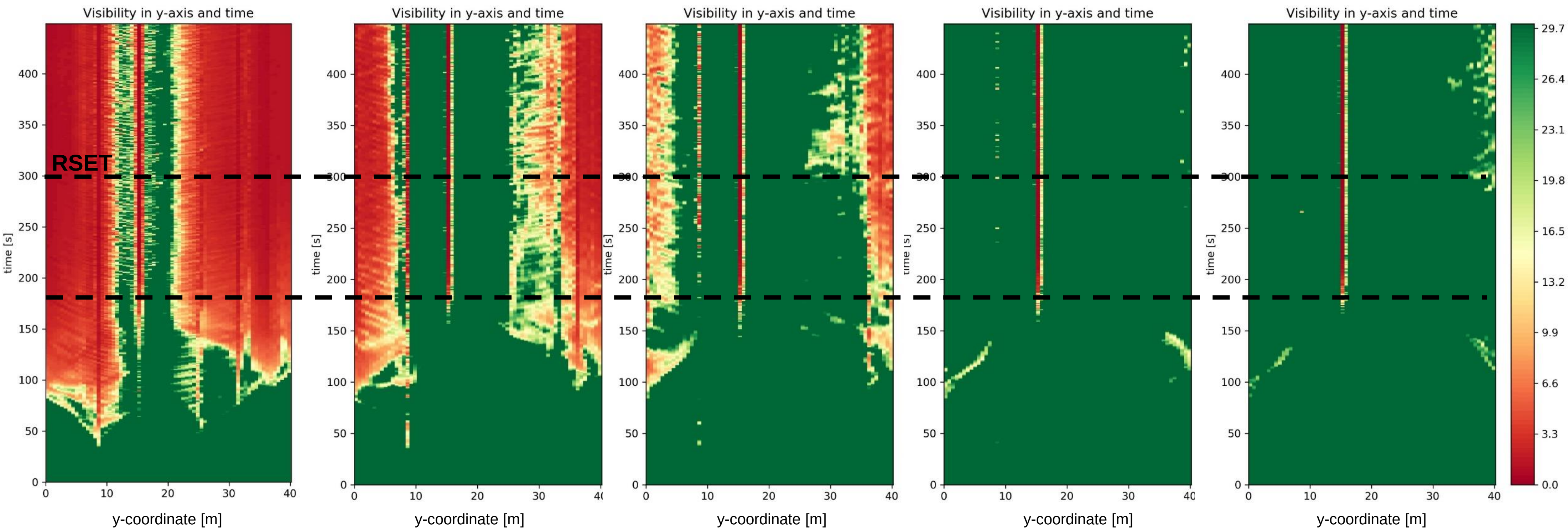
Jet-fans ($88\ m^3/s$)	Jet-fans ($44\ m^3/s$)	Ducts ($50\ m^3/s$)	Ducts ($17\ m^3/s$)	No vent

H = 2.40 m, HRR = 1.40 MW (TNO Growth)

results – impact of height

Increase of car-par height improved the outcomes significantly in the evacuation time, even for the lowest capacity systems.





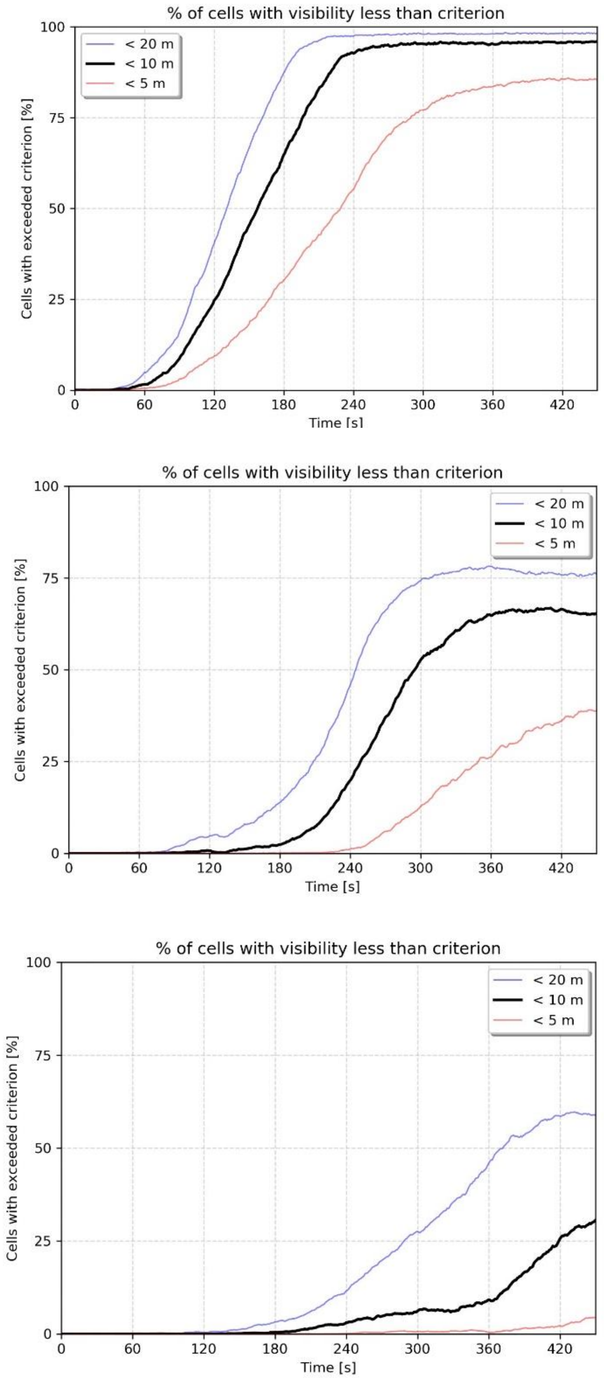
H = 2.40 m | H = 2.70 m | H = 3.00 m | H = 3.30 m | H = 3.60 m

Ducts, 17 m^3/s, HRR = 1.40 MW (TNO Growth)

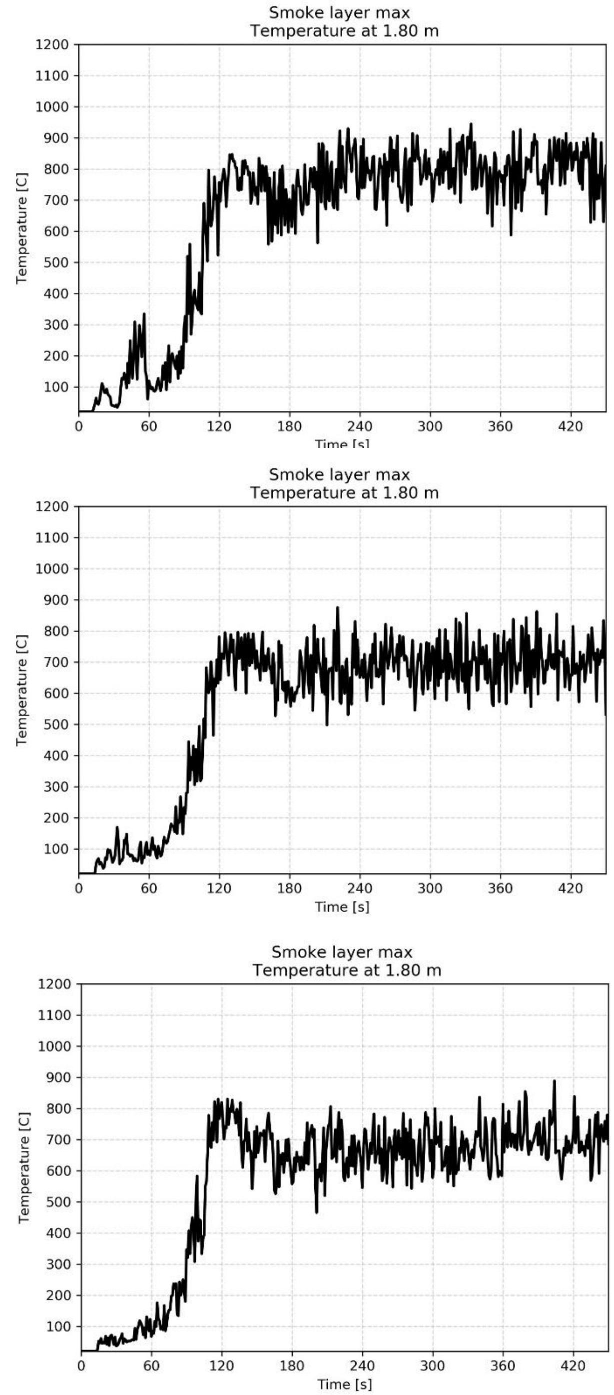
H = 2.40 m

H = 3.00 m

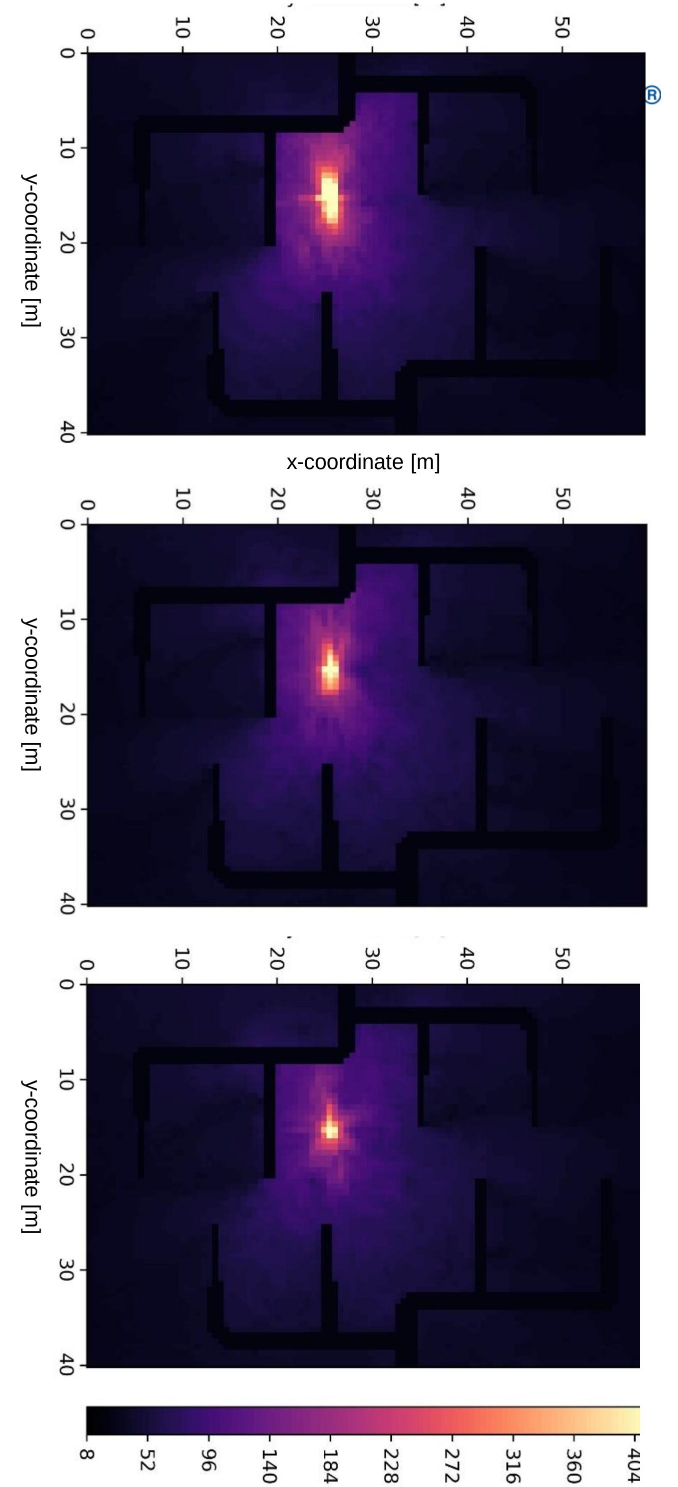
H = 3.60 m



% of cells with visibility threshold value at 1.80 m

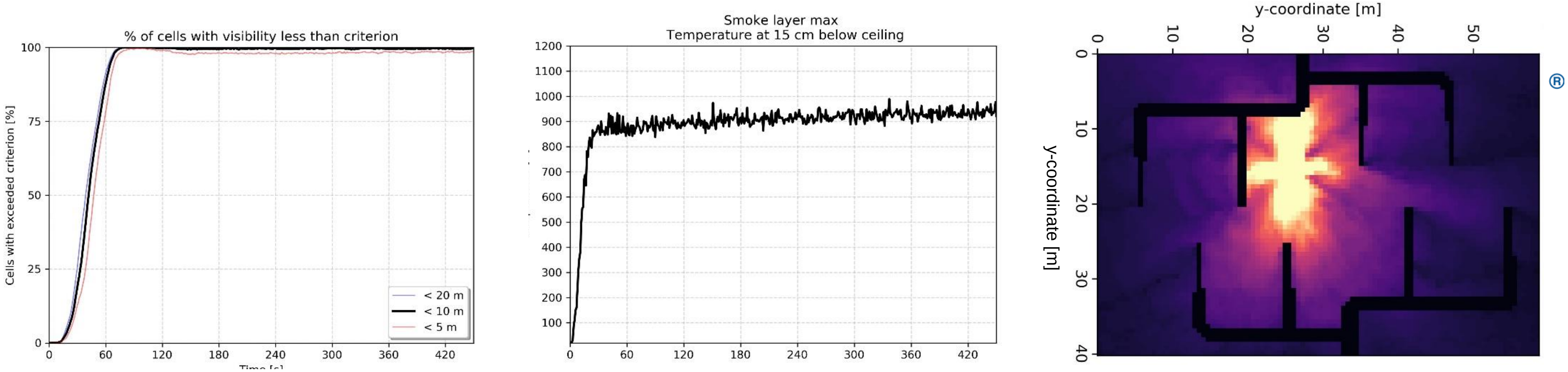


plume temperature under the ceiling

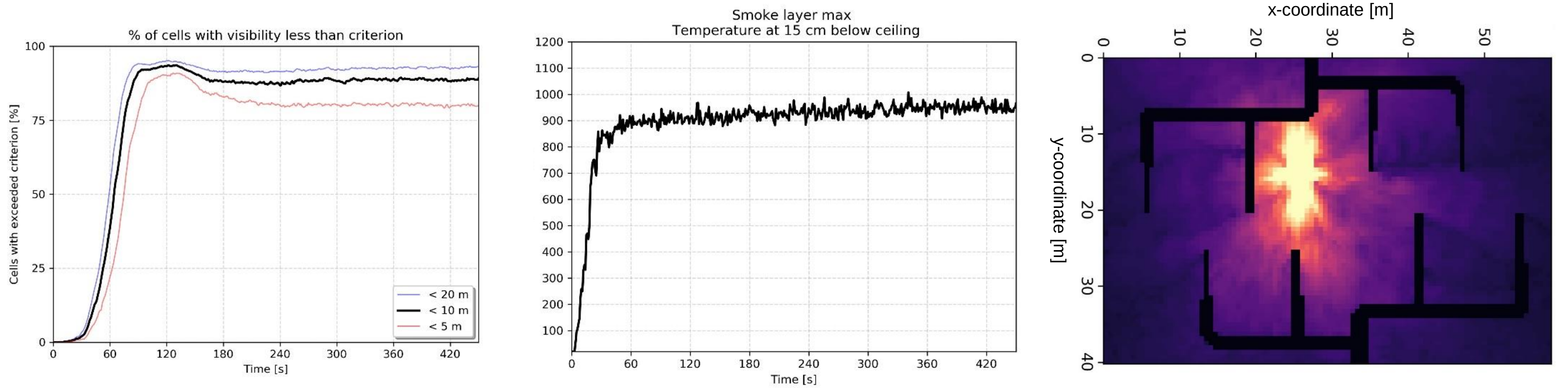


Ducts, 17 m^3/s, HRR = 1.40 MW (TNO Growth)

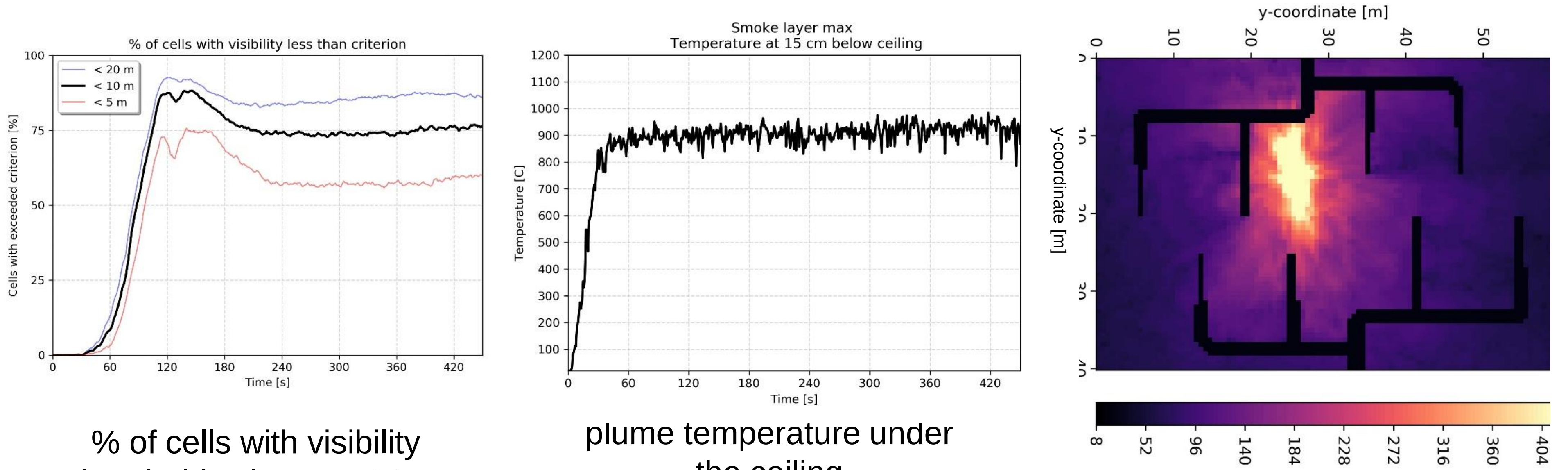
H = 2.40 m



H = 3.00 m



H = 3.60 m



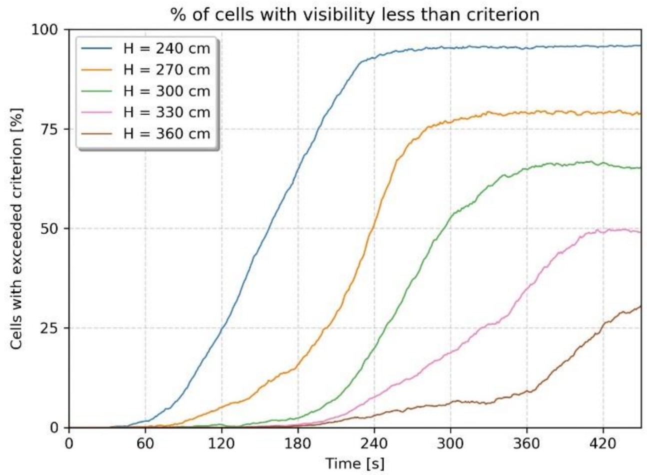
% of cells with visibility threshold value at 1.80 m

plume temperature under the ceiling

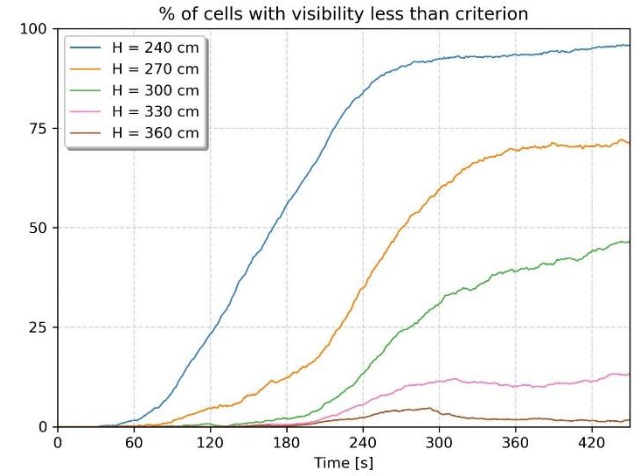
Ducts, 34 m^3/s, HRR = 8.00 MW (const.)

results – heigh and ducts

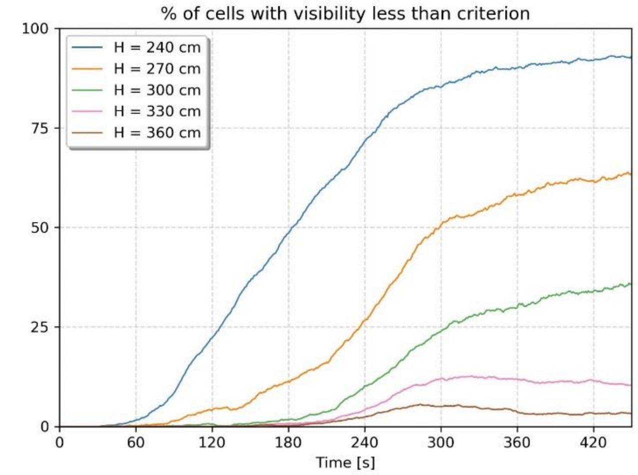
1.40 MW



Ducts
(17 m^3/s)

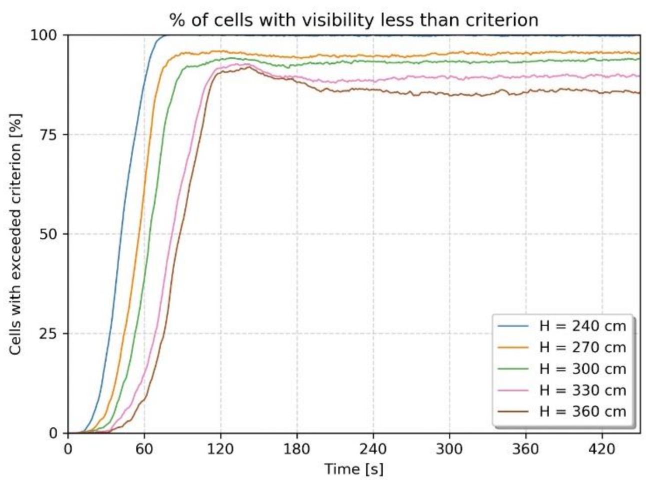


Ducts
(34 m^3/s)

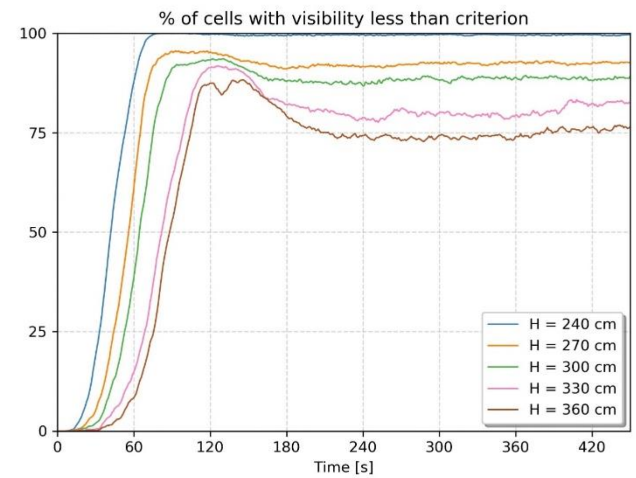


Ducts
(50 m^3/s)

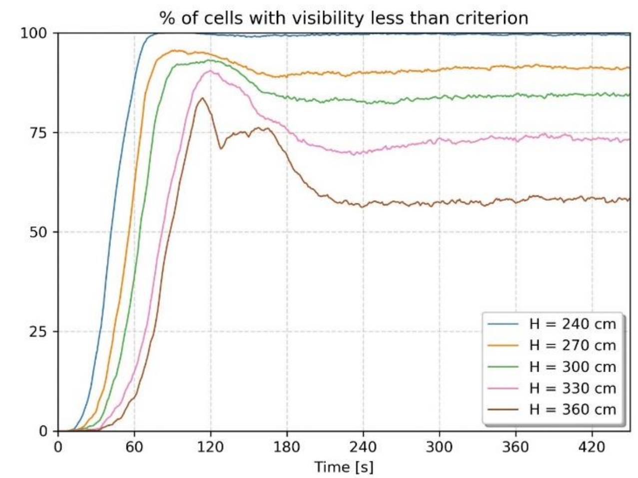
8.00 MW



Ducts
(17 m^3/s)



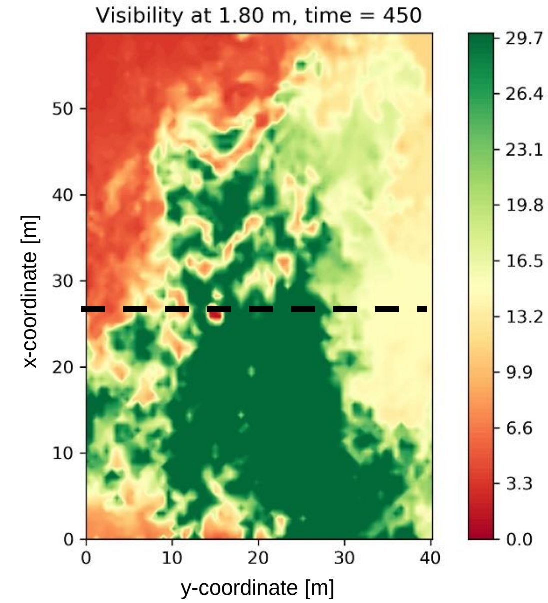
Ducts
(34 m^3/s)

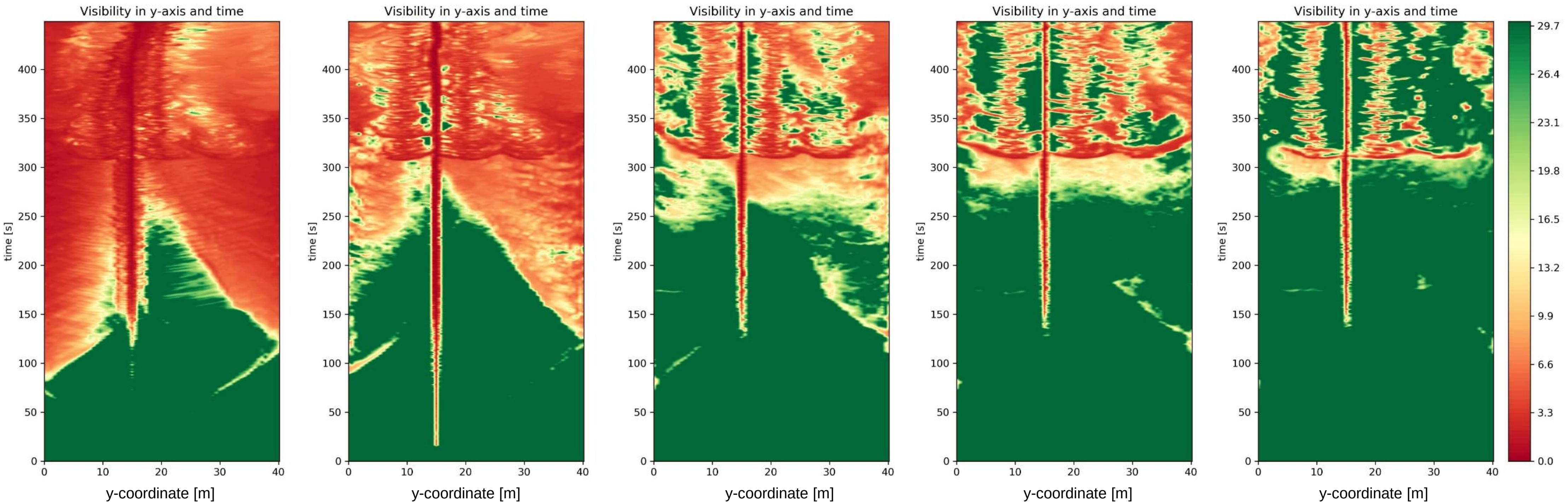


Ducts
(50 m^3/s)

results – jet fans

Increase of car-par height improved the outcomes significantly in the evacuation time, even for the lowest capacity systems.





H = 2.40 m

H = 2.70 m

H = 3.00 m

H = 3.30 m

H = 3.60 m

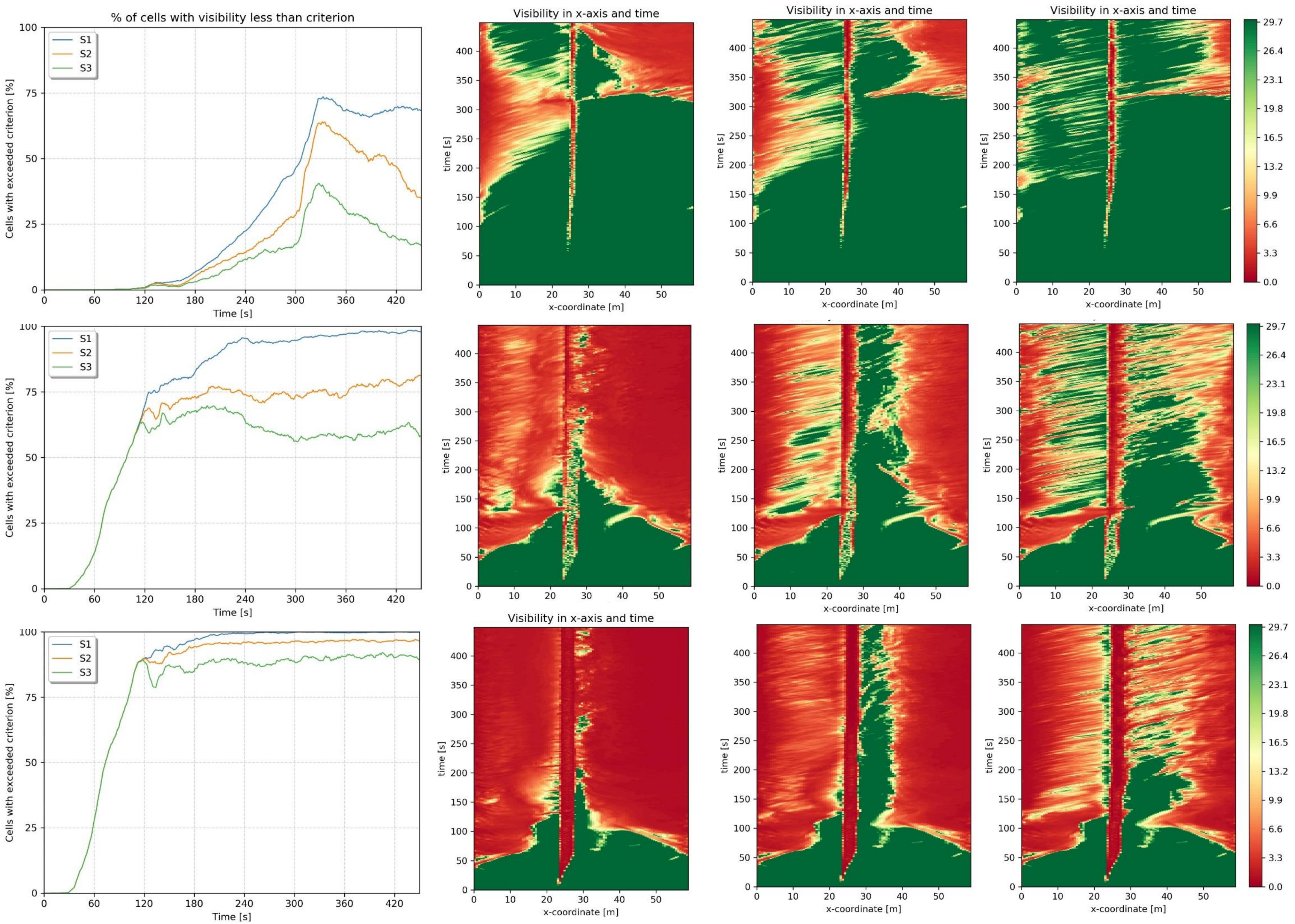
Jet fans, 44 m³/s, HRR = 1.40 MW (TNO Growth)

	$V = 44\ m^3/s$	$V = 66\ m^3/s$	$V = 88\ m^3/s$

1.40 MW

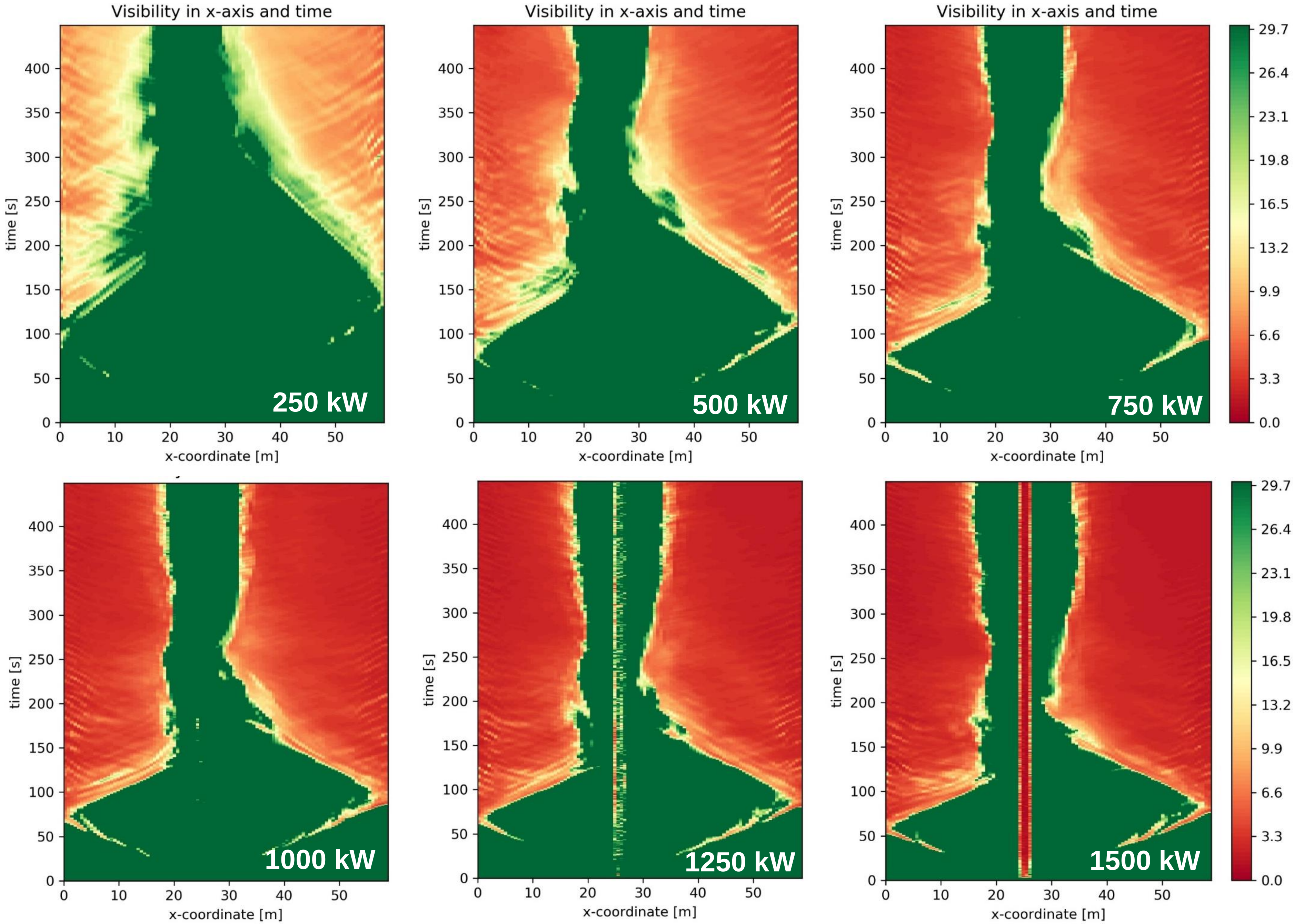
4.00 MW

8.00 MW



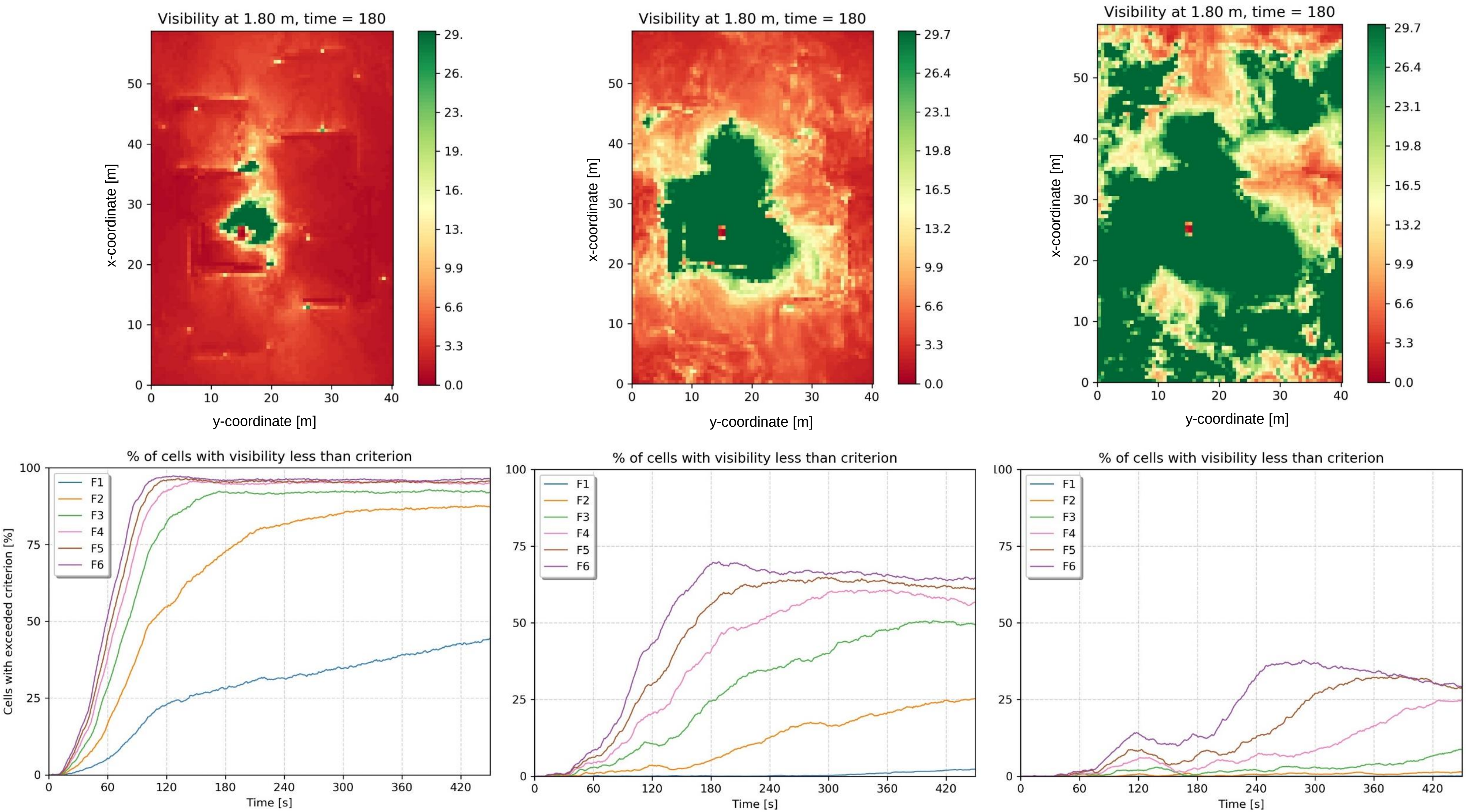
Jet fans

results – rapidly growing fires



No vent, H = 2.70 m

results – rapidly growing fires



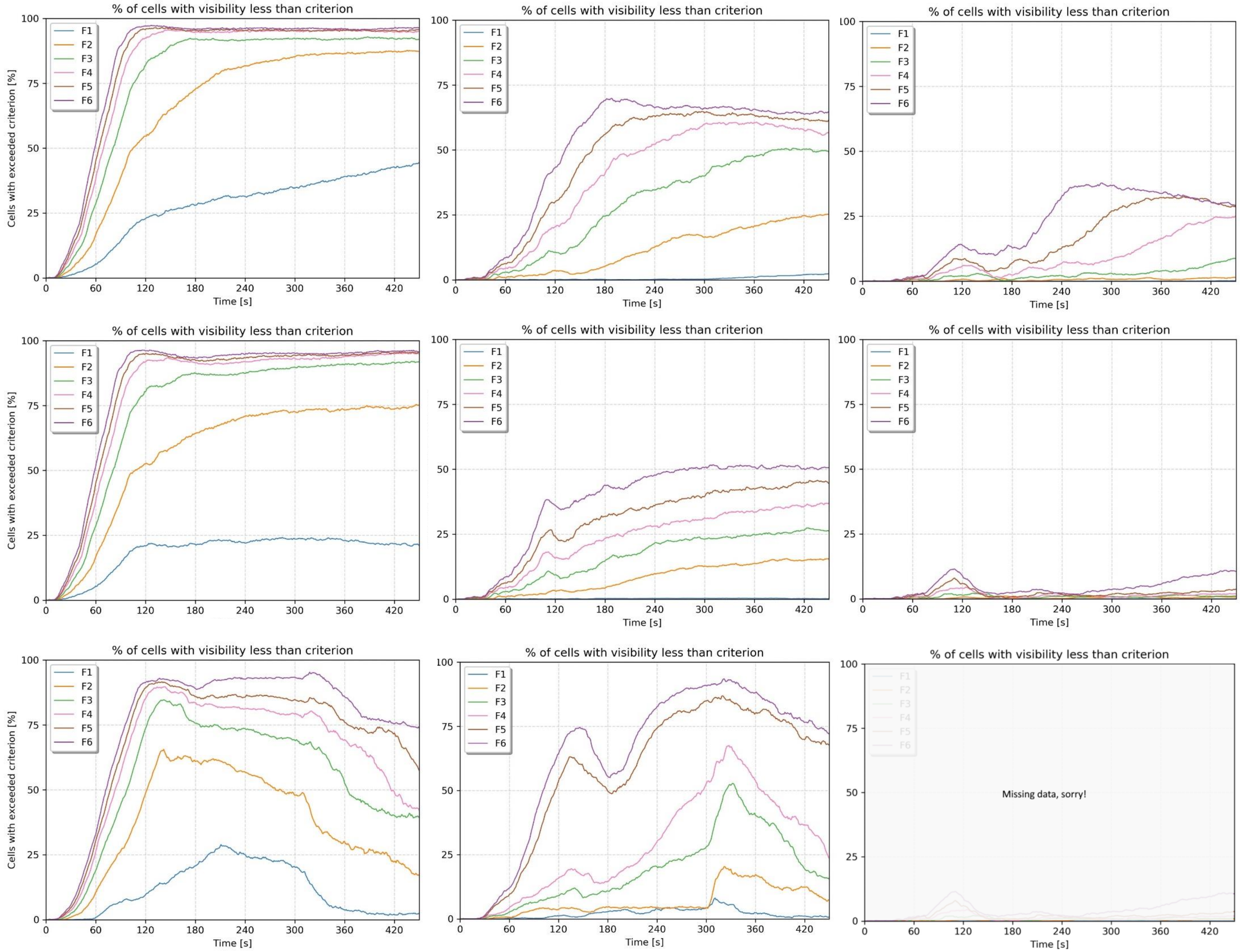
H = 240 cm H = 300 H = 360 cm

No vent, H = 2.70 m, t = 180 s

No vent

Ducts
(34 m³/s)

Jet-fans
(66 m³/s)



H = 240 cm

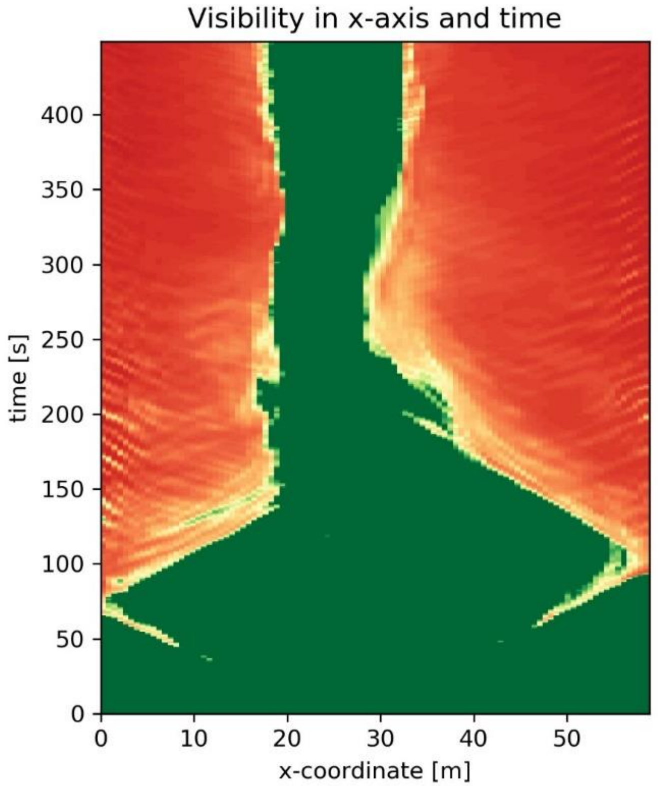
H = 300

H = 360 cm

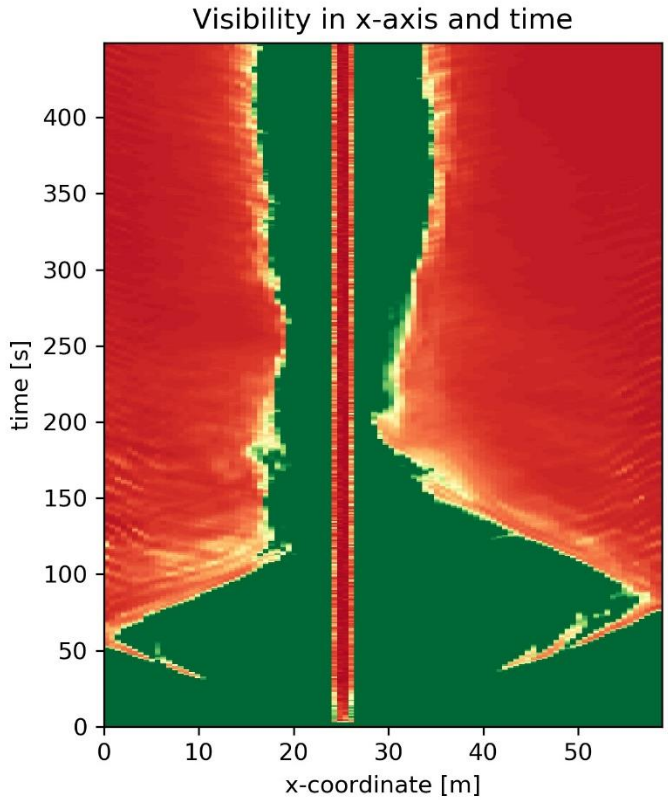
No vent, H = 2.70 m

results – rapidly growing fires

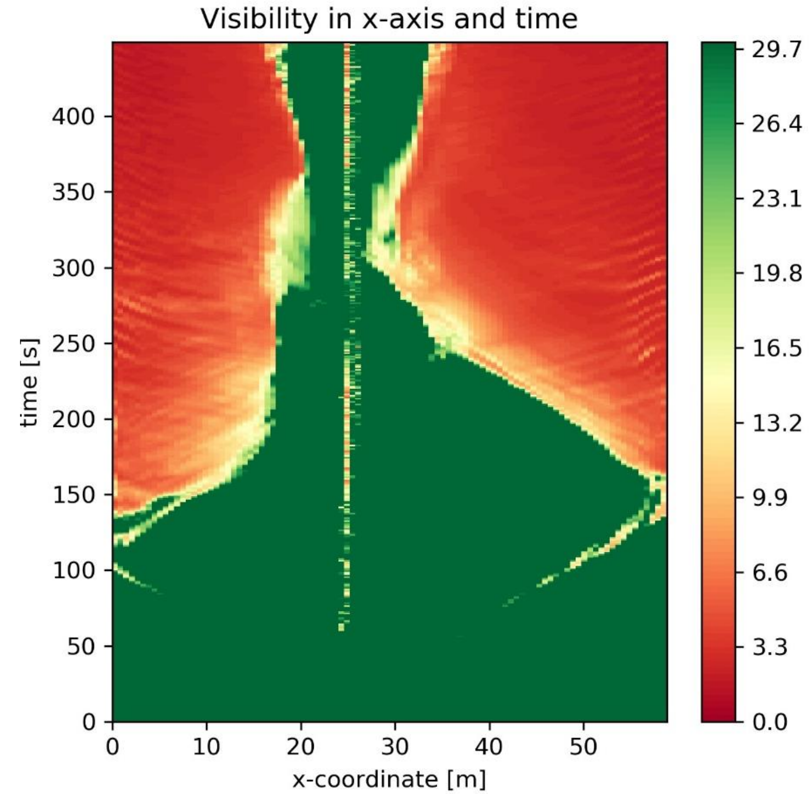
Car parks that were designed with CFD for ‘traditional’ design fires may have difficulties in providing sufficient time to evacuate in a rapidly growing fire scenario.



HRRmax = 750 kW



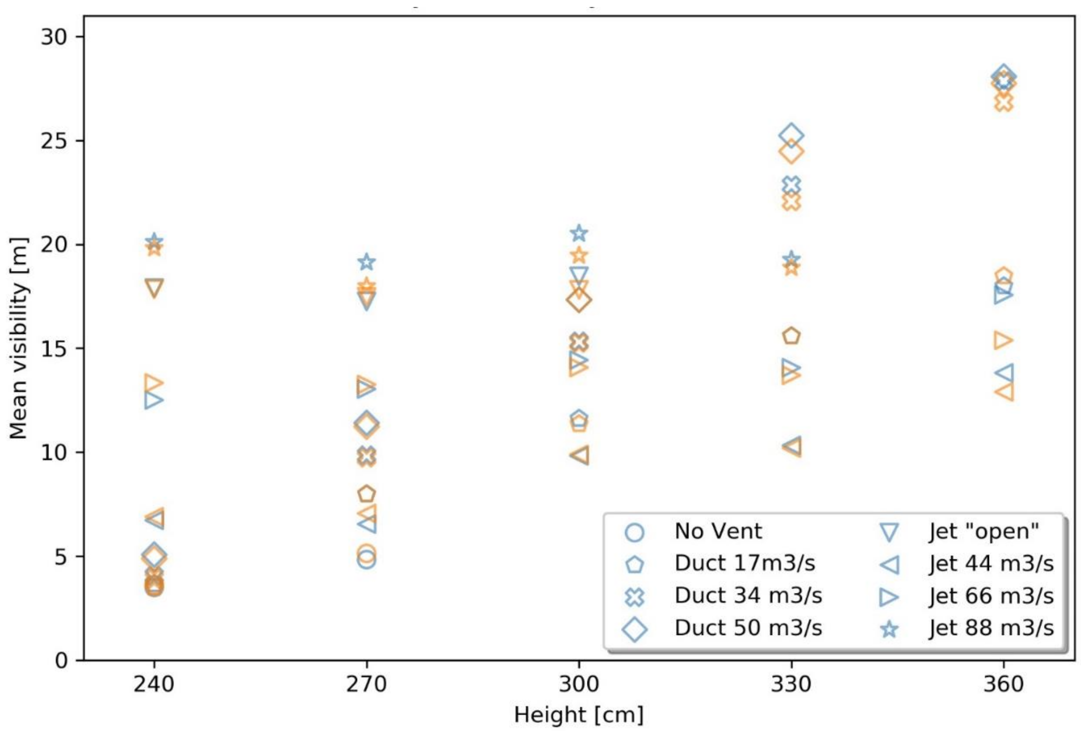
HRRmax = 1500 kW



TNO fire

No vent, H = 2.70 m

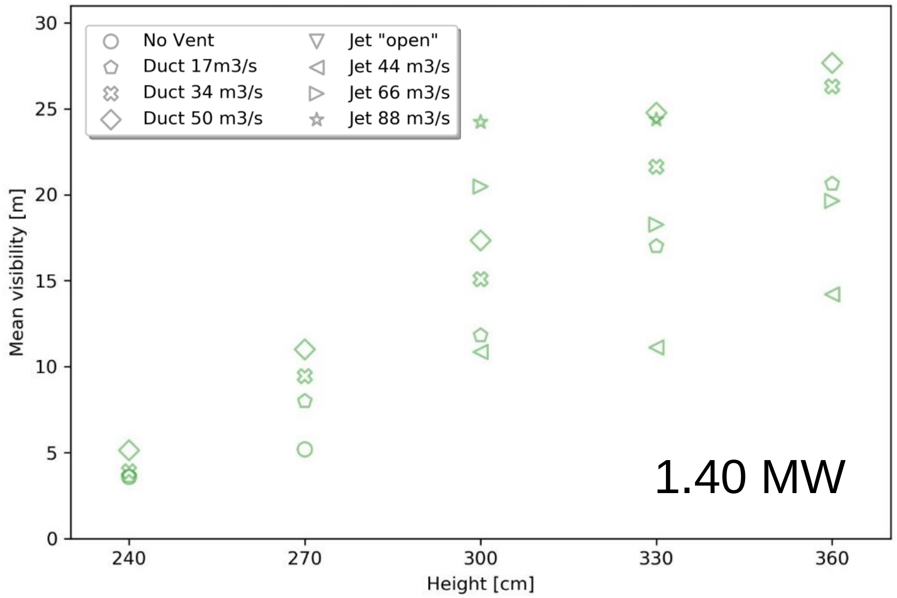
summary – growing fires

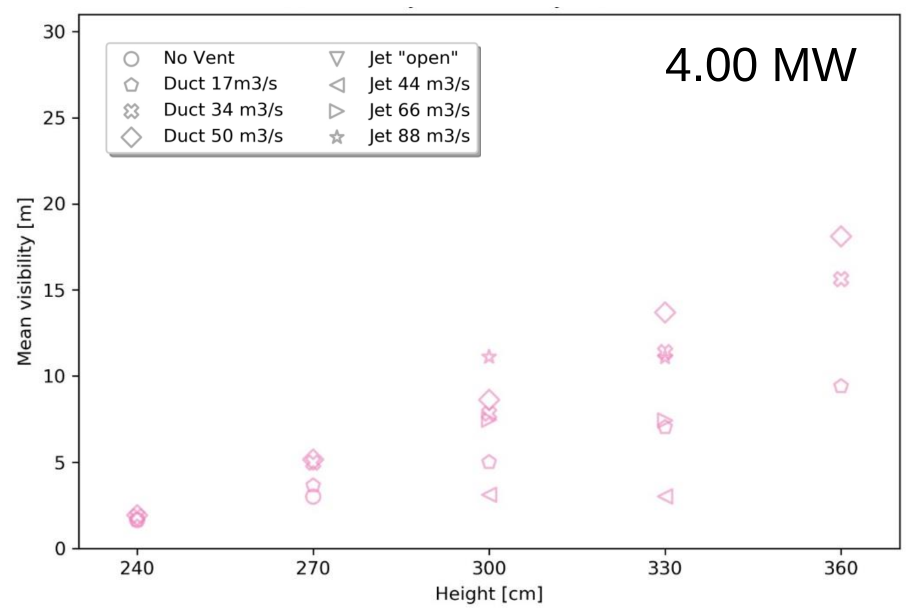


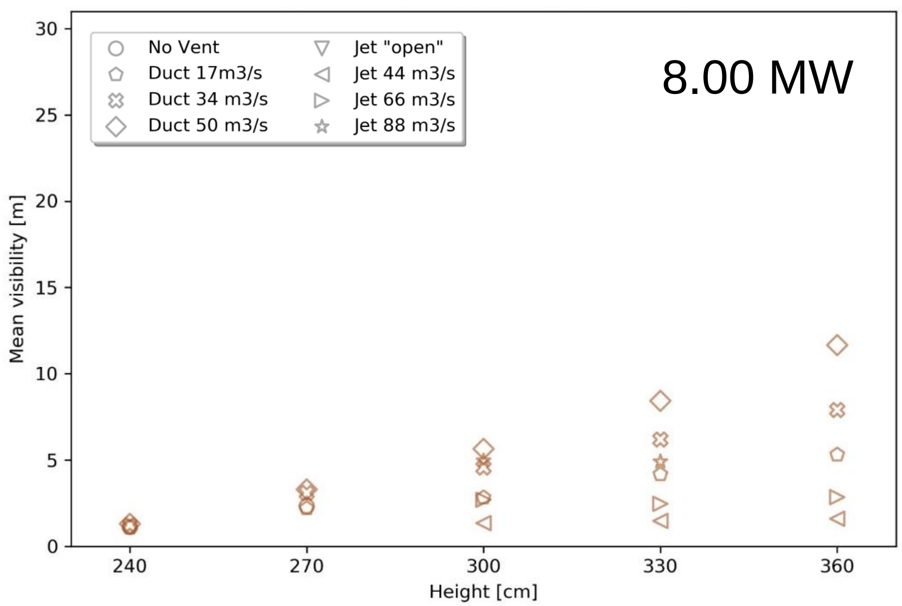
TNO fire and αt² fires

- No significant difference between linear and exponential growth of the design fire;
- Performance at 2.40 m is below expected, while at 3.60 m is generally very good;
- Prior to jet-fan activation in a sufficiently high car park the evacuation conditions are maintained without system operation
- Jet-fan systems lead to larger parts of car-park filled with smoke, but improve the 'approach' conditions for firefighters

summary – steady state fires

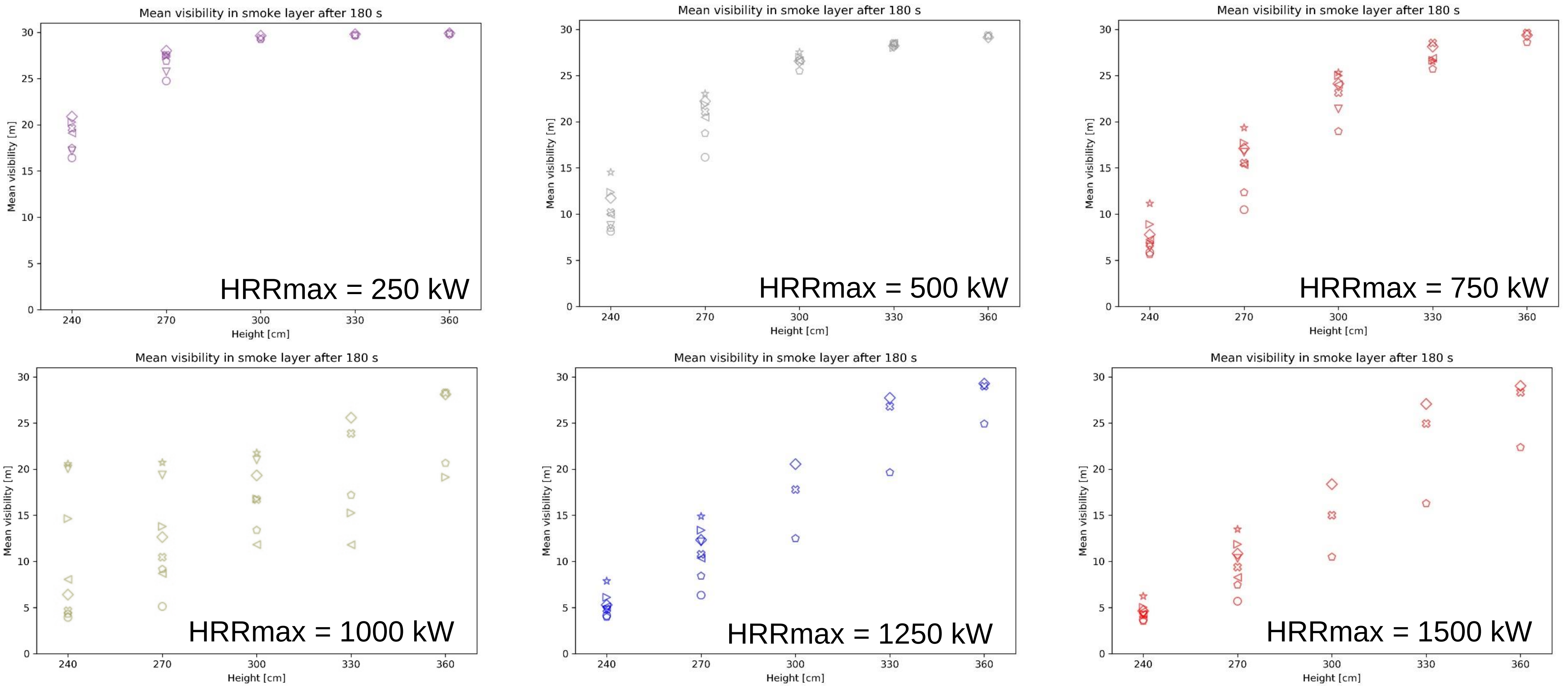






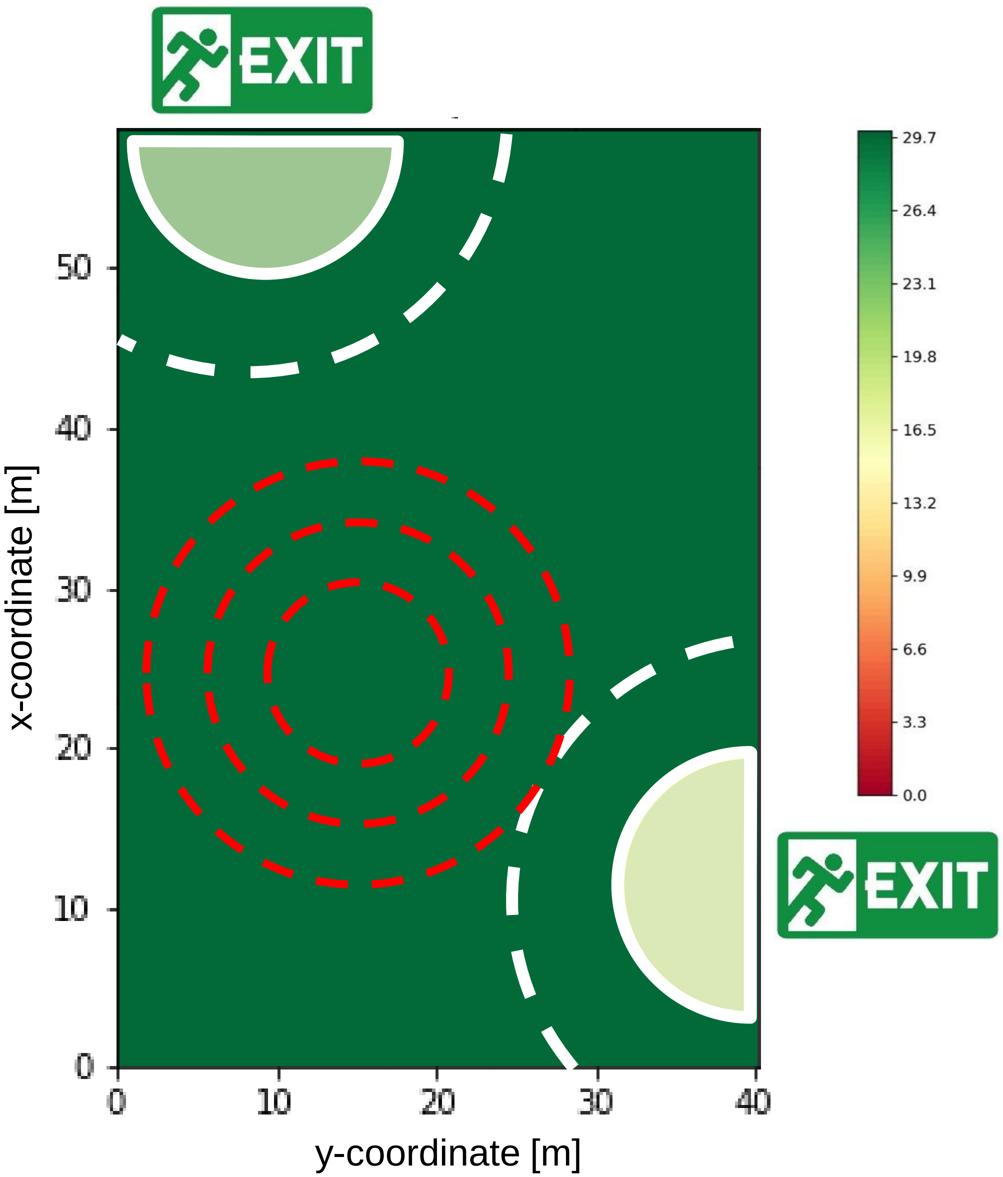
- Increase of the HRR significantly changes the outcomes, the change from 1.40 -> 4.00 MW had more impact than from 4.00 MW -> 8.00 MW;
- For large fires in low-height car parks it was not possible to provide smoke-free access for firefighters, no matter the type or capacity of the tested solution;

summary – rapid growth fires



- It is unknown which of the design fires is the best representation of an EV HRR, thus a range of fires was considered
- Rapidly growing fires up to 750 kW had similar consequences to commonly used TNO fire scenario (smoke toxicity was not considered)

future work – QoSC index



Quality of Smoke Control index:

- Automated 'what-if' analysis investigating multiple aspects of occupant safety and the access to the car park for rescue services
- Takes into account evacuation routes, entrance points etc.
- Evaluated based on multiple variables (eg. visibility, smoke temperature)
- Unbiased, based on global and local statistics in predefined areas of the car park
- Transient
- Pass-fail criteria easily defined with a 'threshold conditions matrix' input file

Thank you!

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