Photometric measurement of visibility in case of fire

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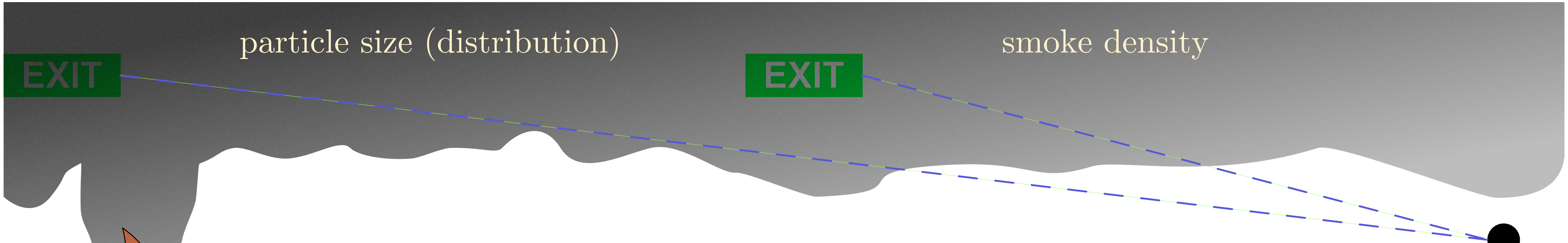
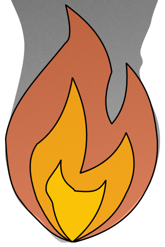
Offen im Denken
JÜLICH Forschungszentrum

Overview

1. What is visibility?
2. Parameters affecting visibility
3. LEDSA - A photometric approach for measuring visibility
4. Uncertainties of the measurement method
5. Conclusion and Outlook

What is visibility?



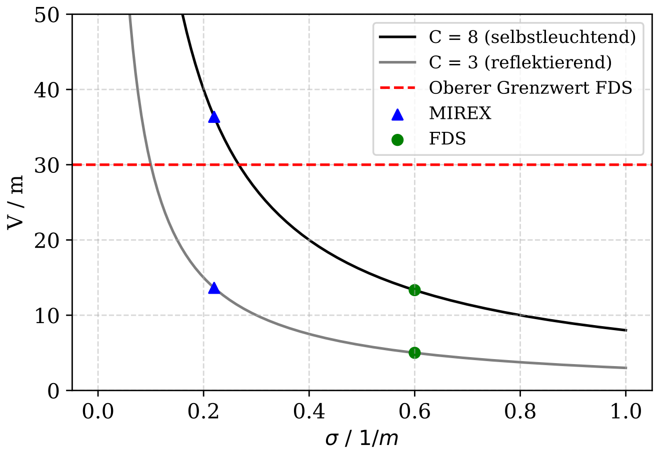


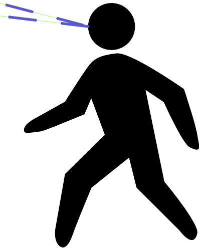
A simplification of Jin's law allows **local** prediction of visibility with CFD models: $V = \dfrac{C}{\sigma}$

where:

C: Non-dimensional constant, depending on viewed object [-]; C = 8 for light emitting sign, C = 3 for self reflecting sign

σ: Extinction coefficient [1/m]





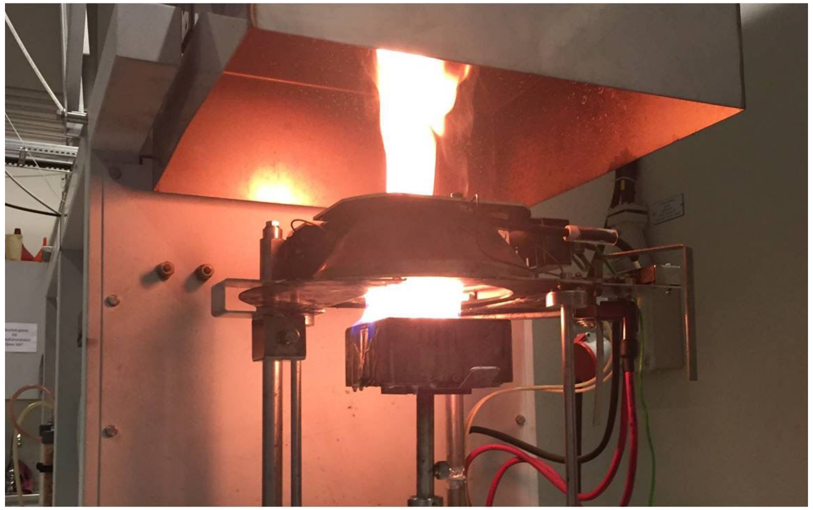
Overview

Parameters affecting visibility

- Visibility is a major tenability criterion in performance-based safety concepts
- Light transmission T depends on mass specific extinction coefficient K_m, smoke density $\rho \cdot Y_s$ and the path length of light Δs

$$T = \frac{I}{I_0} = exp(-\tau) \qquad \tau = \underbrace{K_m \cdot \rho \cdot Y_s}_{\sigma} \cdot \Delta_s = \sigma \cdot \Delta_s$$

- K_m and Y_s usually determined by small-scale optical measurements (e.g., with a cone calorimeter) and may not be valid for modelling large-scale fires by CFD models
- Sparse data of spatial and temporal resolved extinction coefficients available



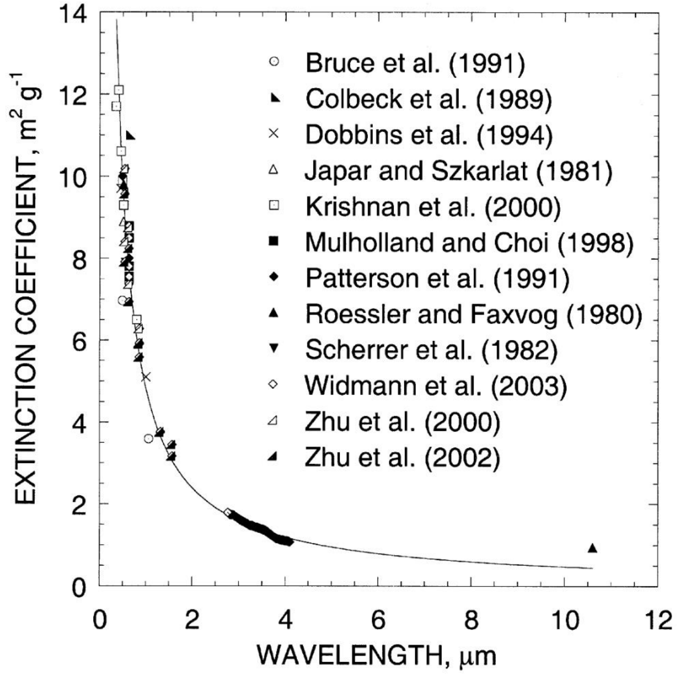
Mass specific extinction coefficient

- Mullholland and Croarkin: Evaluation of seven experiments with 29 different fuels shows almost uniform mass specific extinction coefficient of $K_m = 8700\ \mathrm{m^2/kg}$ for measurements at $\lambda = 633\ \mathrm{nm}$ for well ventilated fires without smoldering and pyrolysis

- Widmann: correlation of λ and K_m

$$K_m = 4.8081\lambda^{-1.0088}$$

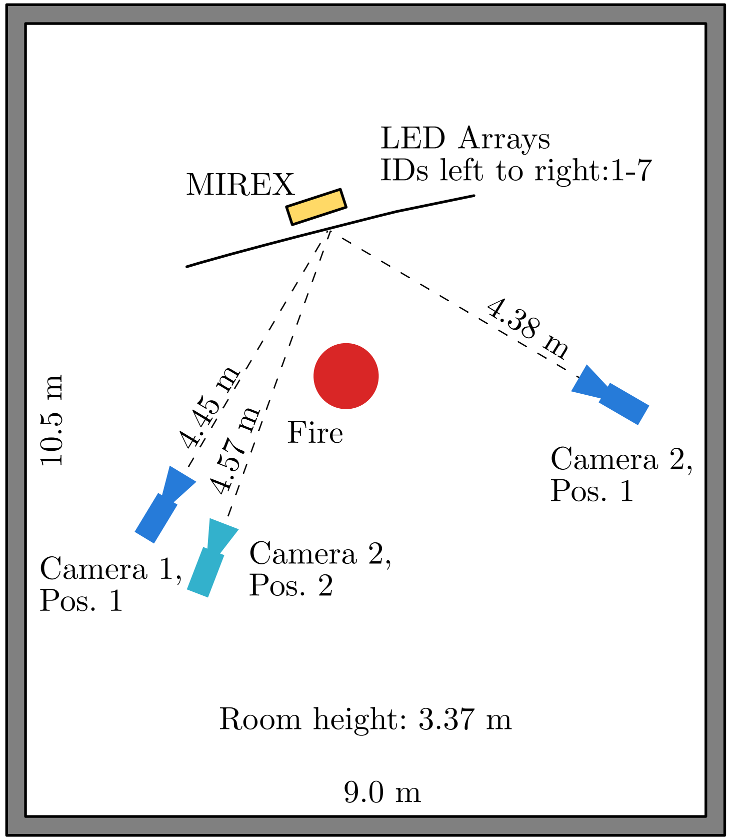
($K_m = 7175\ m^2/kg$ at $\lambda = 633\ \mathrm{nm}$)

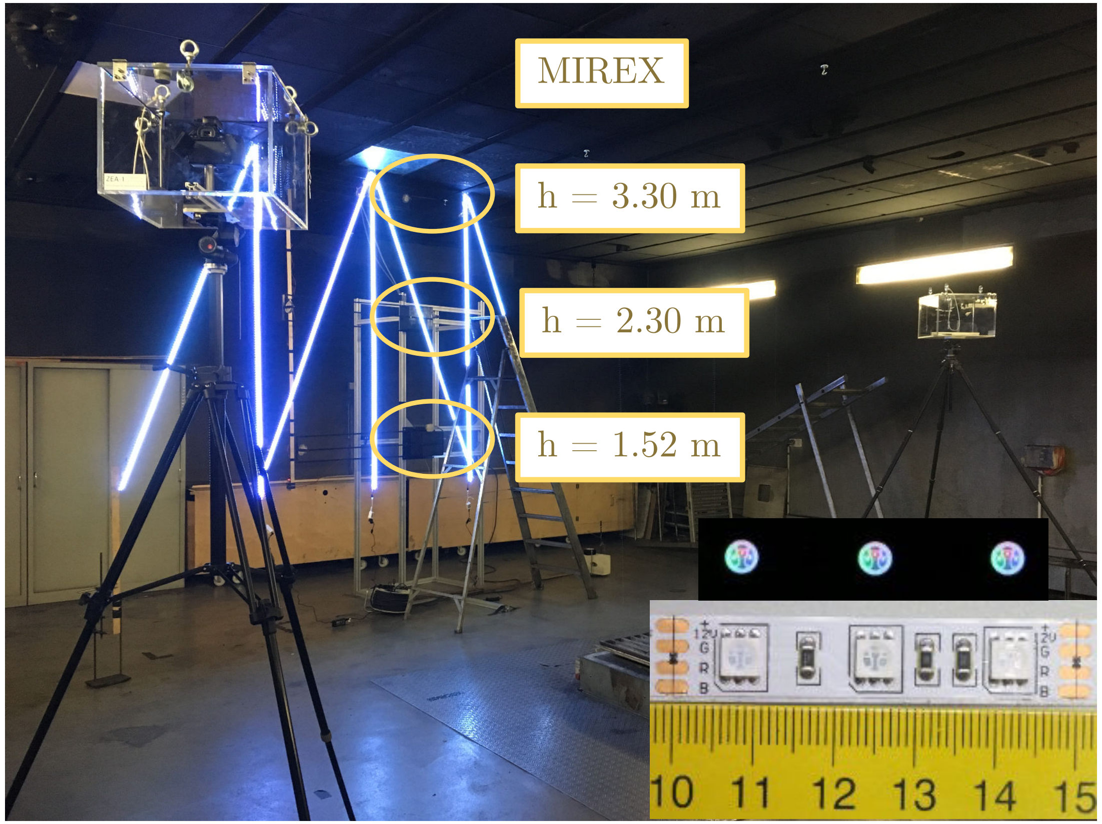


Widmann, Evaluation of the planck mean absorbtion coefficient for radiaton transport through smoke, 2003

Overview

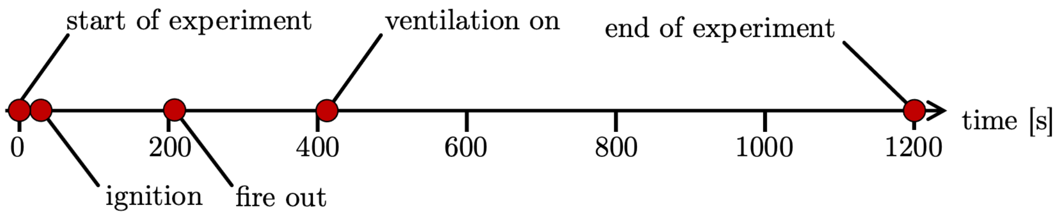
Experimental setup

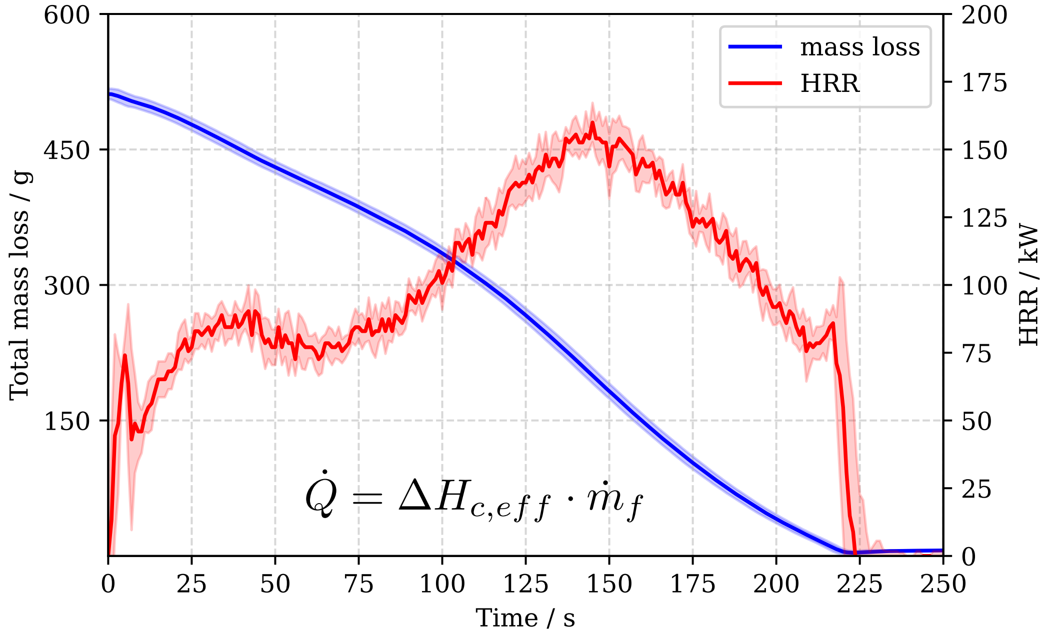




Test fire TF 5 / EN 54

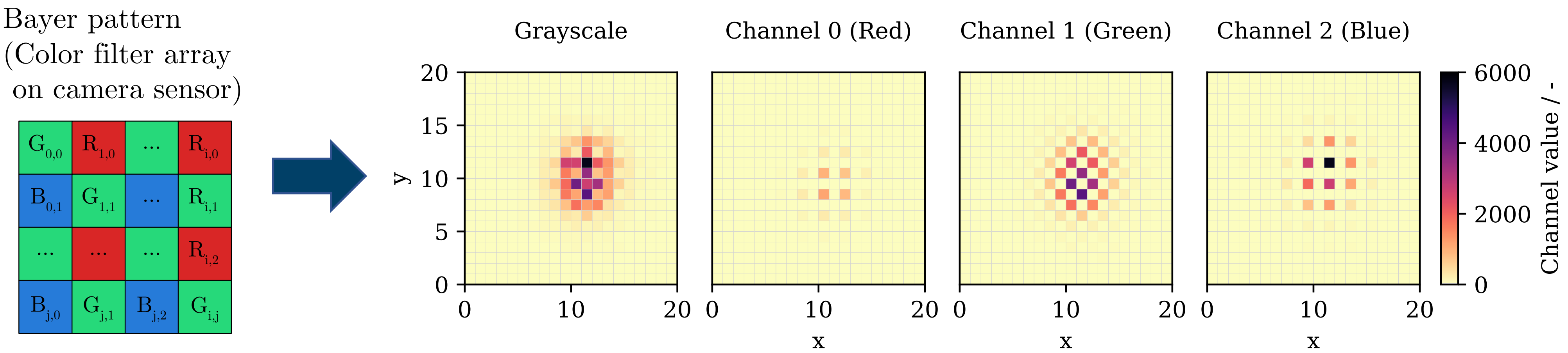
- Test series of six experiments in total with identical boundary conditions
- Fuel: 500g n-heptane
- HRR measured by mass loss rate
- Images captured at 1 Hz





Determination of the light transmission

- LED Intensities measured as integral value of a 20 x 20 pixel array



- Raw sensor data is scaled by black level B and saturation point W to tonal range b

$$P(x,y) = (P'(x,y) - B) \cdot \frac{2^{b-1}}{W-B} \qquad I_{e,c} = \sum_{all\ pixels\ i,j} P_c(i,j)$$

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Layer model

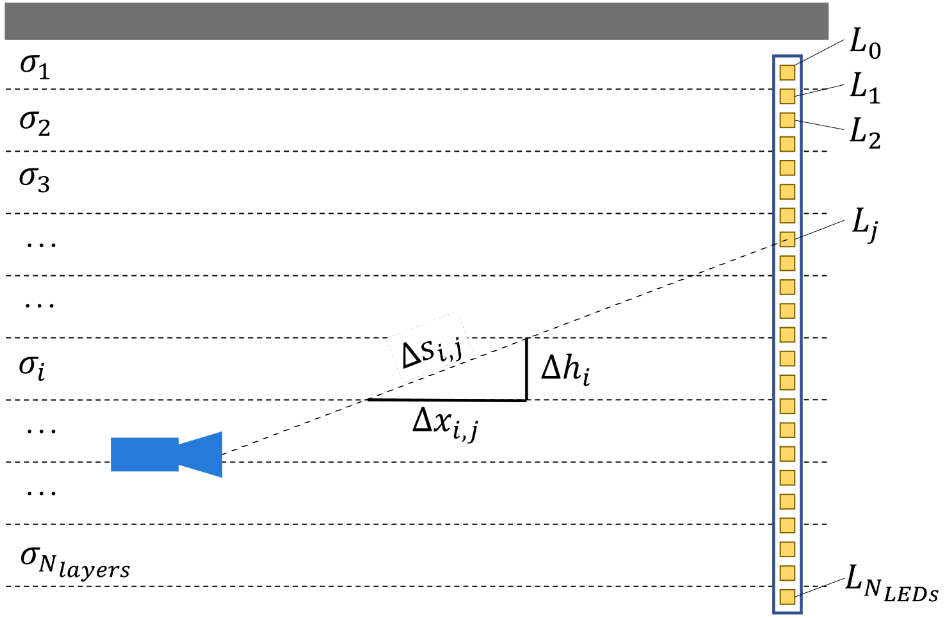
- Modeled Intensities $I_{m,j}$ can be described as:

$$I_{m,j} = \exp\left(-\sum_{i=1}^{N_{\text{Layers}}} \sigma_i \Delta s_{i,j}\right)$$

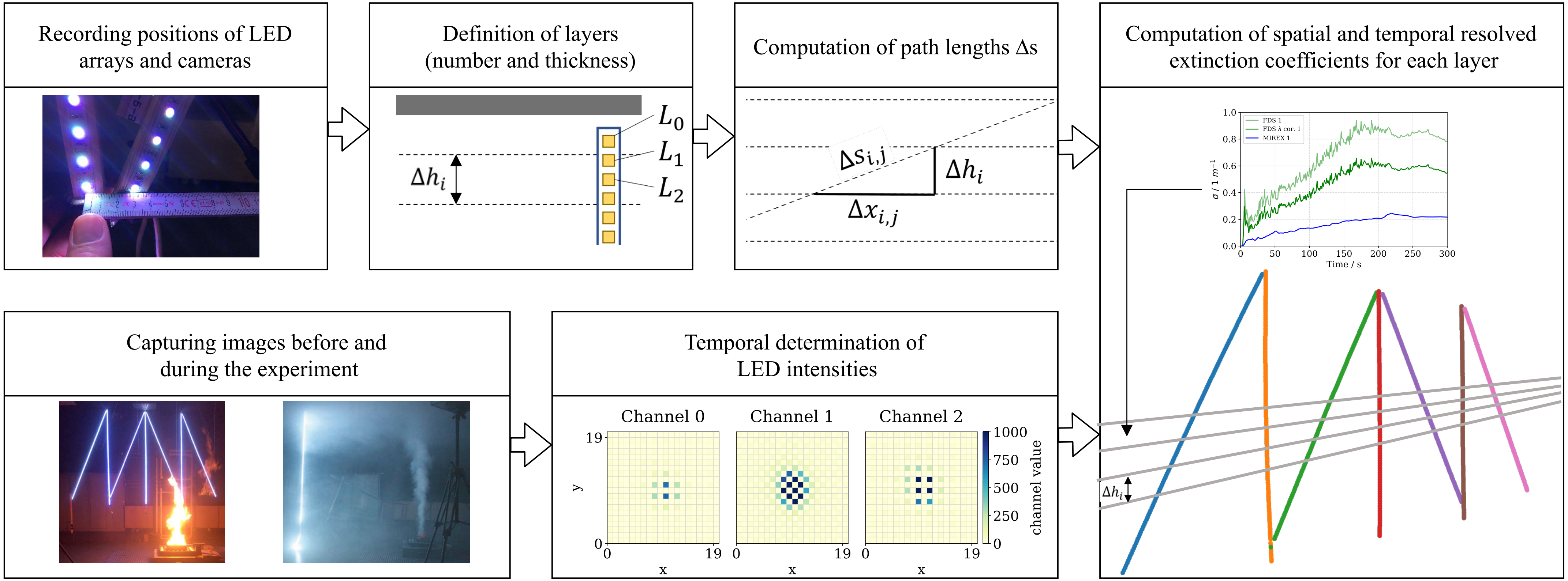
- Cost function to find extinction coefficients σ_i that match the experimental intensities $I_{e,j}$

$$\Omega_\sigma = \sum_{j=i}^{N_{\text{LEDs}}} \left(I_{m,j} - I_{e,j}\right)^2 + \phi_s \sum_{j=2}^{N_{\text{layers}}-1} \left(\sigma_{i-1} - 2\sigma_i + \sigma_{i+1}\right) + \phi_a \sum_{i=1}^{N_{\text{layers}}} \sigma_i$$

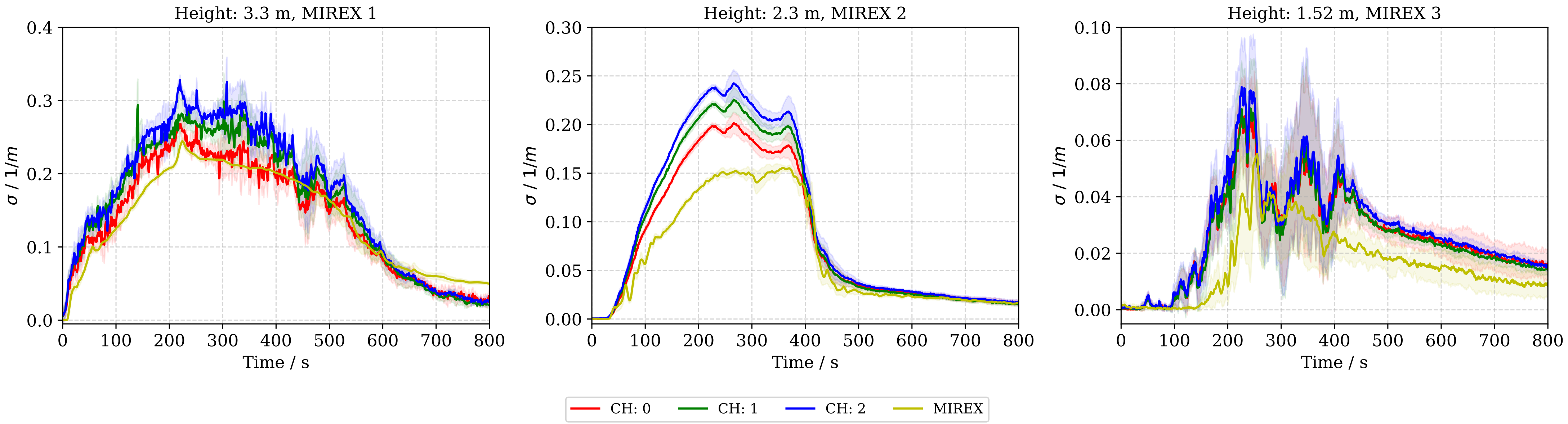
- Two weighting factors consider the smoothness of the solution (ϕ_s) and whether to process low or high values for the extinction coefficient (ϕ_a)



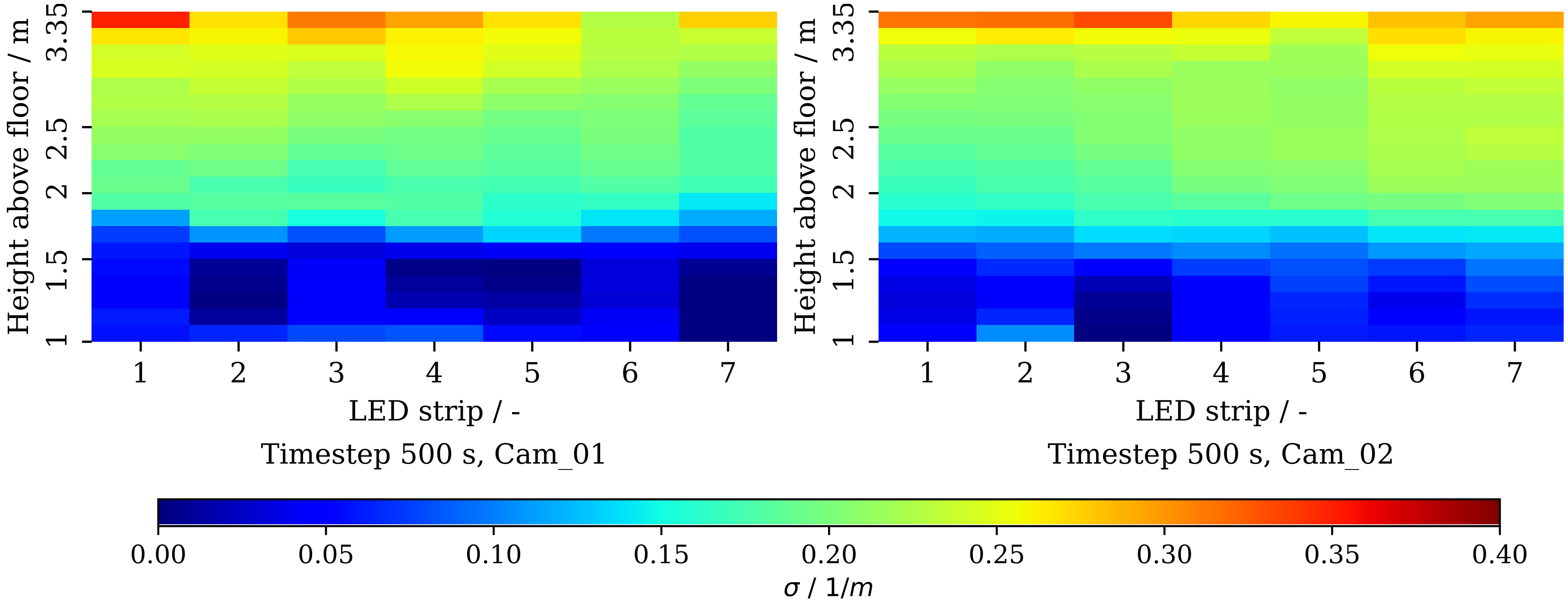
Evaluation steps



Experimental reproducibility



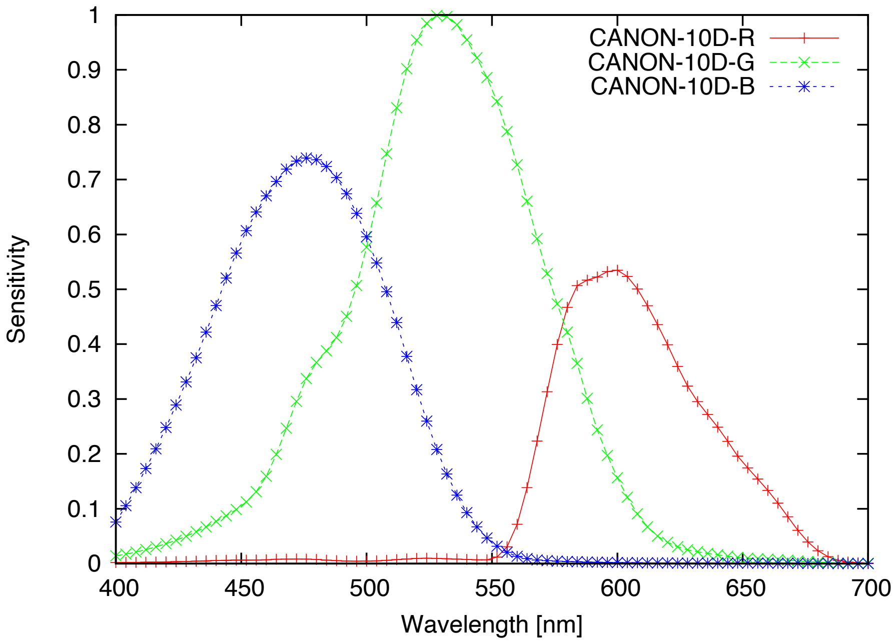
Extinction coefficient per time and layer



Overview

Camera spectral response

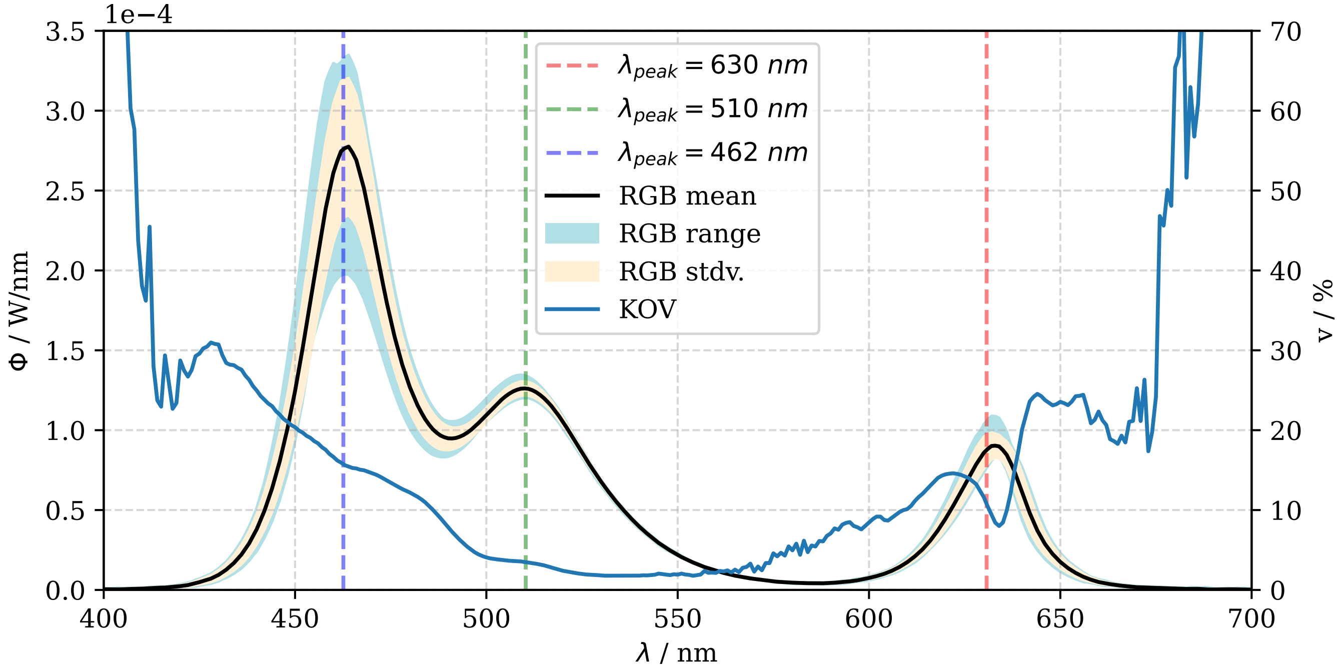
- Response spectrum of the camera has a high bandwidth and does not match the emitted spectrum of the LEDs
- Light from the LEDs is detected in different channels of the camera and therefore falsifies the measurement



https://nae-lab.org/~rei/research/cs/zhao/database.html,

Uncertainties of the intrinsic LED parameters

- Parallel measurement of RGB LEDs reveals high uncertainty (eleven LEDs, three repetitions)
- Relative standard deviation (KOV) significantly higher for blue and red than for green LEDs
- Corrupting influence on adjacent color channels is hard to quantify



Estimation of the temperature-related errors

- Influences from temperature may weaken emitted LED intensities to fraction α

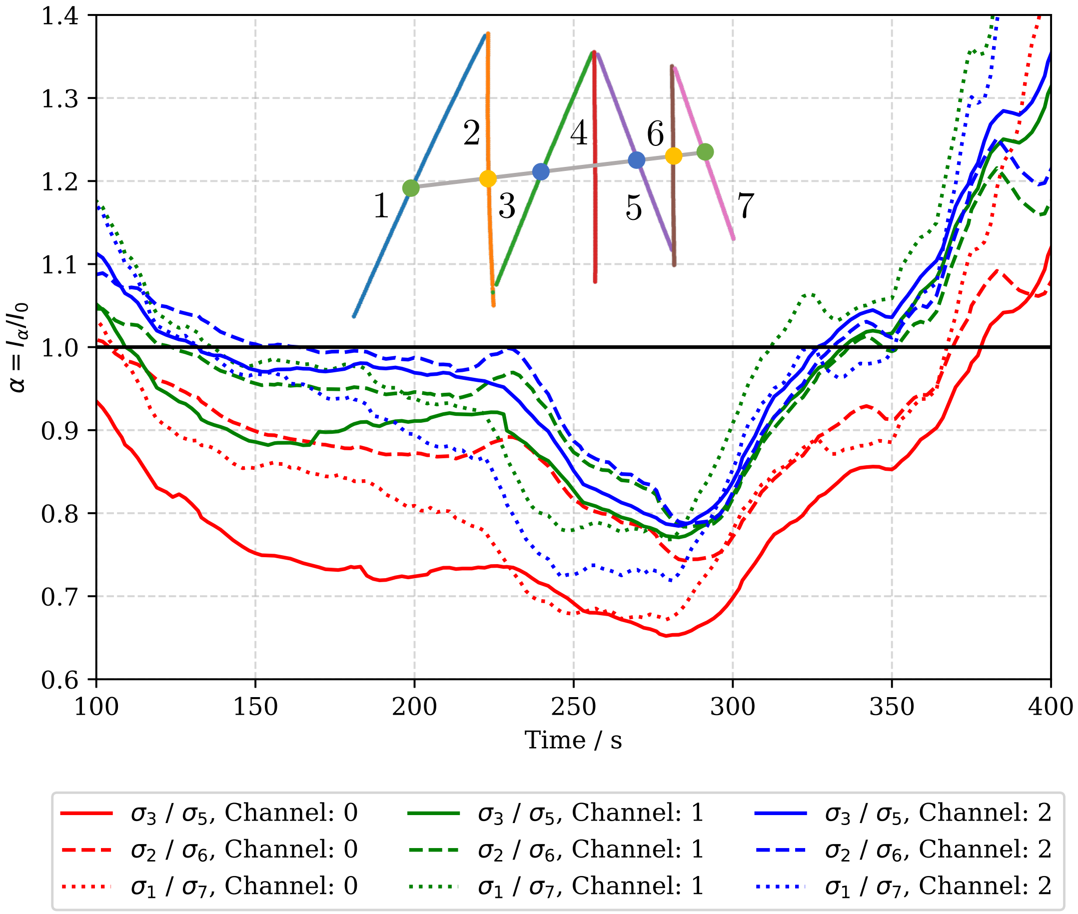
$$I_\alpha = exp(-\sigma_r \cdot l) \cdot I_0 \cdot \alpha$$

- The modelled extinction coefficients may be corrupted depending on pathlength l and α

$$\sigma_m = \sigma_r - \frac{\ln \alpha}{l}$$

- α can be estimated from different LED arrays

$$\alpha = exp\left(\frac{\sigma_{m,2} - \sigma_{m,1}}{\frac{1}{l_2} - \frac{1}{l_1}}\right)$$



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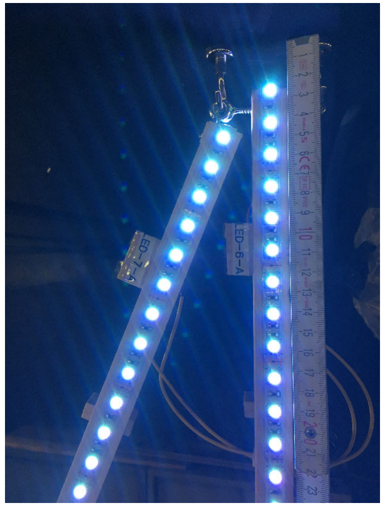
Conclusion

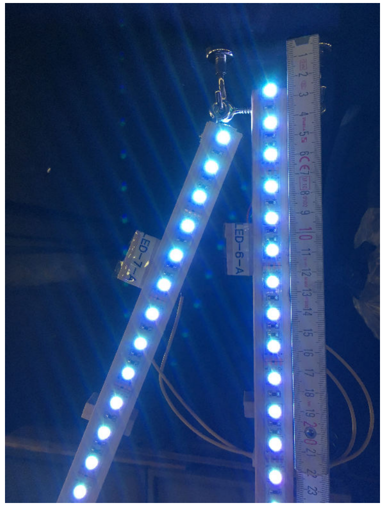
- LEDSA results are in good agreement with MIREX measurement
- Method is easy applicable, since there is no need for complex experimental setups or expensive measurement devices
- Effects from an inhomogeneous smoke stratification as well as temperature influences on the LEDs may corrupt the photometric measurement
- Due to the spatiotemporal resolution, the approach can be referred to as a reliable basis for the validation of numerical simulations



Link: Spatiotemporal measurement of light extinction coefficients in compartment fires

Outlook / current issues

- Thermal stability of LEDs in terms of light intensity and spectral range needs to be improved
- Effects of deposition and agglomeration may be considered
- Ratio of extinction coefficients at different wavelengths may be used to draw conclusions about change in particle size
- LEDSA may be extended to a three-dimensional level
- Other test fires but the TF 5 may be investigated



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