ACCEPTANCE CRITERIA IN FIRE SAFETY ENGINEERING: A REVIEW AND CASE STUDY

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Introduction

- Methods to verify safe egress
  - *Qualitative methods*
  - ***Scenario-based methods***
  - *Risk-based methods*
- Scenario-based methods
  - *ASET/RSET-analysis*
  - *Fractional effective dose (FED) concept*

- Traditional ASET/RSET analysis
  - *Simple (yet complex)*
  - *Fire model to find ASET*
    - evaluated against **absolute values**
  - *Evacuation software to find RSET*
- Fractional effective dose (FED) concept
  - *More common when evacuation through smoke*
  - *More complex method*
  - *Fire model (CFD) to calculate concentrations*
  - *Evacuation model to calculate dose*

Acceptance criteria for absolute values

- Defined in some building regulations
  - *Sweden*
  - *New Zealand*
- European initiative
  - *Still variation between countries*
- No uniform set of criteria in a global perspective

Criteria	Swedish building regulations[1] BBRAD 3	New Zealand Building Code[1] C/VM2
Smoke layer above floor level	Smoke layer > 1.6 + (ceiling height)*0.1 [m]	-
Visibility	Visibility > 10 m (spaces > 100 m^2)	Visibility[2] > 10 m (spaces > 100 m^2)
Visibility	Visibility > 5 m (spaces < 100 m^2 or spaces where queuing start early in the evacuation)	Visibility[2] > 5 m (spaces < 100 m^2)
Thermal radiation	Radiation < 2.5 kW/m^2 or a short-term radiation of < 10 kW/m^2 combined with a maximum energy dose of < 60 kJ/m^2 in excess of the energy from a radiation level of 1 kW/m^2	Requirements for radiation exposure along egress routes.
Temperature	Temperature < 80 °C	$FED_{thermal}$ criteria specified
Carbon monoxide toxicity	[CO] < 2000 ppm	FED_{CO} criteria specified
Carbon Dioxide toxicity	[CO_2] < 5%	-
Oxygen availability	[O_2] > 15%	-
FED	-	FED_{CO} < 0.3 $FED_{thermal}$ < 0.3[2]

Acceptance criteria for absolute values

- Simple to work with
- Low sensitivity to changes in the combustibles
- Generally well accepted

- Required inputs
  - *Fire size,*
  - *Growth rate,*
  - *CO yield,*
  - *CO_2 yield,*
  - *Soot yield*
  - *Heat of combustion*
  - …

FED tenability acceptance criteria

- Some design situations require alternative measures to assess the consequences of a certain fire scenario
  - *When exposed to smoke during longer durations*
  - *Road tunnels*
  - *Rail tunnels*
  - *Sprinklered buildings*
- It is common that the responsibility lies with the designer to asses:
  - *the methodology to use*
  - *Which asphyxiant (and/or irritant) gases to consider*
  - *acceptable accumulated dose to verify life safety against*

FED tenability acceptance criteria

- Common values
  - *FED<1.0*
    - 50 % of the population being susceptible
  - *FED<0.3*
    - 11 % of the population being susceptible

- Input yield data
  - *highly dependent on fire conditions*
  - *Difficult to find reliable information (seldom reported)*

Purpose and goals

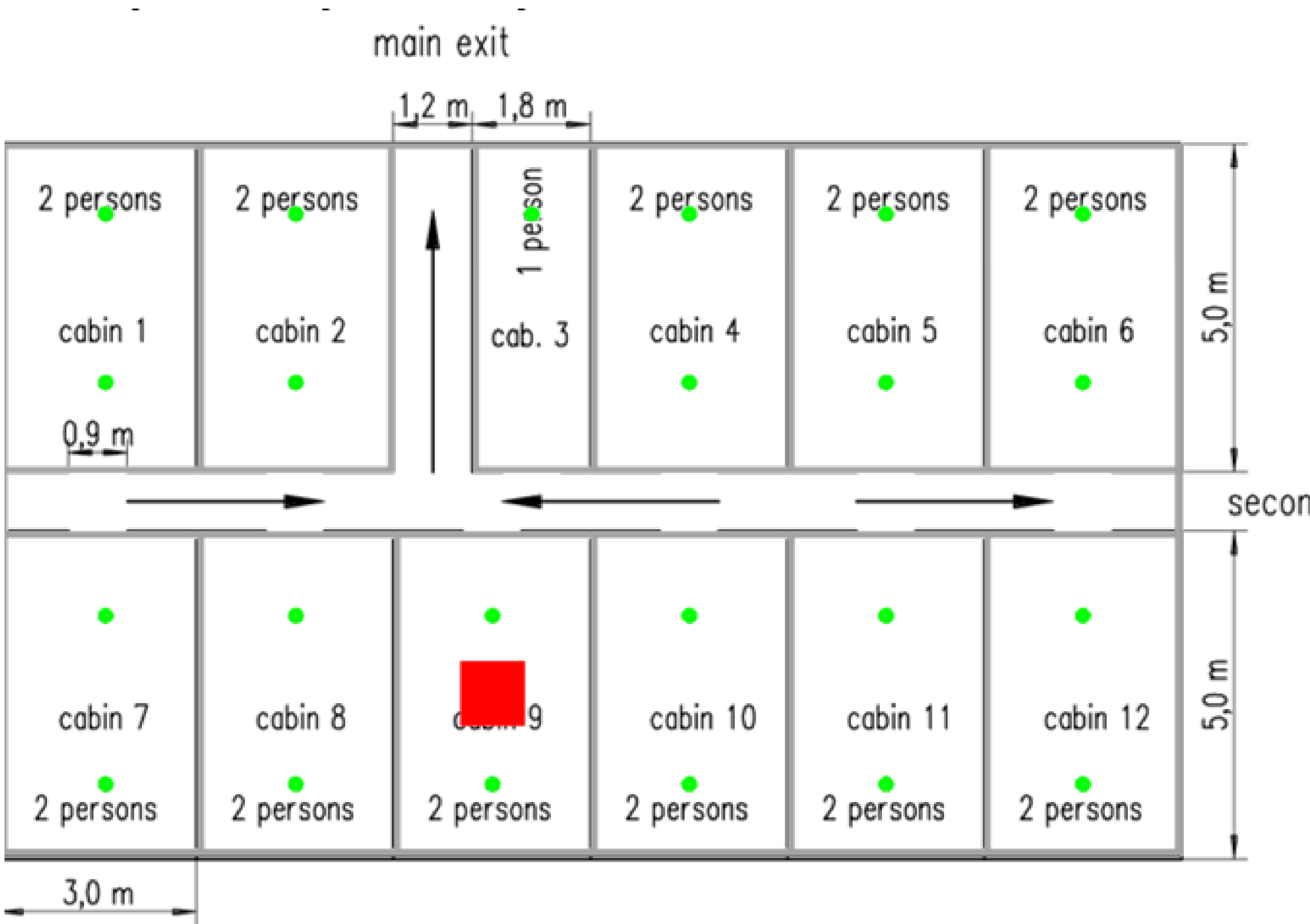
"Investigate the consequences of applying different methods and acceptance criteria to verify fire life safety."

Goals:

1. *How the fire safety outcome is affected by the method used (i.e. absolute values or FED).*
2. *How the fire safety outcome is affected by the acceptance criteria (e.g. different acceptance criteria for the same variable)*
3. *Address the challenges an engineer faces when working with alternative methods and acceptance criteria compared to traditional or regulated approaches.*

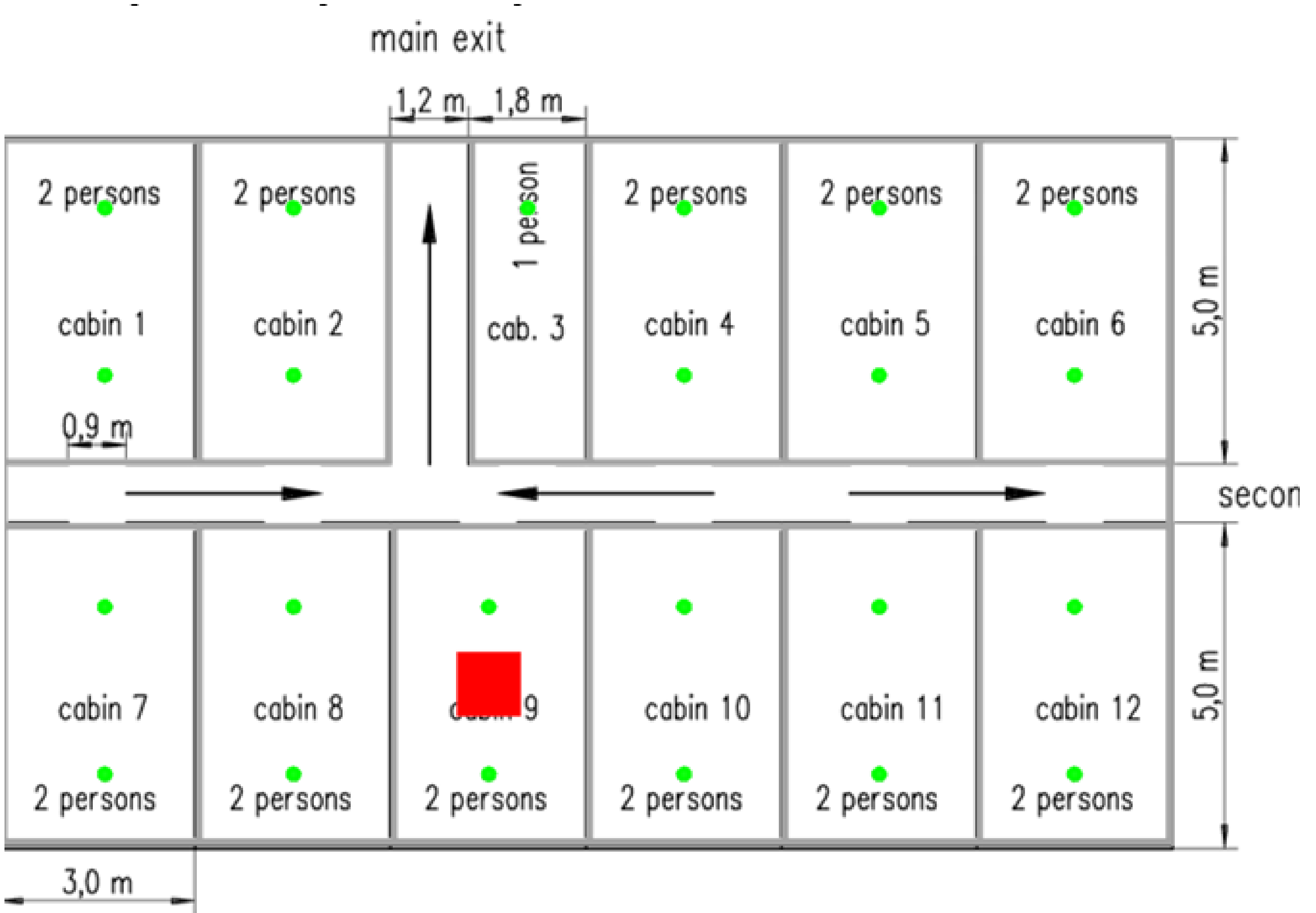
Case study: Geometry

- Simple geometry
  - *IMO test 10*
  - *Cabin arrangement on a passenger ship*
  - *12 cabins*
- People asleep
  - *No movement*
  - *23 occupants*



Case study: Geometry

- FDS 6.7.0
- Grid size 5 to 10 cm
- Room height 2.8 m
- Openings at exits
  - *Door width x 0.6 m*
- Fire source in Cabin #9
- Data recorded at 2 m height



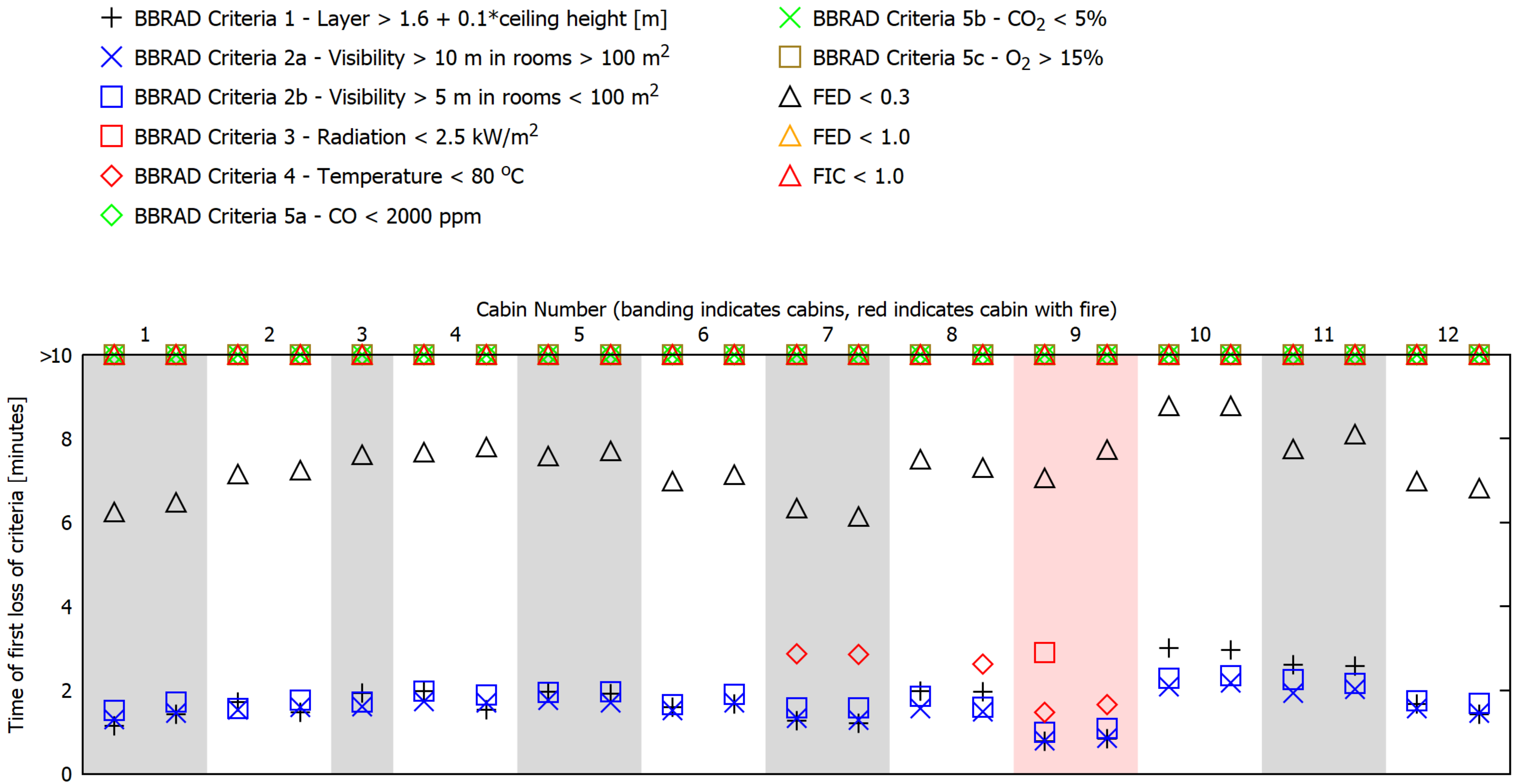
Yield	Units	BBRAD 3	NIST sofa‡
Peak fire size (no sprinklers)	MW	5	-*
Growth rate (t-squared)	kW/m^2	0.047	-*
Heat of combustion	MJ/kg	20	-*
Fraction of Hydrogen in soot	-	0.1†	0.1†
Yields (per gram of fuel consumed)			
Soot	[g/g]	0.1	-*
Carbon Dioxide (CO_2)	[g/g]	2.5	1.59
Carbon Monoxide (CO)	[g/g]	0.1	0.0144
Hydrogen Cyanide (HCN)	[g/g]	-	0.0035
Hydrogen Chloride (HCl)	[g/g]	-	0.018
Nitrogen Dioxide (NO_2)	[g/g]	-	0.07
Acrolein (C_3H_4O)	[g/g]	-	0.008
Formaldehyde (CH_2O)	[g/g]	-	0.02

Methodology: Two cases

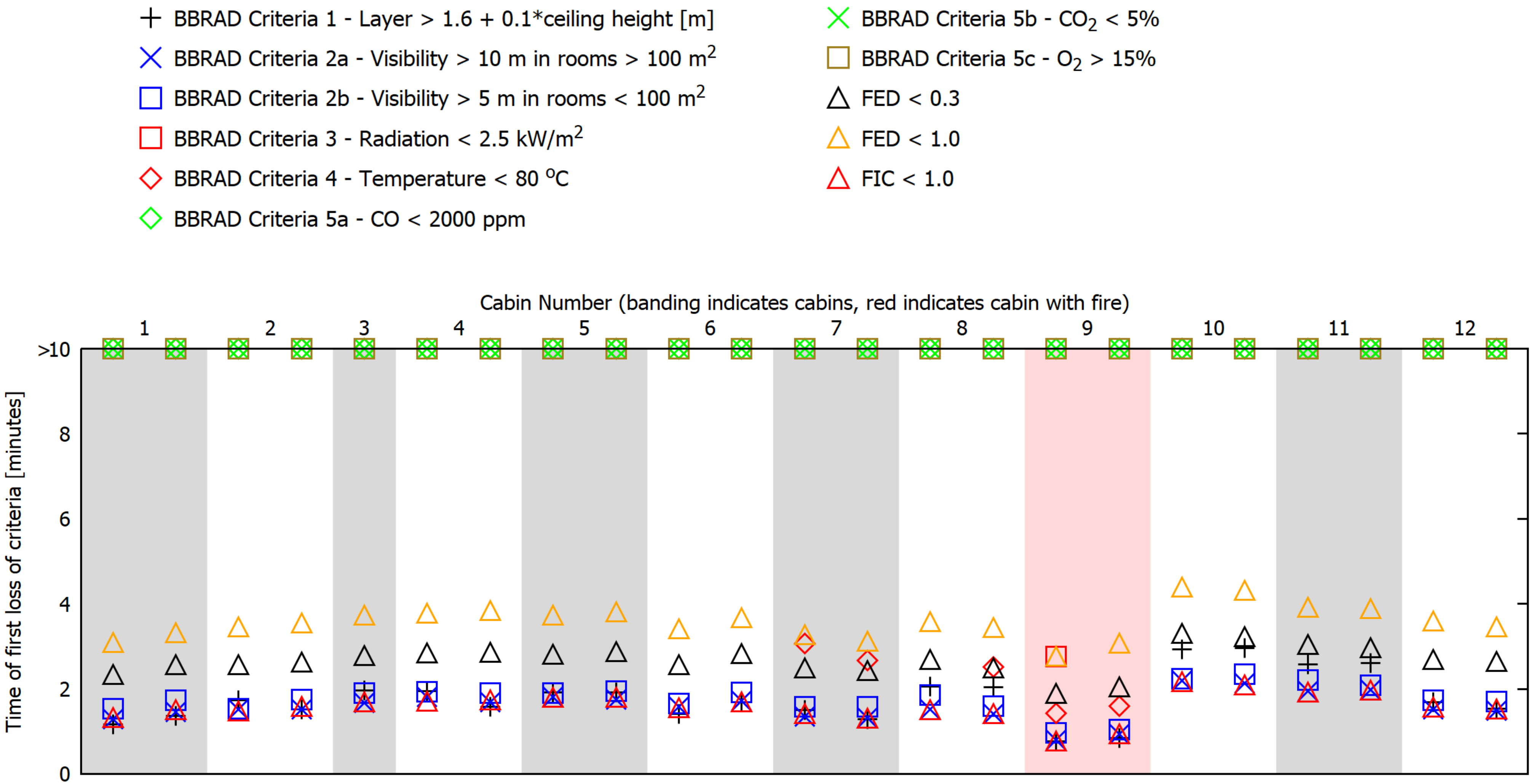
- BBRAD 3 case
  - *Well defined input data and acceptance criteria*
  - *CO, CO_2 and soot*
  - ***Simple chemistry***
    - Single mixing-controlled reaction
    - Fuel molecule contains only C, O, H, and N.
    - $C_{4.56}H_{6.56}O_{2.34}N_{0.4}$

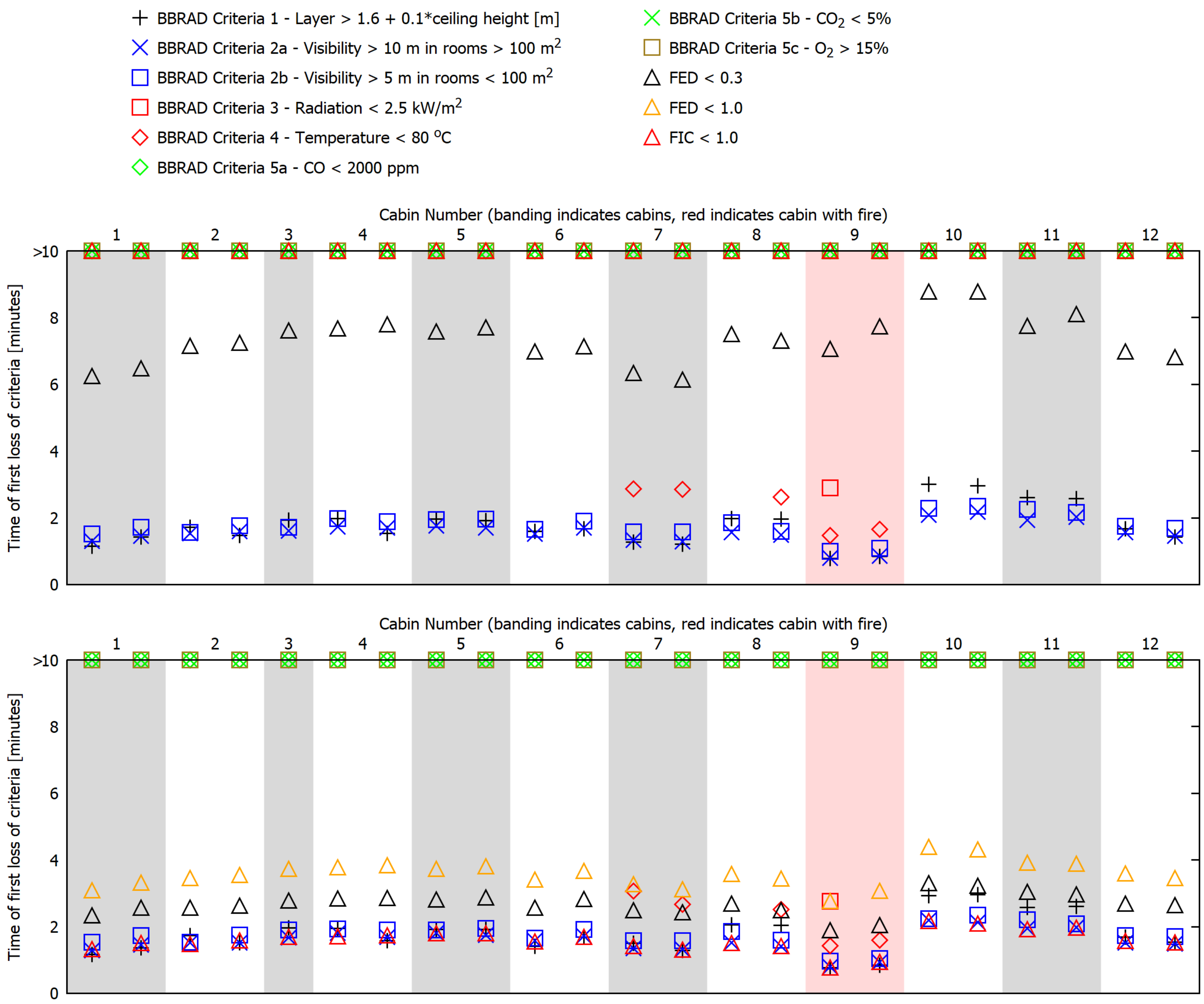
- NIST Sofa case
  - *HCN, HCl, NO_2, C_3H_4O and CH_2O also considered*
  - ***Complex chemistry***
    - Additional species were lumped in the model
    - The volume fractions calculated from the stoichiometric coefficients of the primitive species

Results: BBRAD 3 case



Results: NIST Sofa case





BBRAD Criteria 1 - Layer > 1.6 + 0.1*ceiling height [m]
BBRAD Criteria 2a - Visibility > 10 m in rooms > 100 m2
BBRAD Criteria 2b - Visibility > 5 m in rooms < 100 m2
BBRAD Criteria 3 - Radiation < 2.5 kW/m2
BBRAD Criteria 4 - Temperature < 80 oC
BBRAD Criteria 5a - CO < 2000 ppm
BBRAD Criteria 5b - CO2 < 5%
BBRAD Criteria 5c - O2 > 15%
FED < 0.3
FED < 1.0
FIC < 1.0
Cabin Number (banding indicates cabins, red indicates cabin with fire)
Time of first loss of criteria [minutes]
>10
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Time of first loss of criteria [minutes]
>10

Discussion: How the fire safety outcome is affected by the method used?

- Using FED as a criteria will allow for longer ASET compared to using absolute tenability criteria
  - *Impaired visibility is the tenability criteria first exceeded*
  - *Takes 4-8 times longer for FED to exceed 0.3 (without additional species)*
- As more species were added
  - *FIC<1 matches the visibility criteria*
  - *Less difference between FED<0.3 and visibility*
  - *The “simple model” became a good indicator of ASET*

Discussion: How the fire safety outcome is affected by the acceptance criteria ?

- The tenability criteria for visibility (both 5 and 10 m) and layer height is exceeded roughly at the same time
  - *Two-zone model?*
  - *Different layer height criteria would most likely have little influence on the results*
- Difficult to estimate in the BBRAD case since FIC<1 and FED<1 were not exceeded
- With additional species
  - *FIC<1 was first exceeded*
  - *FED<0.3 approx. one minute later*
  - *FED<1 approx. one minute after FED<0.3*

Discussion: The challenges an engineer face

- Applying absolute tenability criteria to a case is pretty straight-forward
  - *Mandated input data and acceptance criteria reduce the risk of not getting approval*
- Using FED concepts is more difficult
  - *No uniform agreement on acceptance criteria*
  - *No uniform agreement on which species to add*
  - *Difficult to find reliable data (a big part of this study)*
  - *Complex chemistry might introduce a greater risk of user-error*
- The tools (FDS) can handle the complexity
- Evacuation models need to account for reduced walking speed in smoke

Thank you!

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