Efficiency of a wood stove electrostatic precipitator in mitigating particulate emissions

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Efficiency of a wood stove electrostatic precipitator in mitigating particulate emissions

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Black carbon and particle lung-deposited surface area in residential wood combustion emissions: Effects of an electrostatic precipitator and photochemical aging

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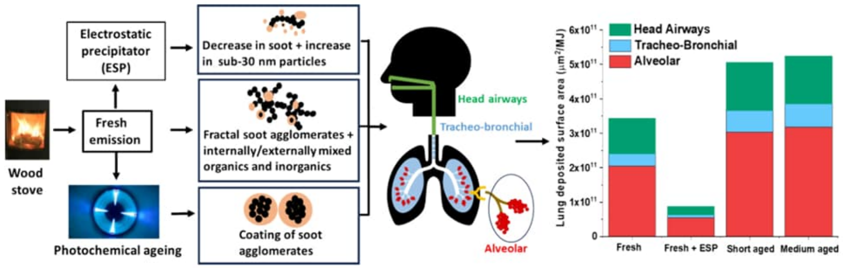

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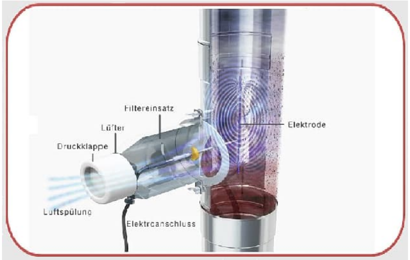
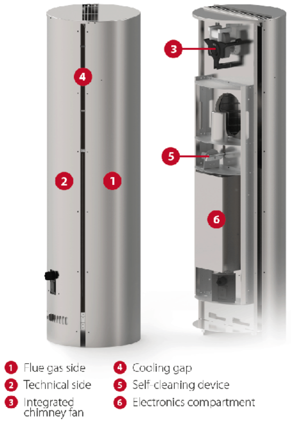
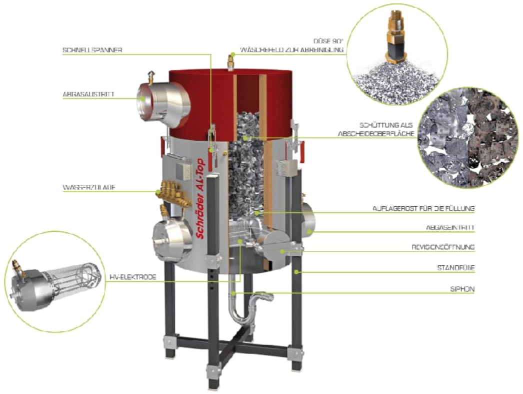
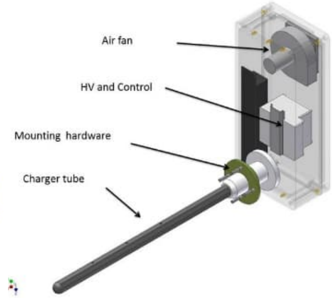
Background & motivation

- Electrostatic precipitators (ESPs) are seen as a promising technology to mitigate particulate matter (PM) pollution from residential biomass combustion
- Commercialized small-scale ESPs or electrical filters
  - Oekosolve Oekotube (Switzerland)
  - Kutzner + Weber Airjekt (Germany)
  - Tassu ESP Electrical Diffusion Filter (Finland)
  - Carola Clean Air (Germany)
  - Schräder AL-Top (Germany)
  - Spartherm Airbox (Germany)
  - Exodraft (UK)
  - NOETON (Finland)



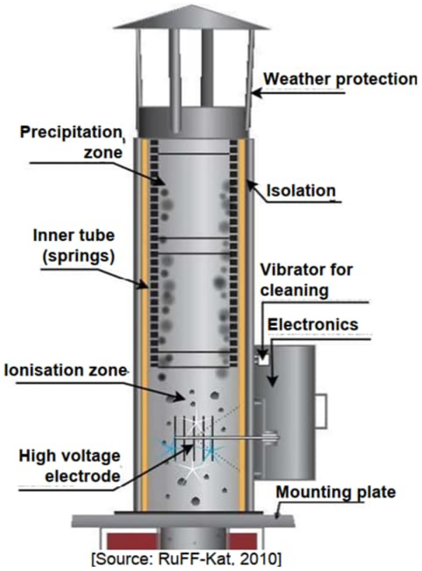






Background & motivation

- Most wood stove ESPs introduced into the market are tube-type electrostatic precipitators
  - Other techniques include diffusion charging (Tassu ESP), two stage precipitation (CCA) and high-T electric filtration (NOETON)

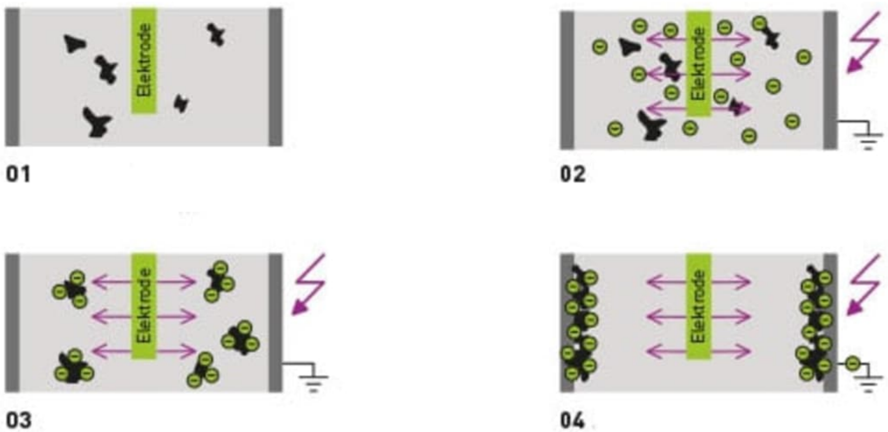


Ruff-Kat ESP

Oekotube, outside model

Oekotube, inside model

Operation principle (Oekosolve):



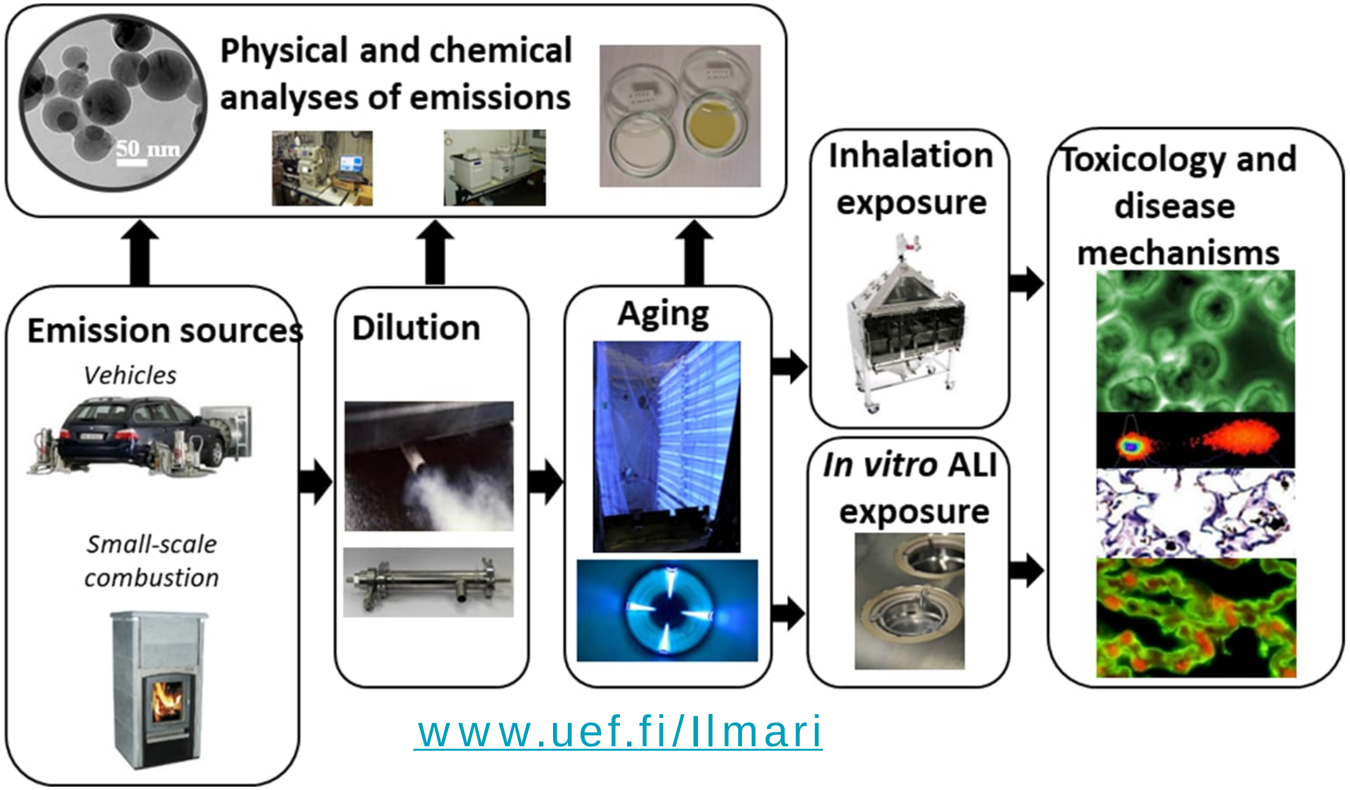
Previous studies (Literature)

- Previous studies have reported large variation in PM reduction efficiencies for tube-type ESPs used in batch-wise operated wood combustion appliances.
  - PM1 reduction efficiencies vary between 44% and 98% when utilizing tubular ESP logwood combustion (Brunner et al., 2018)
  - PM reduction efficiencies in wood stoves might be substantially reduced during long-term operation (Oehler and Hartmann, 2014)
- ESP:s may considerably influence particle size distributions (Suhonen et al., 2021; Omara et al., 2010; Cornette et al., 2024)
- There is a limited knowledge especially on:
  - PM health-relevant characteristics: particle size distributions, detailed particle physico-chemical properties and toxicological properties
  - the efficiencies of ESP under different operation conditions and combustion phases
  - Long-term performance of the ESP in wood stoves

Objectives

1. Determine the efficiency of a tube-type electrostatic precipitator in reducing particle emissions
2. Investigate how ESP influences particle physico-chemical characteristics
3. Investigate how combustion conditions / combustion phase influences the performance of the ESP

AeroHEALTH 2021 measurement campaign at UEF



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HELMHOLTZ
International Lab

- Host organization: UEF
- Participants:
  - Helmholtz Zentrum Munich
  - University of Rostock
  - University of Basel
  - Weizmann Institute
- Time: 1.11-15.12.2021

Experimental setup

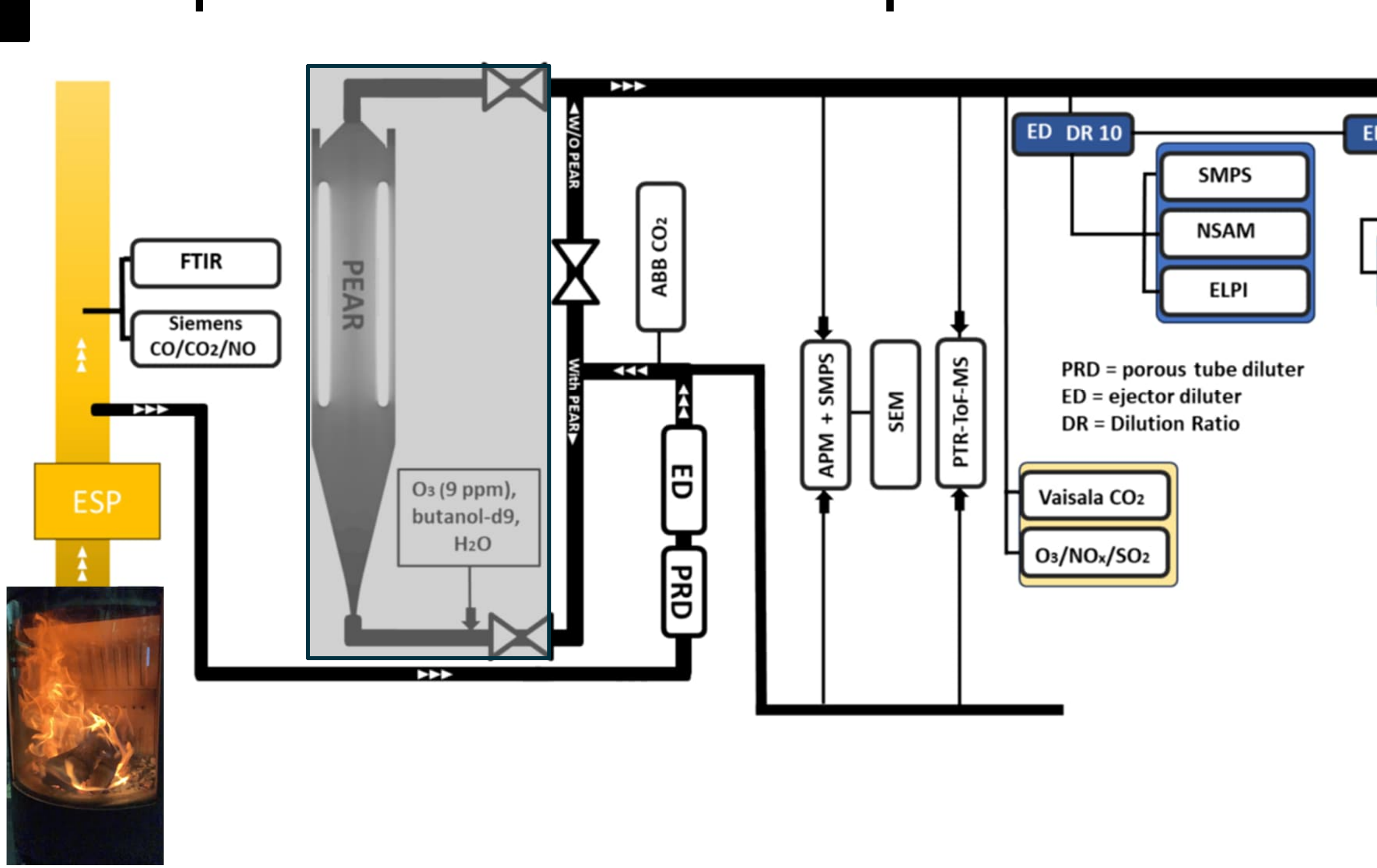
Beech logs

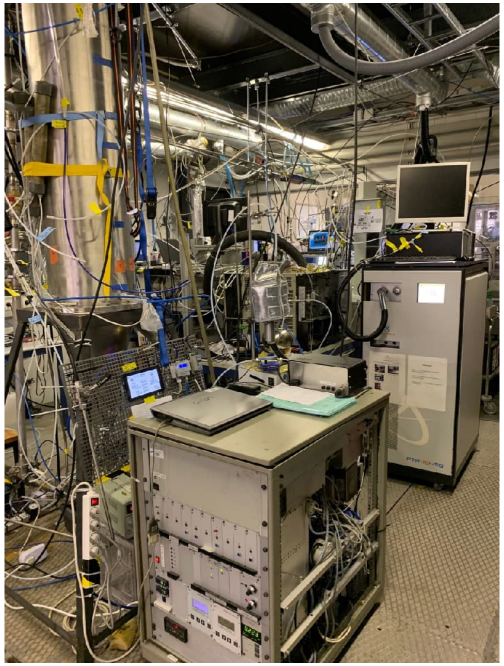
Aduro 9.3 Wood stove

Oekotube, inside model

Enjoying coffee after successful installation

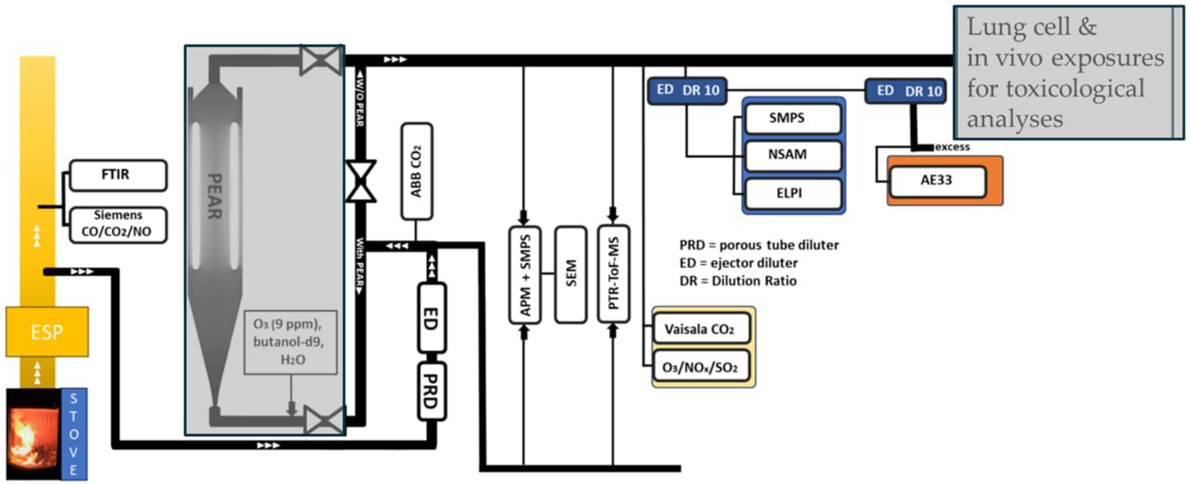
Experimental setup





Measurements

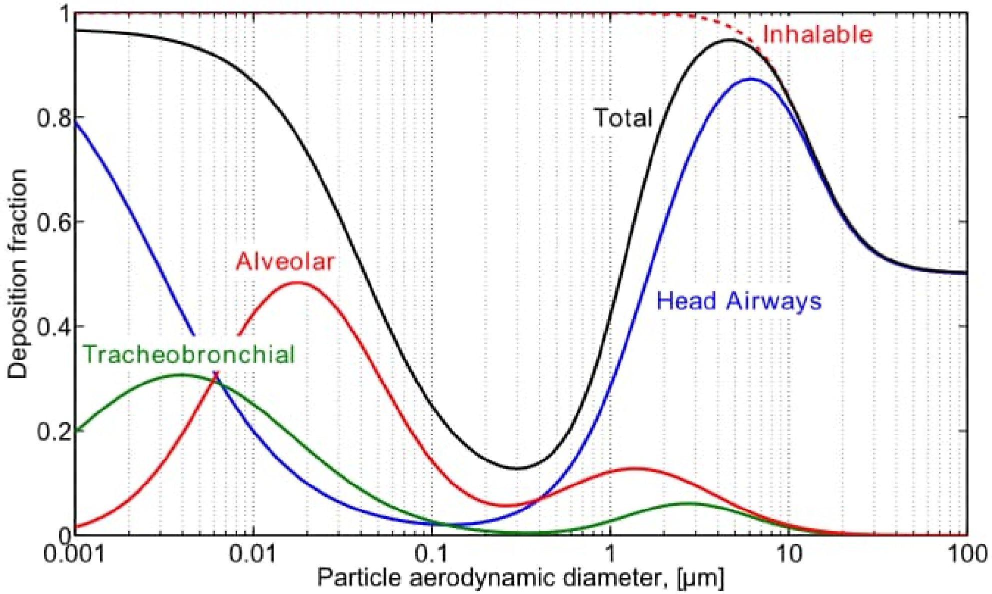
- Gas emissions: FTIR gas analyser & PTR-ToF-MS
- Black carbon (BC) concentrations: Aethalometer (AE33, Magee Scientific)
- Particle number concentrations & size distributions: Scanning Mobility particles sizer (SMPS, TSI) and the Electrical Low Pressure Impactor (ELPI, Dekati)
- Particle mass: ELPI & Aerosol particle mass analyzer (APM, Kanomax)
- Particle morphology: APM-SMPS, Scanning electron microscopy, Transmission electron microscopy
- Particle lung-deposited surface area: Nanoparticle surface area monitor (NSAM, TSI) & ELPI

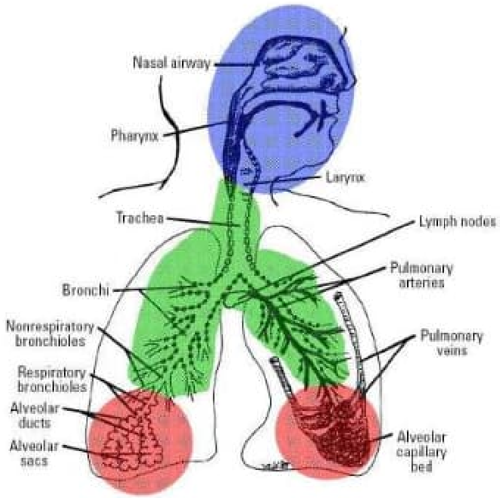


Measurements

- LDSA has been proposed as an important metric to assess health effects of ambient fine particulate matter
- Several instruments have been developed to monitor LDSA of ambient air or emissions (e.g. Partector, Pegasor, NSAM)

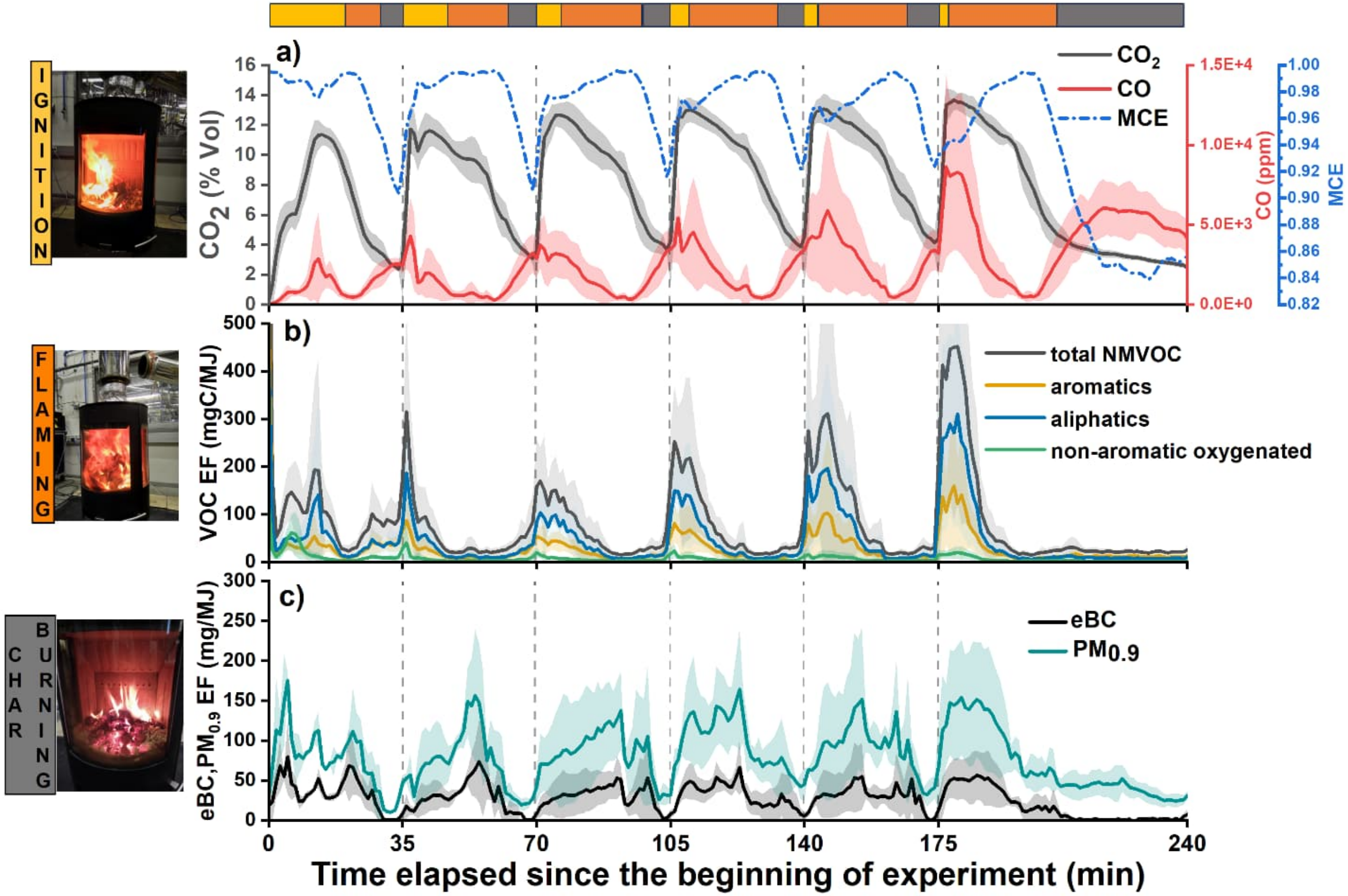
Predicted total and regional lung deposition probalities for light excercise (nose breathing) according to Hinds (1999) [ICRP deposition model]. Adapted by Koivisto (2013)



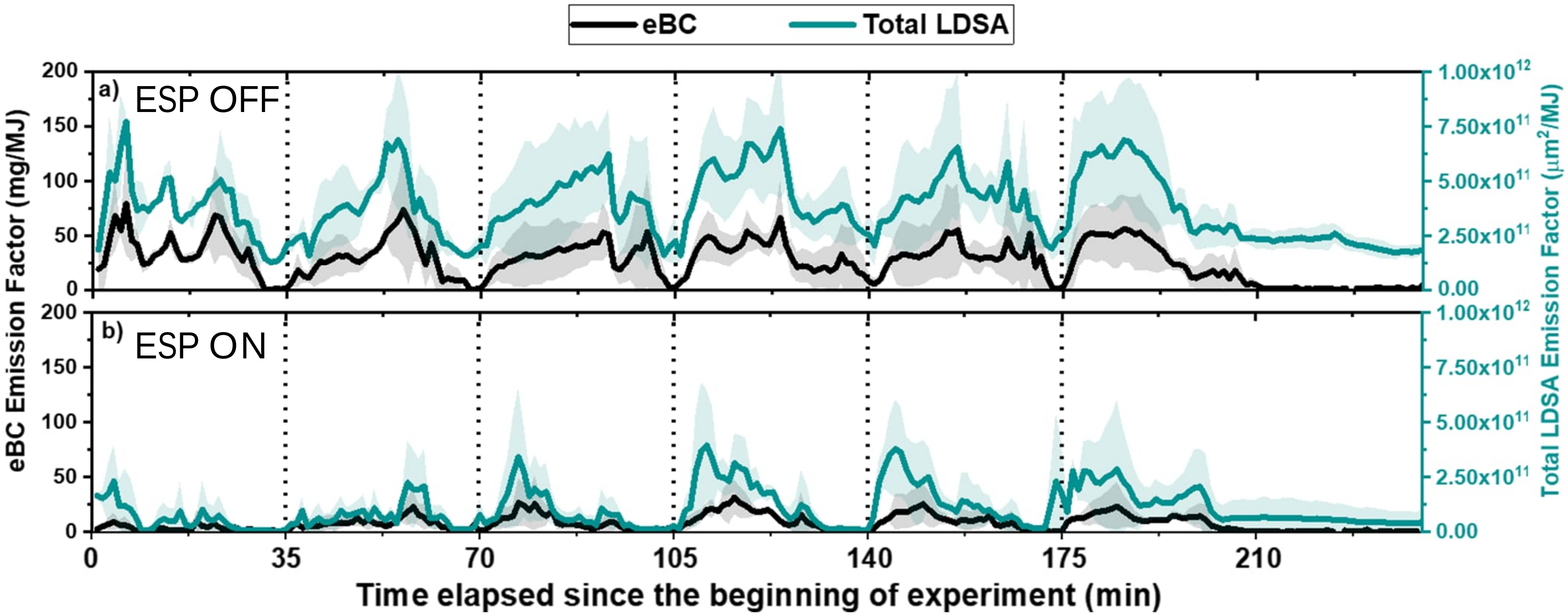


Combustion conditions: gaseous & PM emissions without ESP

- 6 batches of 2 kg beech logs
- Each batch took 35 min
- At the end 30 min of residual char burning
- Combustion phases were defined based on CO2 and CO concentrations
- Mean fine particle mass emission (PM0.9) approx. 80 mg/MJ



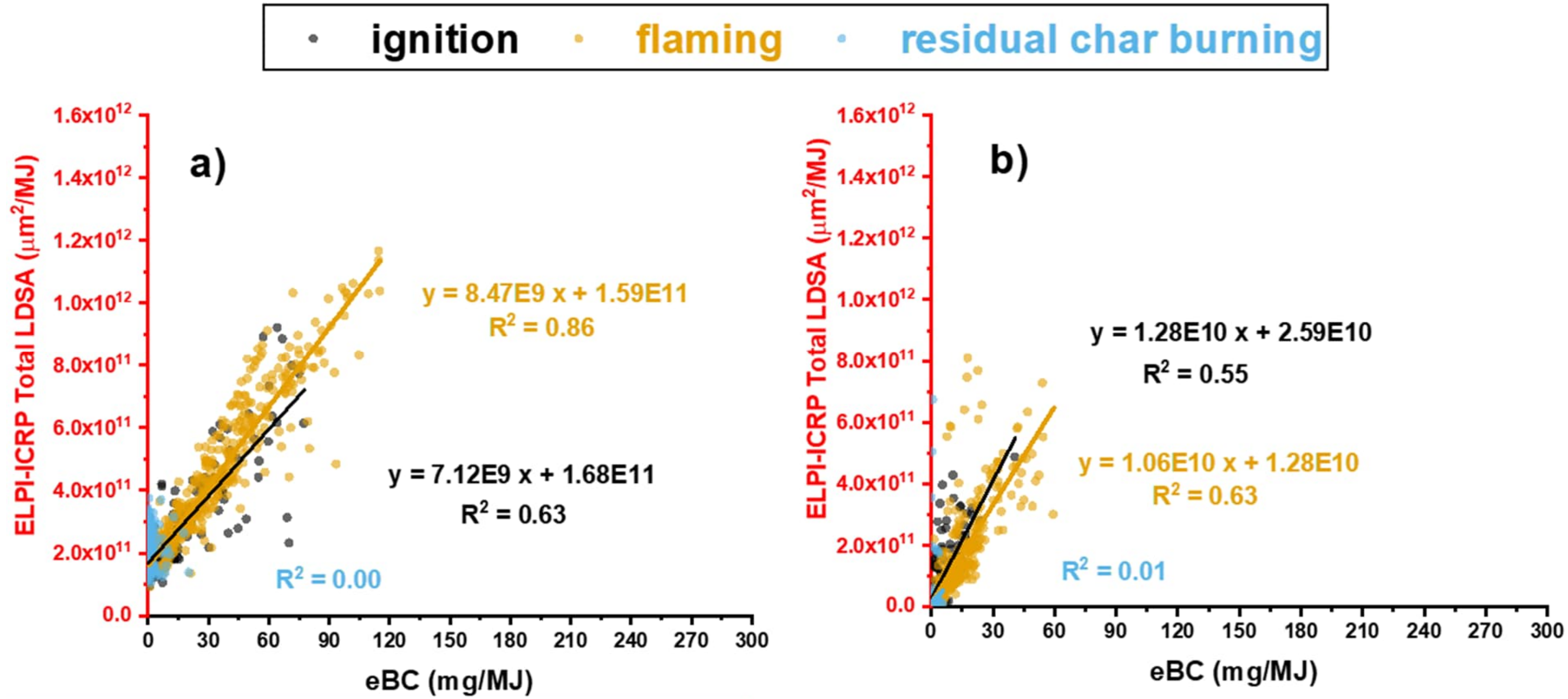
Effects of ESP on black carbon and LDSA



ESP reduction efficiencies:

- Black carbon (eBC): 69%
- LDSA: 73%
- Total fine particle mass (PM0.9): 71%

Correlation of black carbon and LDSA

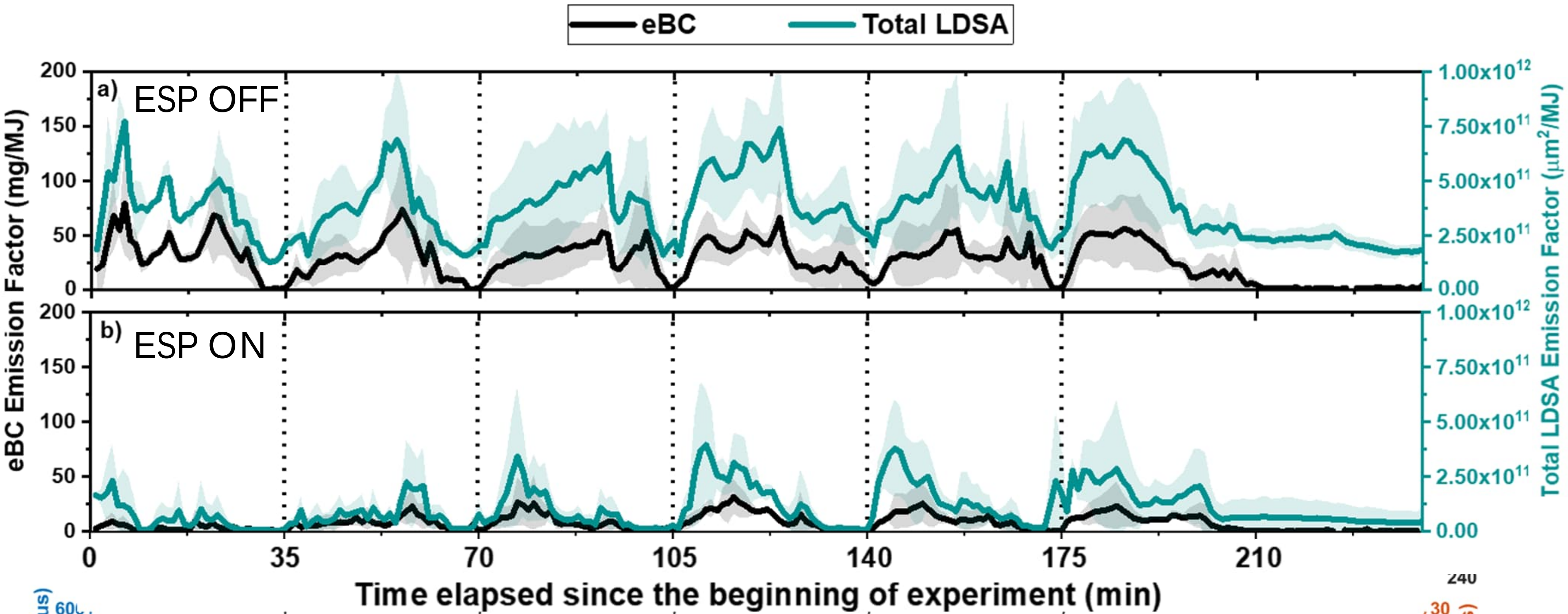


ESP reduction efficiencies:

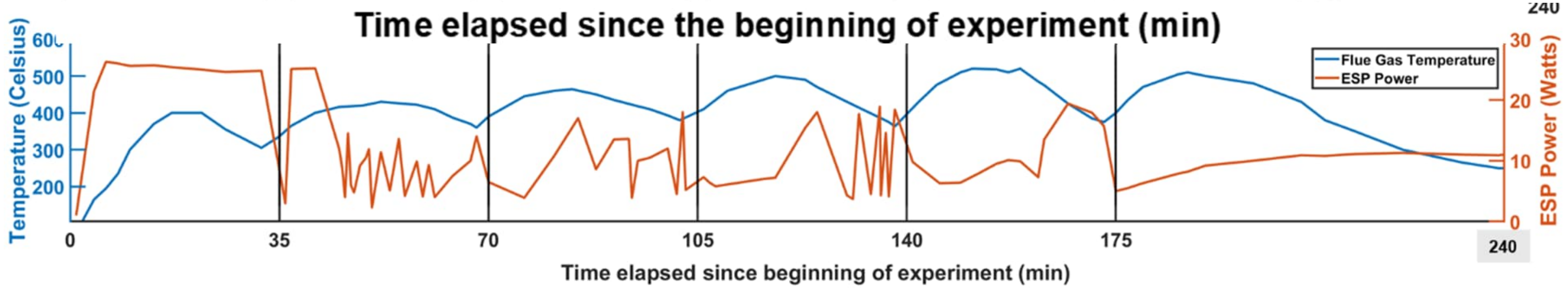
- Black carbon (eBC): 69%
- LDSA: 73%
- Total fine particle mass (PM0.9): 71%

Effects of ESP on black carbon and LDSA

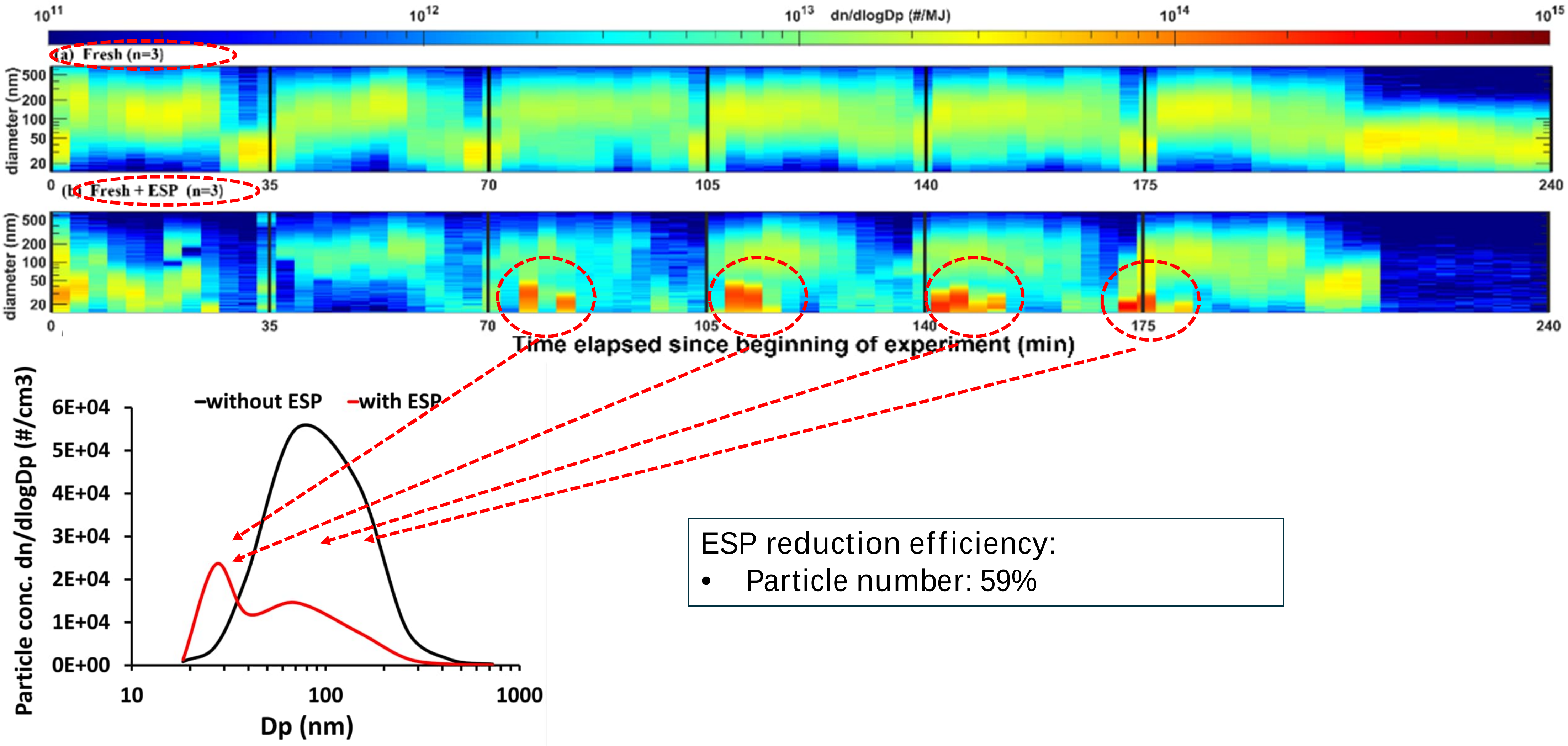
Mean emissions of all experiments:



Example data of ESP conditions during one experiment:



Effects of ESP on particle number emission and size distribution



ESP reduction efficiency:

- Particle number: 59%

Effects of ESP on particle number emission and size distribution

- Increase in sub-30 nanoparticles due to new particle formation by nucleation
- Potential mechanisms:
  - Ion-induced oxidation reactions of organic gases leading to nucleation?
  - ESP forms O3, that oxidizes organic gases?

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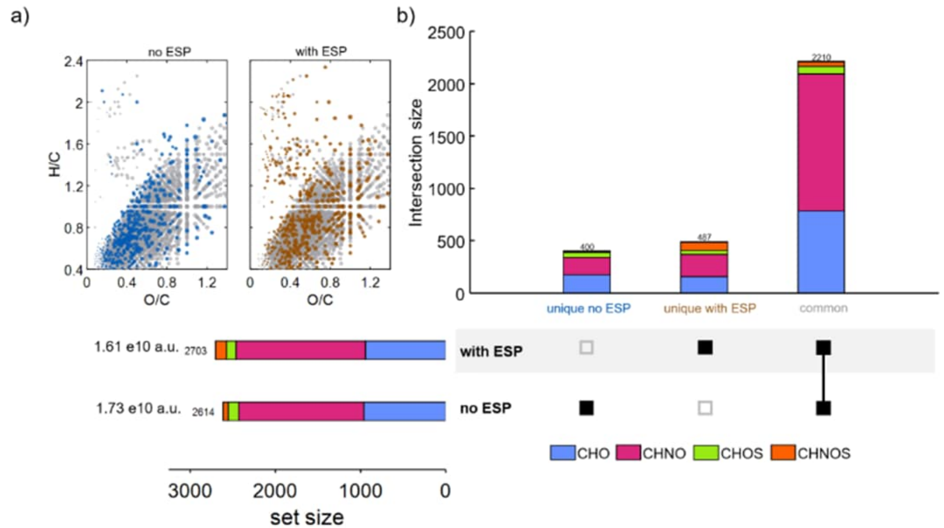
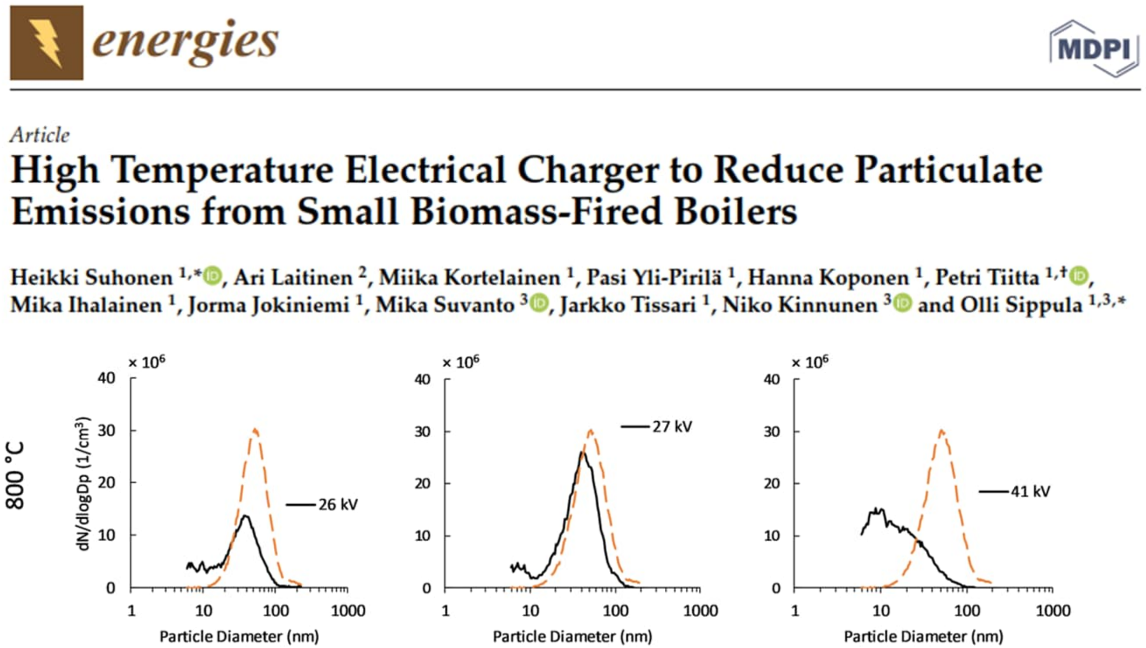
Molecular composition of fresh and aged aerosols from residential wood combustion and gasoline car with modern emission mitigation technology†

Eric Schneider,[ab] Hendryk Czech,[*ac] Anni Hartikainen,[d] Helly J. Hansen,[a] Nadine Gawlitta,[c] Mika Ihalainen,[d] Pasi Yli-Pirilä,[d] Markus Somero,[d] Miika Kortelainen,[d] Juho Louhisalmi,[d] Jürgen Orasche,[‡c] Zheng Fang,[e] Yinon Rudich,[e] Olli Sippula,[df] Christopher P. Rüger[ab] and Ralf Zimmermann[abc]

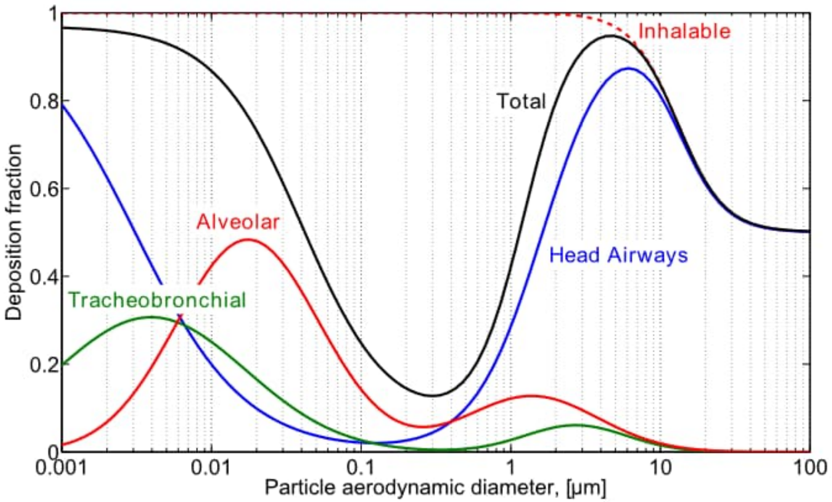


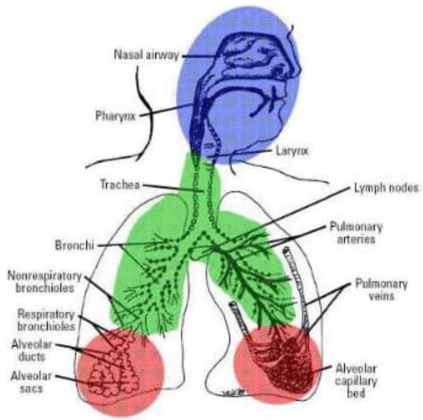
Effects of ESP on particle number emission and size distribution

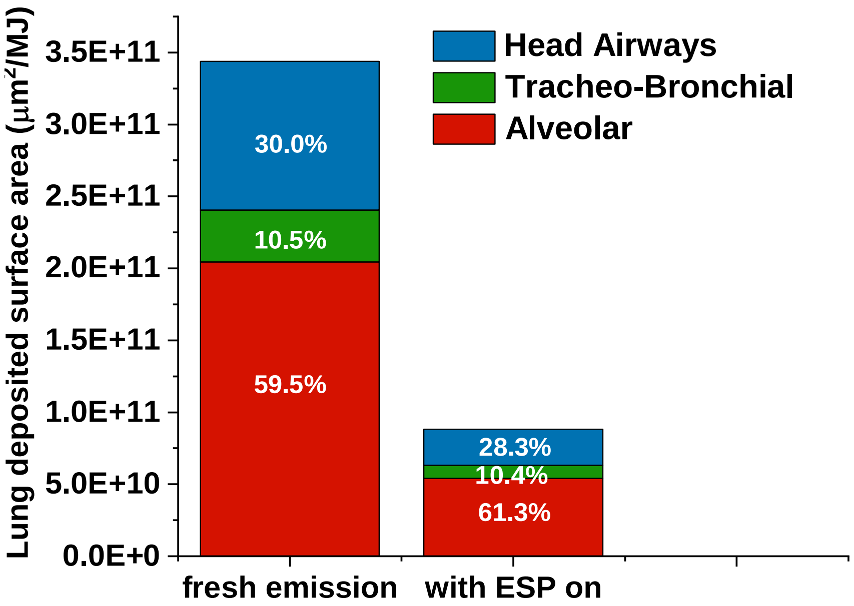
- Increase in sub-30 nanoparticles due to new particle formation by nucleation
- Potential mechanisms:
  - Ion-induced oxidation reactions of organic gases leading to nucleation?
  - ESP forms O3, that oxidizes organic gases?
  - ESP influences aerosol dynamics by removing condensation seed particles -> promotes nucleation
  - A likely explanation is a combination of a several of these effects



Estimated lung deposit fractions based on the ICRP-model:
Particle surface area

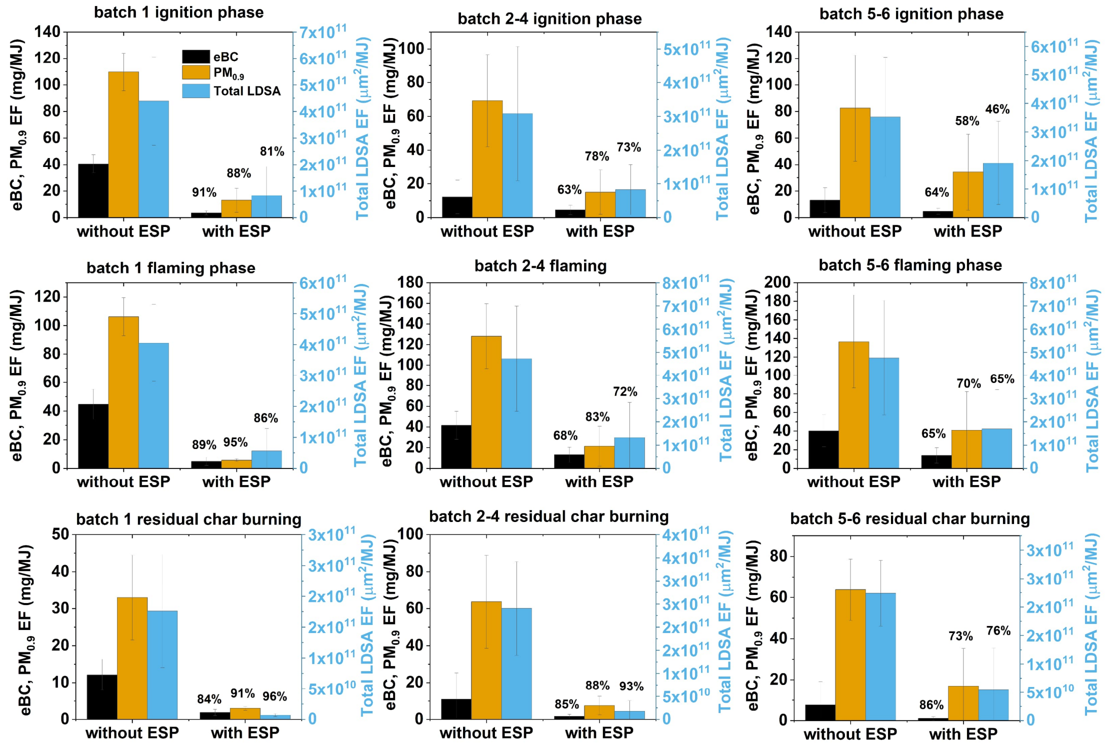






Summary

- Reduction of fine particle mass (PM0.9), black carbon (BC) and LDSA by approx. 70%
- Reduction in total particle number emission by 59%, but increase in sub-30 nm nanoparticle emissions
- Highest emission reduction in the beginning of the combustion (low temperature) and in char burning phases (low PM concentrations, ash particles)
- Long-term performance of ESP need to be further studied
- Results on the influence of ESP on toxicological properties of PM emissions coming later…



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Effects of ESP conditions on particle emissions