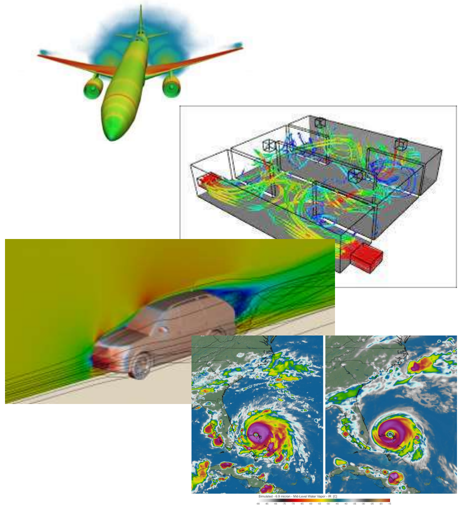
Content of presentation

- CFD
  - General
  - Fire protection
  - Water mist and sprinkler systems

- Example project
  - Using CFD to analyse the impact of forced ventilation for sprinkler and water mist systemsConclusions

CFD

- Computational Fluid Dynamics:
  - Fluid dynamics that uses numerical analysis to solve problems
  - Methodology
    - Varies depending on the different discretization methods
    - Varies depending on the different turbulence models
  - Typical codes used in fire protection:
    - FDS, Openfoam, (Fluent / Star etc.)
- CFD is used:
  - Fluid dynamics
  - Aviation / aerodynamics
  - Automobile industry
  - Weather forecast
  - Heat & combustion in engines
  - Marine applications
  - HVAC



Benefits of CFD in fire protection

- Produce data without destroying anything
- Cost saving compared to fire tests
- Possibility to optimise the fire safety concept easily
  - Playing with extreme scenarios
- Standardised tool e.g. for ventilation design

Challenges of CFD in fire protection

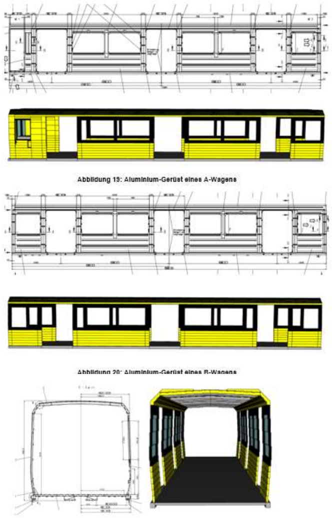
- CFD is based on complex physics, which requires knowledge from the user
  - Heat transfer (in gas, liquid and solid phase)
  - Radiation
  - Mass transport
  - Fluid dynamics
  - Multi phase flows
  - Chemical reactions
  - Phase changes (vaporisation, condensation, melting, …)

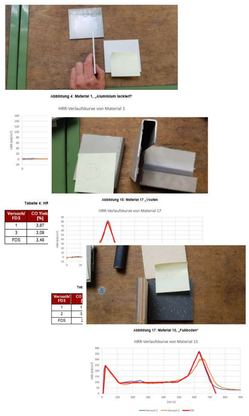
- Validation requires experimental data

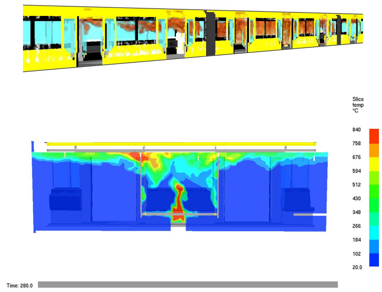
Challenges of CFD in fire protection

- Scale differences
  - Small scale effects (e.g. turbulence, combustion) in large scale applications (e.g. buildings, even forests)
- High variation of velocities, especially with water mist systems or jet fires
- Simulation times often very long (compared to simulated time steps)
- High computational costs

Example – Using CFD for defining design fire curve







Example – Using CFD for defining design fire curve

- Full scale experiments are very costly!

CFD and water mist systems

IFAB

- Water mist is modelled by lagrangian particles:
  - A number of representative droplets is simulated individually
  - Each particle has its own:
    - Velocity
    - Temperature
    - Dimension
    - Mass
- Water droplets can interact with gas and solid phase

CFD and water mist/sprinkler systems

IFAB

- „Easy“ applications (simple validation data):
  - Comparing investigation with single parameter change
  - Geometrical changes
  - Spray patterns in interaction with ventilation
  - Activation of glass bulbs
- „Medium“ applications (requires more validation data):
  - Temperature and smoke distribution
  - Influence to humans (visibility, toxicity)
- „Difficult“ applications (lot of validation data required):
  - Fire spread simulation
  - Combustion (=> Extremely difficult)

Example case

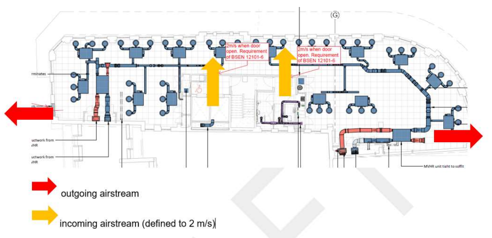
IFAB

- There was a question how forced ventilation potentially influences the efficiency of sprinkler or water mist system (generic question).
- Scenario was including door(s) that were left open from pressurised stair case.
  - Conservative scenario:
    - It is unlikely that fire doors would be blocked open.
    - It is unlikely that there would be fire load stored directly in front of door.
    - It is unlikely that both fire doors would be blocked open same time
- Application:
  - Ordinary hazard 1 (tested without ventilation)

Example case

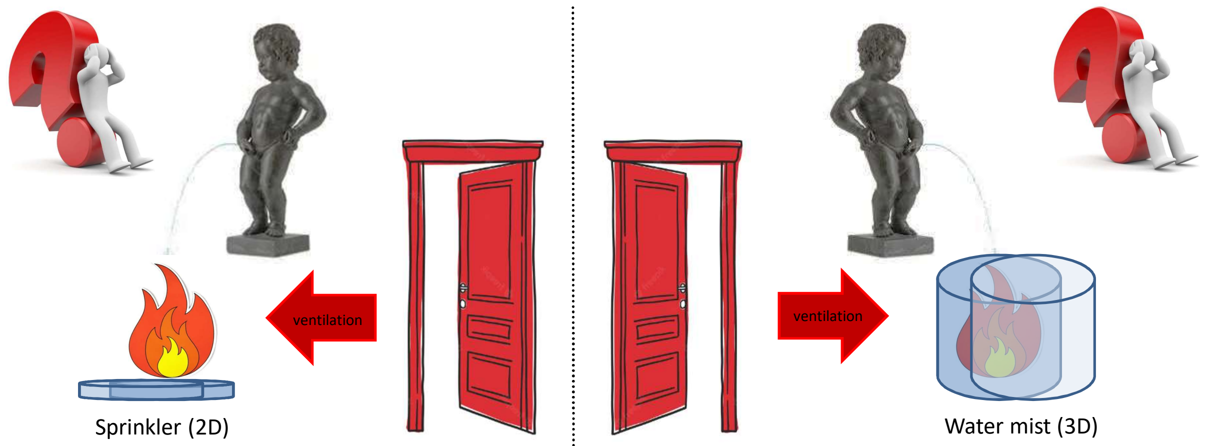
IFAB

- Detailed research questions made:
  - What would be the impact for both water mist and sprinkler system?
    - Sprinkler works 2-dimensional whereas water mist system is 3-dimensional.
  - Is the water mist as efficient as the sprinkler under same conditions (influence of ventilation)?



Example case

- Illustration of research question

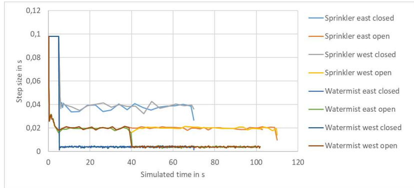


Example case

- Methodology:
  - Modeling the geometry and ventilation conditions (FDS)
  - Modeling sprinkler and water mist system - 2D (FDS)
  - Modeling water mist system – 3D (FDS)
  - Postprocessing data (Python)
  - Evaluation of water distribution in different areas under influence of ventilation
  - Reporting

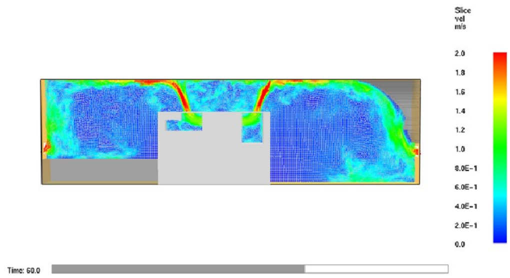
Example case

- Tools:
  - Fire Dynamics Simulator, version 6.7.6
    - Grid size: 5x5x5cm / 10x10x10cm, 1…4 million cells
    - Water mist / sprinkler system characteristics
      - Based on experimental data from right water mist nozzle
      - Data library (FDS) used for sprinkler
  - Python version 3.9

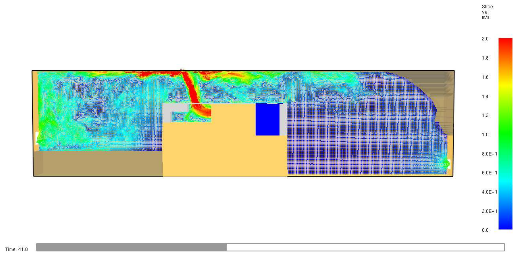


$$F(d) = \begin{cases} \frac{1}{\sqrt{2\pi}} \int_0^d \frac{1}{\sigma d'} e^{-\frac{[\ln(d'/d_m)]^2}{2\sigma^2}} \mathrm{d}d' & (d \leq d_m) \\ 1 - e^{-0.693\left(\frac{d}{d_m}\right)^\gamma} & (d_m < d) \end{cases}$$

Example case



- Both doors are open

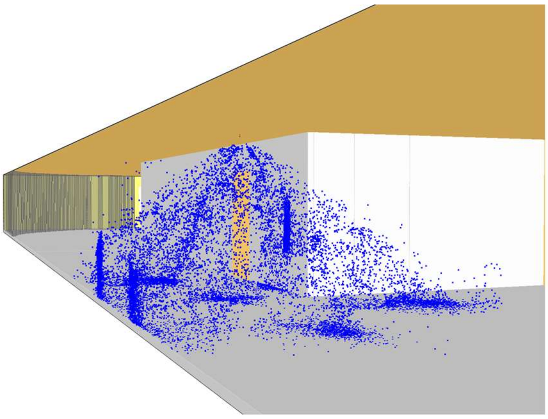


- One door closed

Example case

IFAB

- Mist nozzle spray pattern example
- Blue droplets are Lagrangian particles
- Particles were removed when an obstacle was hit



Example case – 2D

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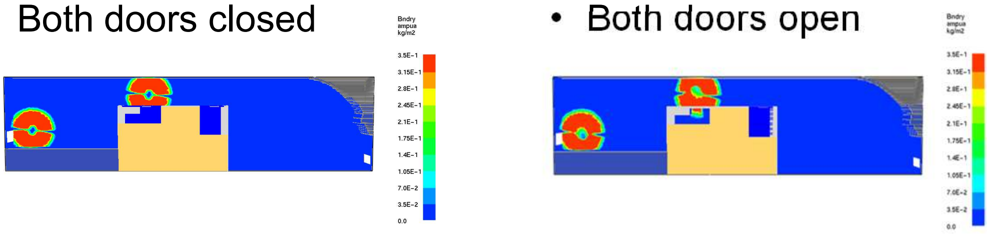
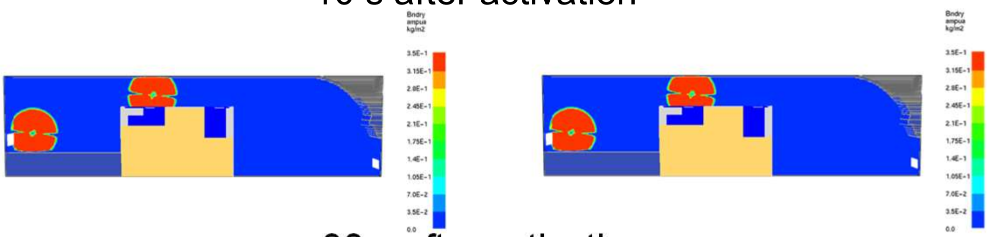
- Both doors closed
- Both doors open



10 s after activation

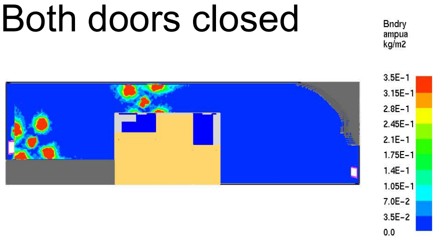


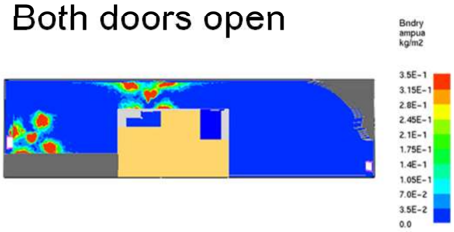
30 s after activation

Example case – 2D

IFAB

- Both doors closed
- Both doors open





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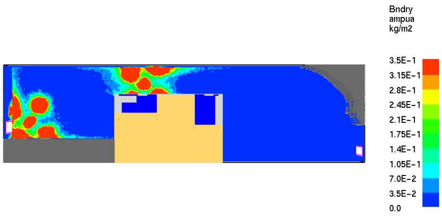
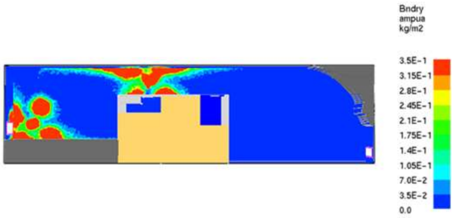




30 s after activation

Example case – AMPUA

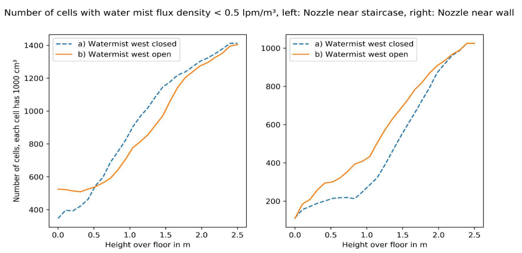
IFAB

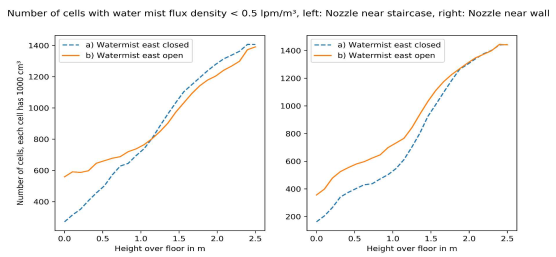
- AMPUA: Accumulated mass per unit area
  - How much kg of water hits every position at the floor in the given time?
- When only AMPUA is used for an assessment, the water mist is more affected than sprinkler
- Taking account of water mist charasteristics, the flux density based assessment had to be done for mist system as well.

Example case – Density

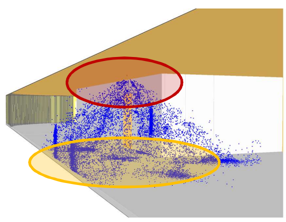
- Another Python script was written for comparison of the scenarios
- Every nozzle was assessed with a cylindrical volume of having 2.4 m radius.
- The threshold value for the sufficient cooling / density was taken from fire tests:
  - 0.5 lpm/m³ mean flux density was the threshold value for analysis
  - Parameters used for evalution
    - θ -> Fraction of cells with > 0.5 lpm/m³ (this could have been also some other value)
    - μ -> Mean value of the flux density over all cells (most relevant for assessing the perfomance)

Example case – Density

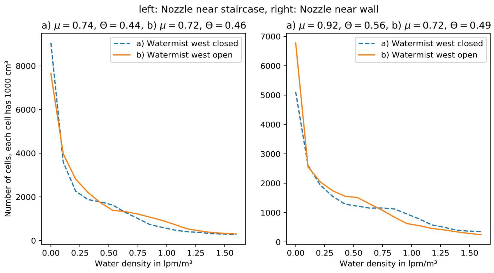


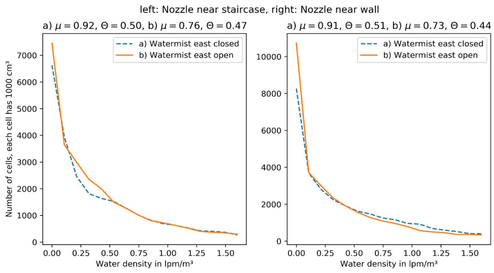


- Most of the cells less than threshold value are in upper part of volume
  - Shape of nozzle spray pattern
  - Mainly small/light droplets
- Ventilation was mainly influencing the lower height (close to floor level)

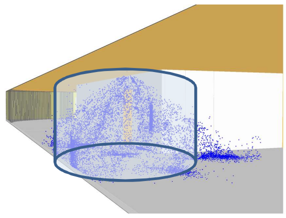


Example case – Density





- When complete volume is compared the mean flux density is most important.
  - Fraction of cells less than threshold is comparable
- The mean density value for complete volme is significantly larger than threshold
  - Nozzle is installed to lower level than tested in fire tests



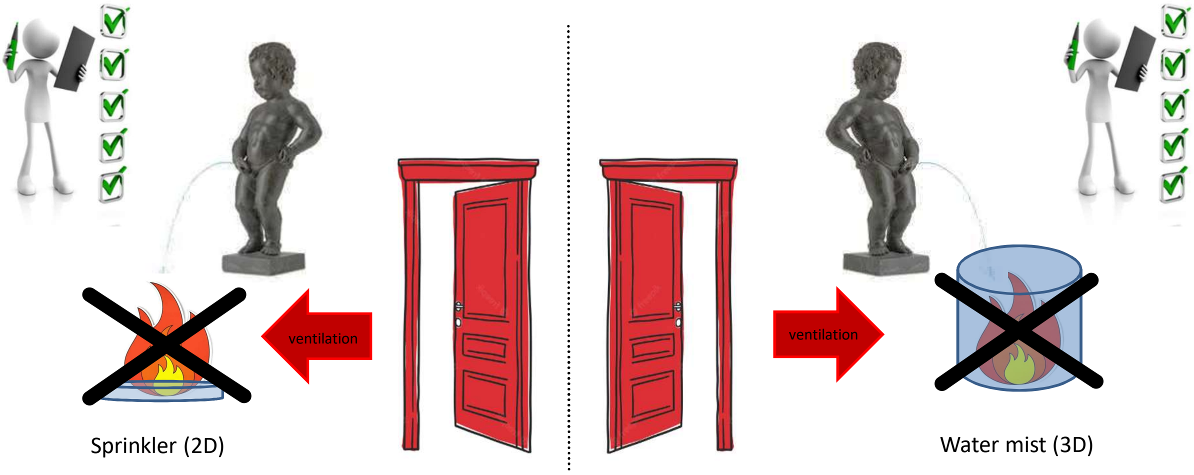
Example case - results

- Sprinkler system was less affected by ventilation system and this could be verified only using surface based method (AMPUA)
  - Conclusion: Impact of ventilation is minor to the perfomance
- Water mist system needs especially flux density based evaluation:
  - Post processing showed which heights are most affected under the nozzle (relevant for information only)
  - Most important is to look mean value and total fraction of cells less than given threshold (relevant for reseach question)
  - Conclusion: Impact of ventilation can be clearly seen with water mist system, but flux density is still much higher than threshold value (tested in fire tests). So impact of ventilation is minor to the performance.

Example case

IFAB

- Answer to research question (fire is out)



Conclusions

IFAB

- CFD is accepted design tool in various application fields in other industries.
- CFD is also used in fire protection industry, especially in special application like ventilation design.
- Using CFD with water based fire fighting systems is still challenging, especially related to the combustion modeling.
- CFD can well be used for the assessment of secondary effects like output of fire (heat & smoke) especially to interpolation of the results to different geometries.
- The <u>user competence</u> is normally most limiting factor using CFD

Conclusions

- CFD was used to show the impact of forced ventilation (worst case scenario) to nozzles nearby.
  - Extremely unlikely scenario but valid for research
- Using AMPUA (2D) sprinkler system was less affected by ventilation.
- Using flux density (3D) is more relevant for evaluation ventilation impact on water mist system.
  - Mean flux density showed that same performance is same or better than tested in fire tests.
  - Additionally water distribution under nozzle could be evaluated with different parameters.
- Both systems can be considered performing in given unlikely conditions.
  - Ceiling height is critical paremeter, especially for water mist system.

THANK YOU! (Q&A)