Emissions from residential wood combustion: A comparison of residential wood and pellet stoves

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Importance of biomass burning

- Complex processes
  - Pyrolysis, combustion etc.
  - Primary vs Secondary chemistry
- Global, regional & local scales
- Anthropogenic & natural

- Source of carbonaceous gases and particles to the atmosphere
  - Health effects
    - e.g. particulate matter (PM)
  - Climate effects
    - e.g. Direct effect, deposition

Global burden

Natural

Anthropogenic (Large uncertainties!)

Tg a^{-1}	Savanna and grassland	Tropical forest	Temperate forest	Boreal forest	Peat fires	Agricultural residues	Biofuel burning	Charcoal making	Charcoal burning	Total	A&M2001
Tg dry matter burned	2400	2880	300	450	172	240	2134	180	45	8800	8600
CO_2	3980	4670	470	690	270	340	3310	90	110	13 900	13 400
CO	170	300	34	55	45	18	180	17	9.4	820	690
CH_4	6.5	19	1.6	2.5	1.6	1.4	15	3.4	0.27	50	39
Total VOCs	12.2	16	4.0	2.7	3.7	1.8	17	4.8	0.3	62	49
$PM_{2.5}$	16	24	5.5	8.4	3.2	2.0	14.5	3.6	0.14	77	58
TPM	21	31	5.5	6.9	0.0	3.1	14.9	2.5	0.09	85	82
TC	7.6	16	2.5	4.4	2.5	1.3	7.3	–	0.09	41	42
OC	7.3	12.8	3.3	2.7	2.4	1.2	6.6	–	0.10	36	36
BC	1.3	1.46	0.17	0.19	0.02	0.10	1.7	–	0.01	4.9	4.8

TPM – particulate matter
TC – Total carbon
OC – Organic carbon
BC – Black carbon

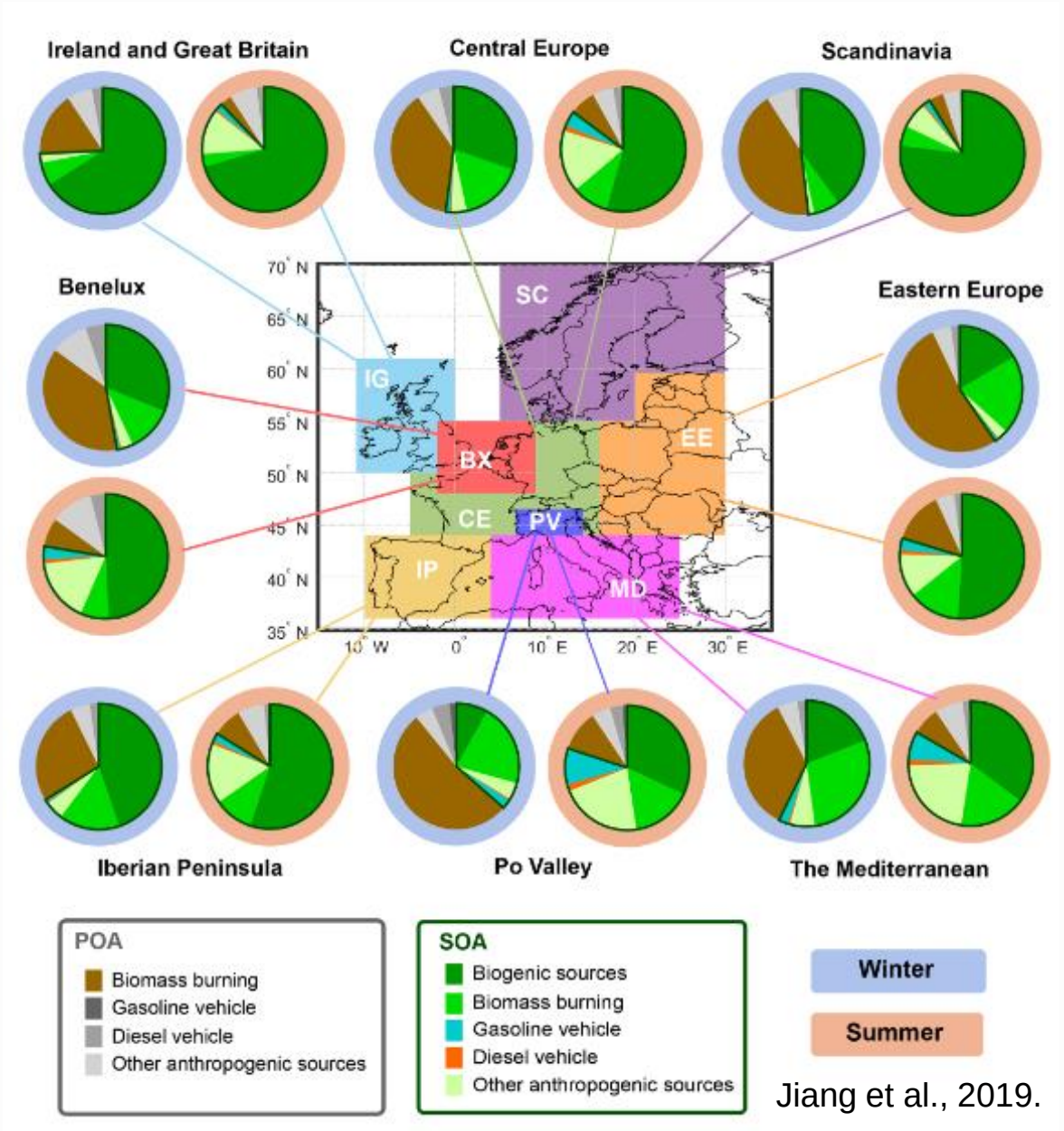
Andreae, 2019.

Biomass Burning in Europe

- Dominant **primary** source of organic aerosol in many regions during **winter** (61%)
- Non-trivial source of **secondary** organic aerosol in **summer**
- (Biomass burning here includes and agricultural combustion)

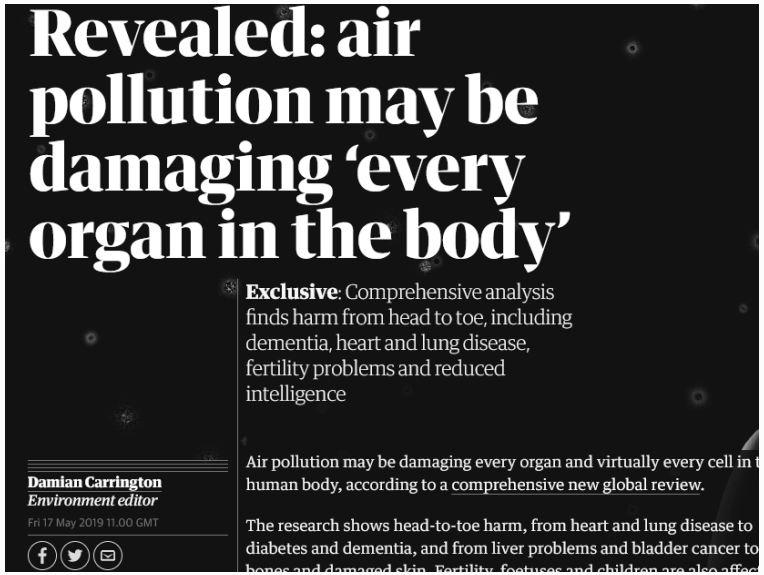
>50% $PM_{2.5}$ from wood combustion

- Po Valley (Piazzalunga et al 2011)
- Southern Germany (Bari et al. 2010)
- Suburban Helsinki (Saarnio et al., 2012)
- Northern Sweden (Krecl et al, 2008)



Jiang et al., 2019.

Human health and associated costs of RWC

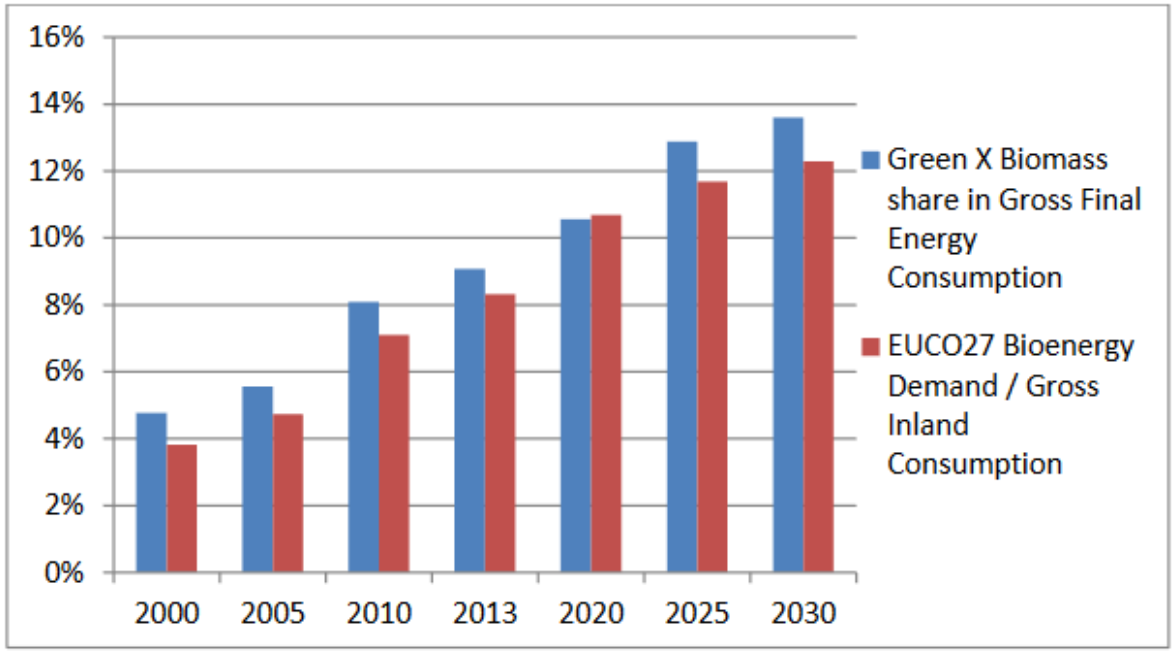


European biofuel consumption will increase until 2030

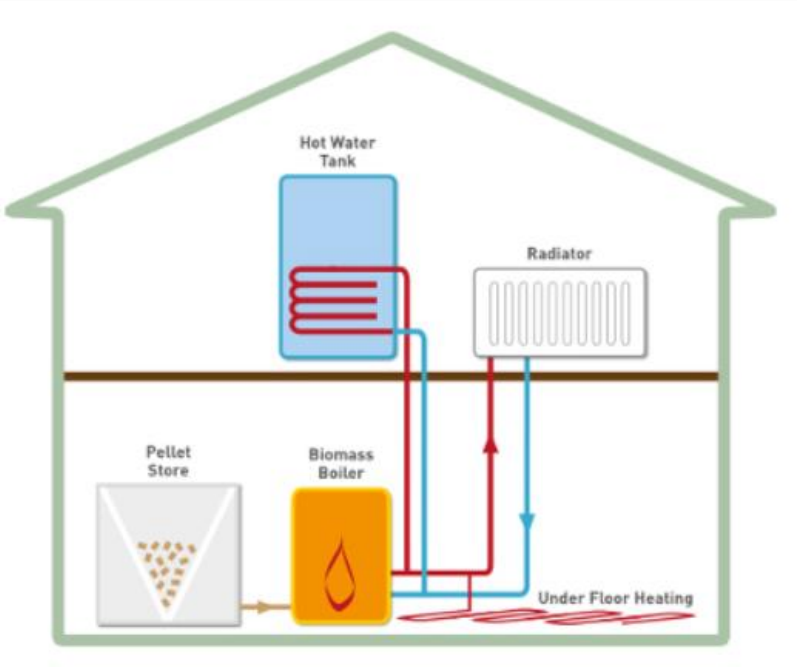
- **Decarbonisation of the EU economy by 2050**
- 80 - 95 % reduction of GHG emissions compared to 1990.
- Renewable energy target of at least 27% by 2030.

European Commission, 2016.
Brack, 2017.

Share of bioenery in total energy demand



Are emissions from pellet and log burning stoves different?



Wood Stove

- Most popular modern model
- Residential
- 2 kg load
- spruce (19.6 % moisture)
- birch no bark (17.0 % moisture)
- 80% heating efficiency

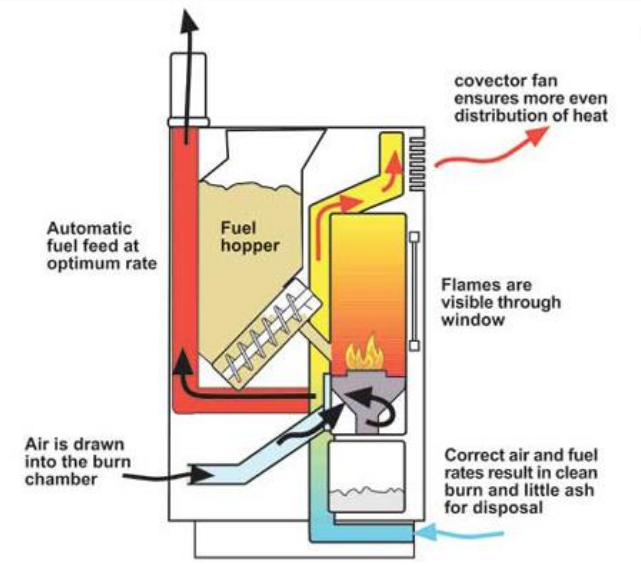
Pellet Stove

- commercial and residential
- 6 mm pellets (logging waste)
- ash content ≤ 0.5 % (w/w)
- moisture content of 6-8 % (w/w)
- High and low loading
- 86% heating efficiency

1. Autonomous
Easy to operate

2. High control of oxygen and fuel

3. Stable temperature
Uniform heating
High thermal comfort



Mack et al., 2018;
Corbin et al., 2015;
Olsen et al., 2020.

Why might emissions be different?

Time evolution of a fire

2. Pyrolysis < 325 °C
- Thermal degradation
- Does not require O_2

1. Evaporation ~100 °C
- No chemical transformations
- Releases VOCs

Temperature

Ignition

Growth

Fully Developed

Decay

3. Flaming 420 °C – 1200 °C
- Combustion of emitted gases and particles
- Most efficient phase

4. Smouldering 300 °C – 600 °C
- Less efficient
- Less combustion of gases (high m_w)

Time

Pollutants

Black carbon, BC.

- Short lived climate pollutant
- Direct heating effect
- High temperatures, High fuel/O_2 ratio

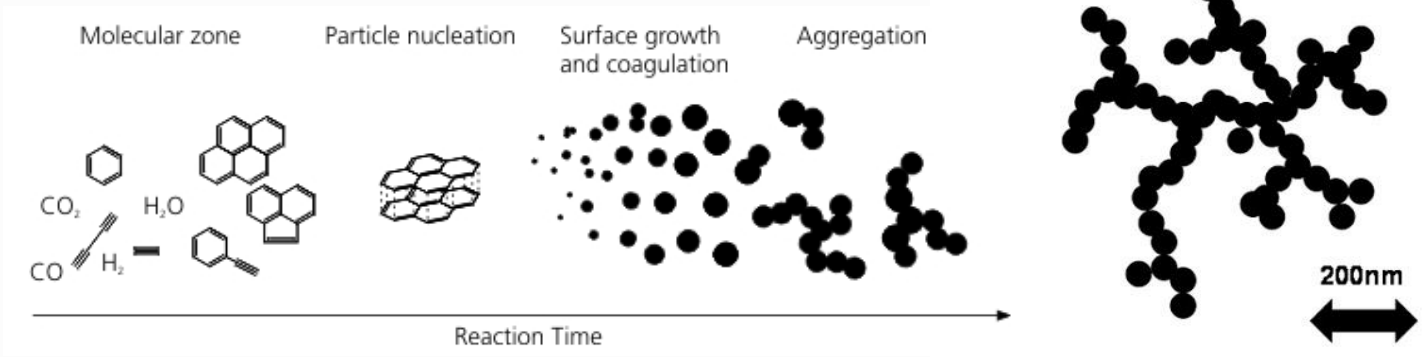
Organic carbon, OC.

- Contributes to particle mass
- Secondary organic aerosol (SOA)?
- Low temperature
- Molecular structures preserved

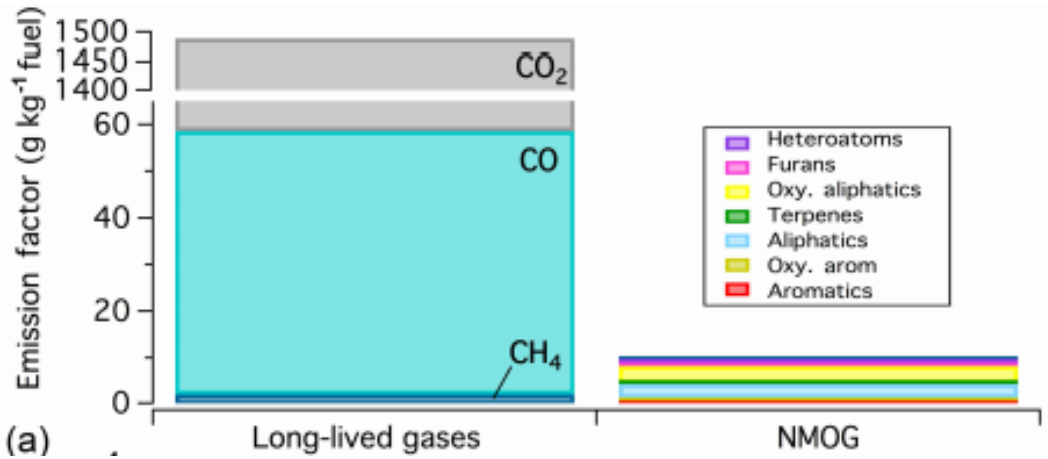
Brown carbon, BrC.

- Organic compounds that absorb light
- Substituted aromatic compounds, PAHs

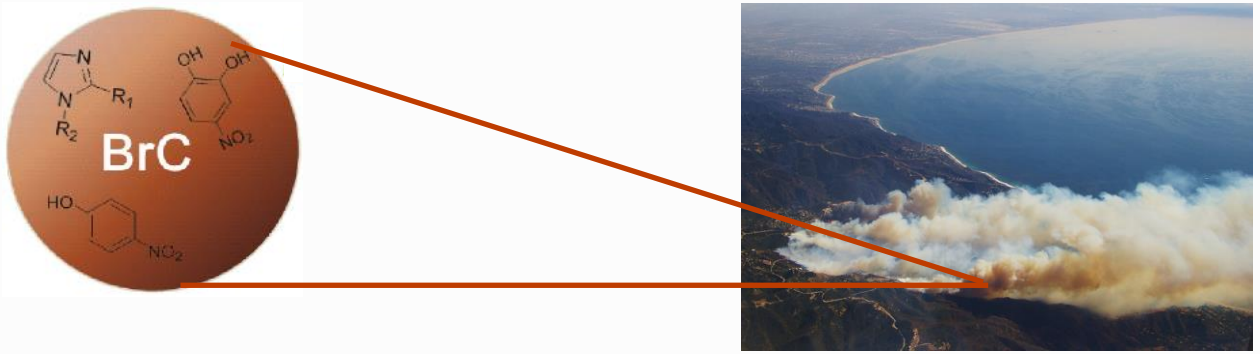
Poly-aromatic hydrocarbons (PAHs)



http://www.forbrf.lth.se/english/research/measurement-methods/laser-induced-incandescence-lii/

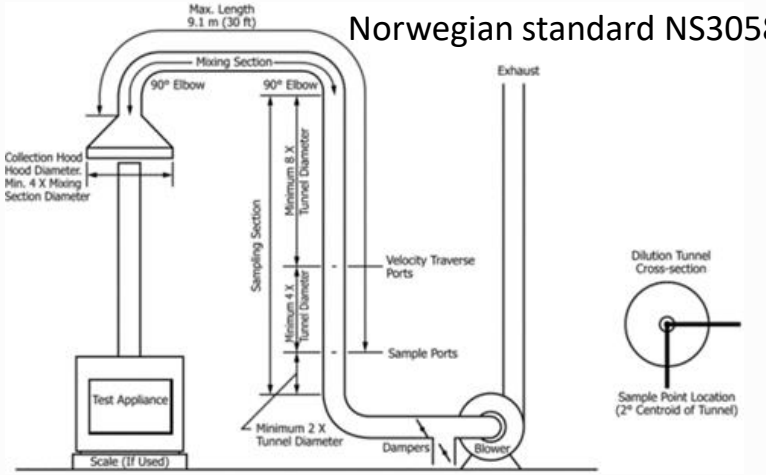


Hatch et al., 2017.



Experiments and set-up

- **Chemical composition,**
- **Optical properties**
- **Gas particle partitioning**, **morphology**, alkali content, ice nucleation



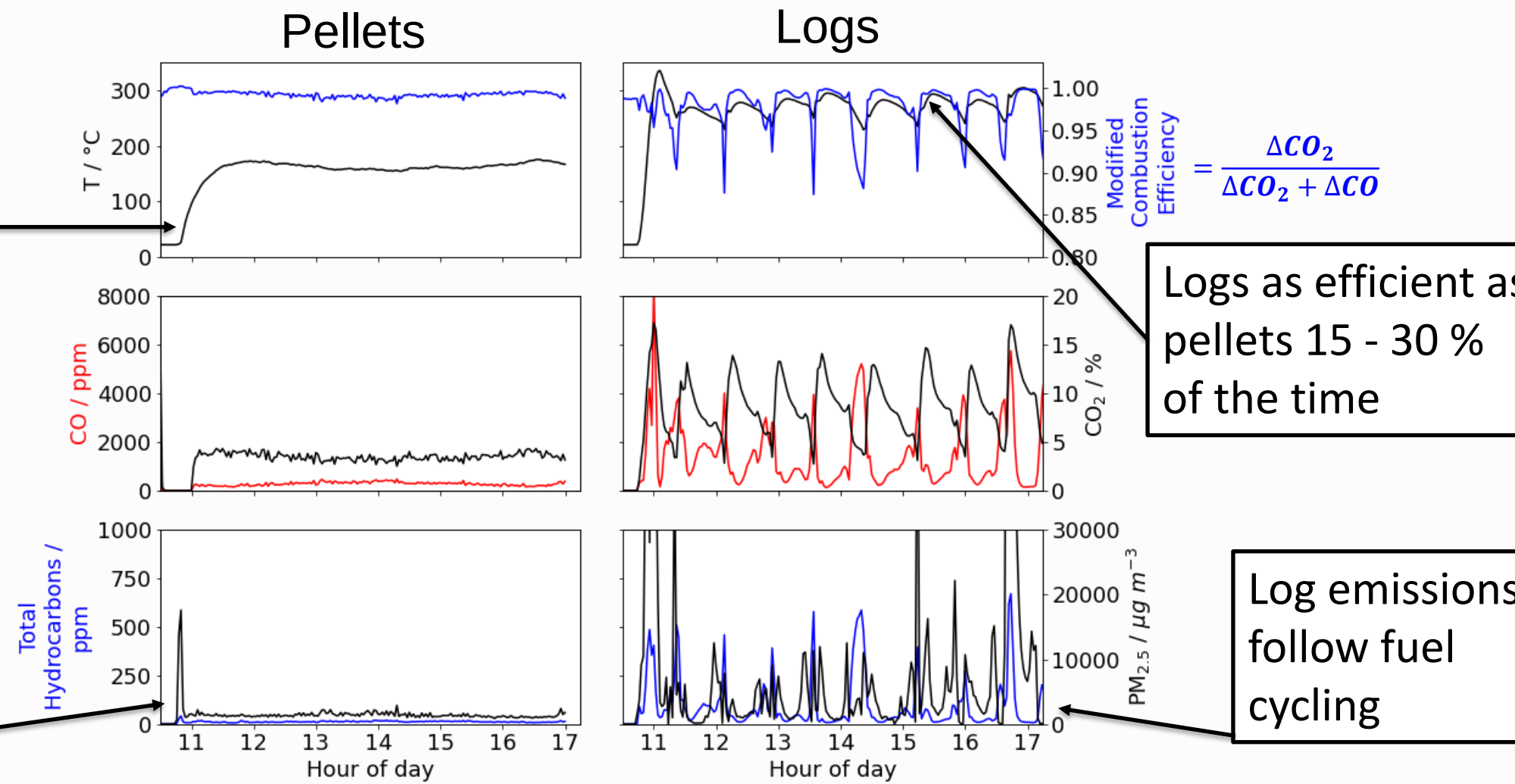
Instruments

- **FIGAERO-ToF-CIMS**
  - Speciated oxygenated organics (OVOCs)
  - Gas and particle phase
- Photo accoustic soot spectrometer (**PASS-3**)
  - Aerosol optical absorption (equivalent BC)
  - 405 nm & 532 nm & 781 nm
- SMPS – particle size distributions
- GC-MS for offline filter analysis of **PAHs**

Overview

Pellets emissions are cooler than logs

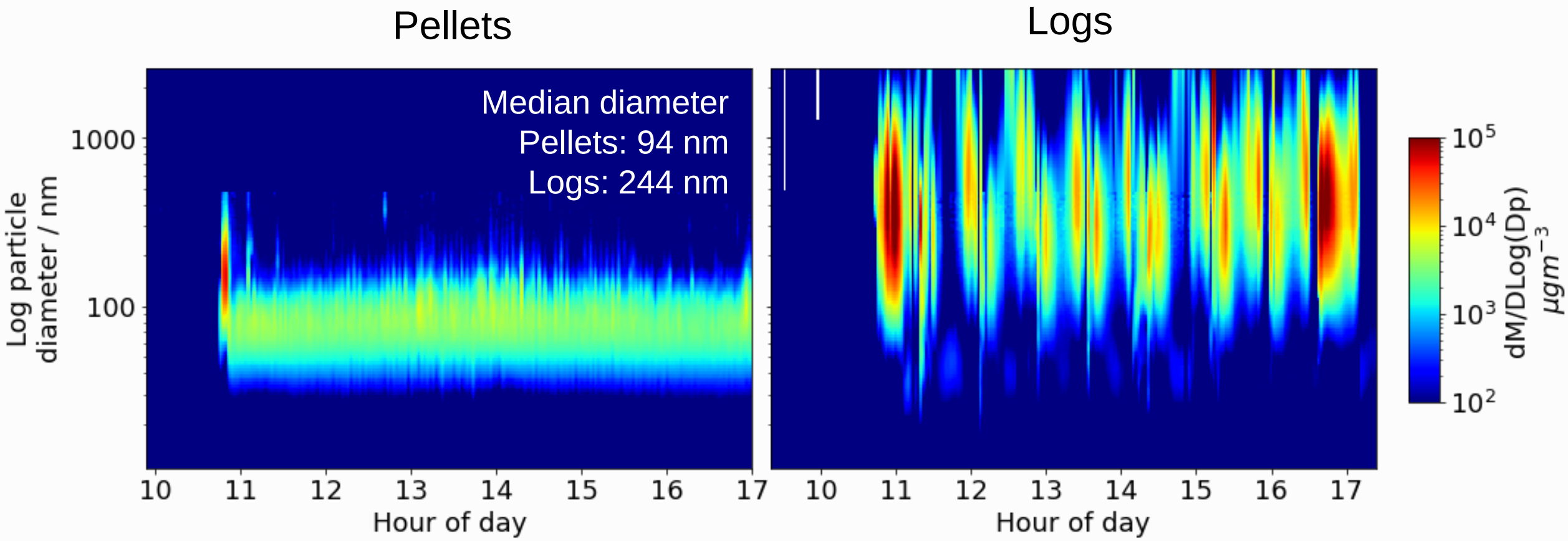
Pellets emissions are constant



Logs as efficient as pellets 15 - 30 % of the time

Log emissions follow fuel cycling

Particle sizes



Assumed density of 1.2 g cm^{-3}
Assume spherical morphology (bad for logs)

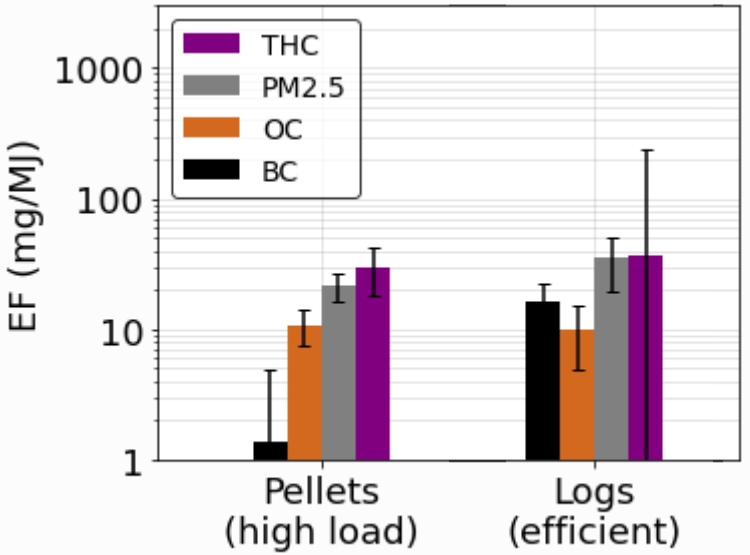
Emissions are very different depending on the RWC appliance

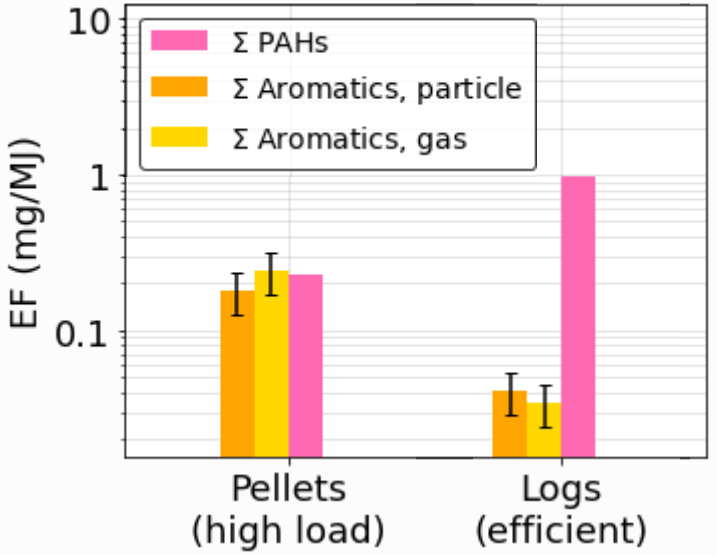
Pellet emissions

- Spherical
- 90% organic material
- Likely BC core
- Low temperature combustion preserves organics e.g. aromatics
- Brown particles!

Log emissions

- Amorphous structure
- 1:1 Organic:BC
- BC coated in organics
- High temperature combustion: lose organics and form more BC and PAHs





Wood log stoves emit more material than pellet stoves

Pellet emissions

- Spherical
- 90% organic material
- Likely BC core
- Low temperature combustion preserves organics e.g. aromatics
- Brown particles!

Log emissions

- Amorphous structure
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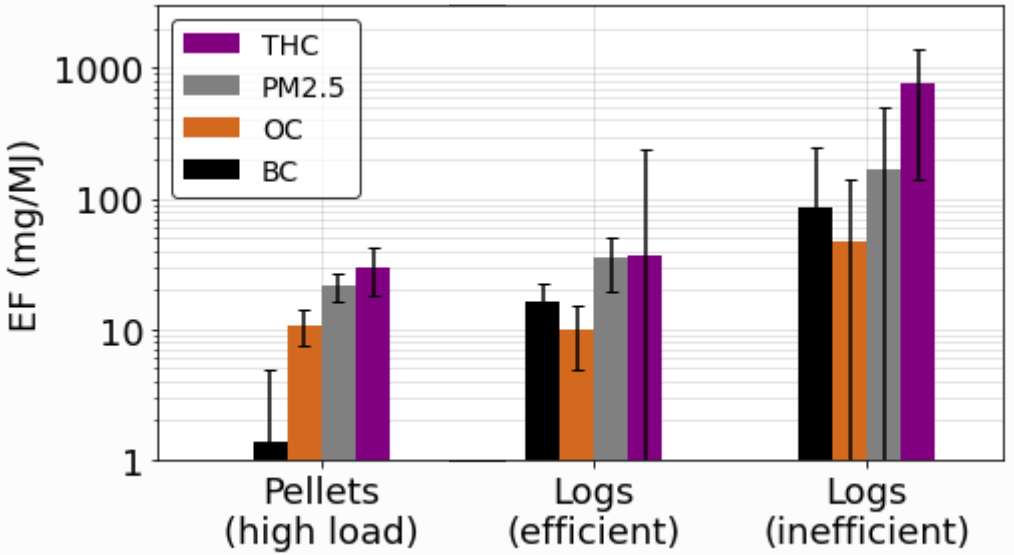
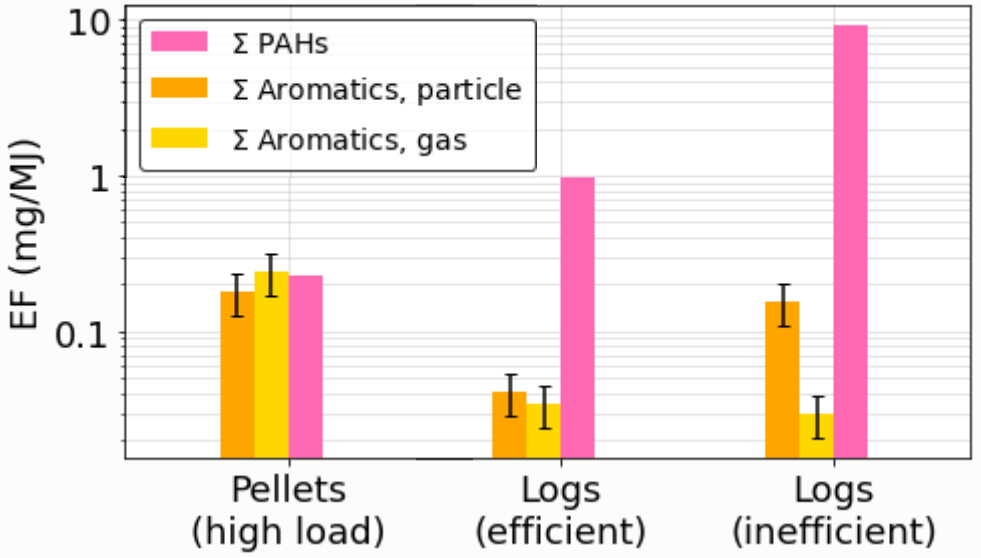
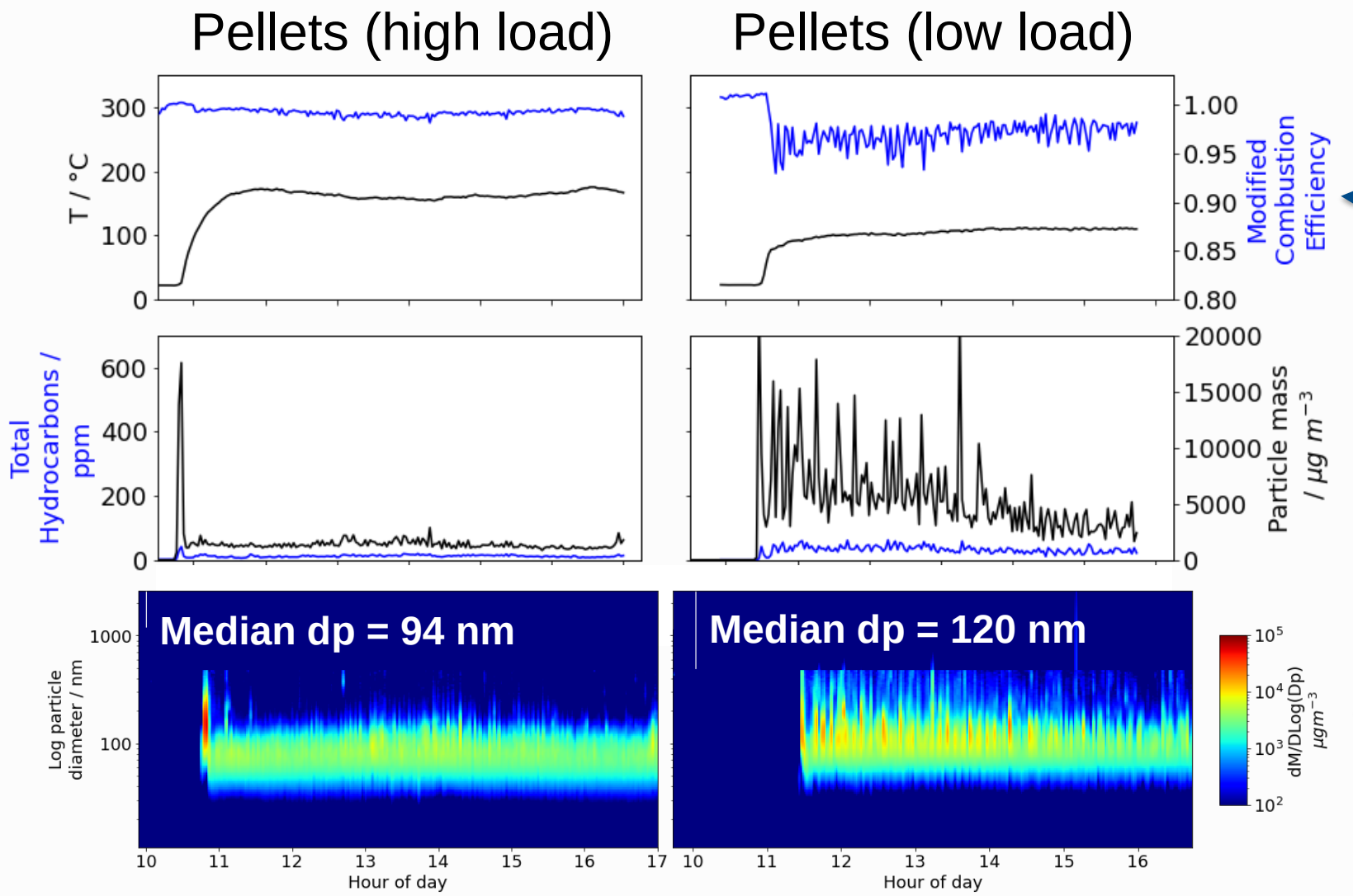




The lower pellet loading is more polluting than higher loading

Decrease the **pellet loading** by 40% from 1.15 kg/h to 0.70 kg/h.



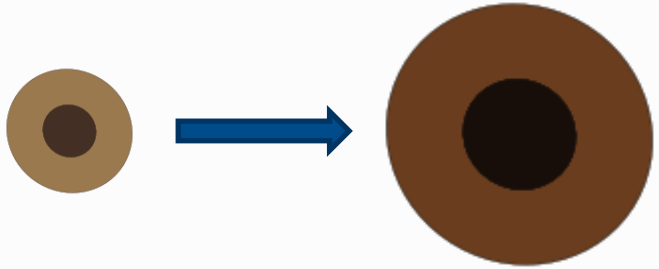
Decrease in MCE
Increase in CO
Decrease in CO_2

Increase in THC and increase in particle mass

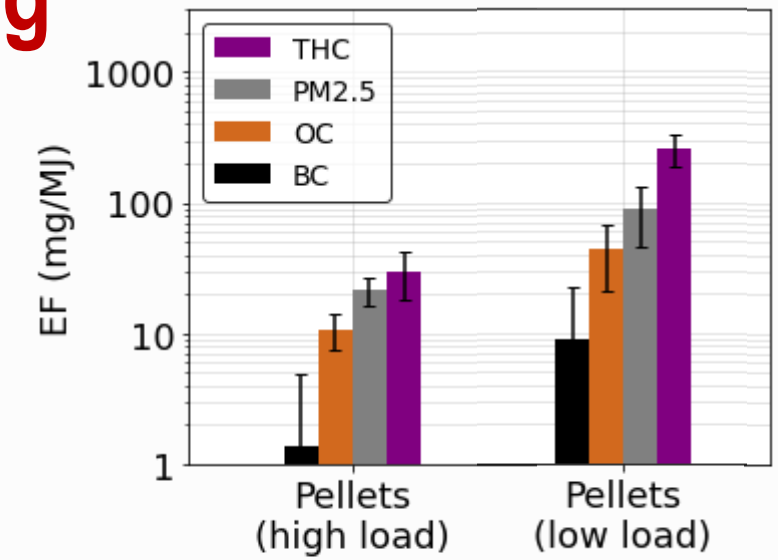
Increase in particle diameter

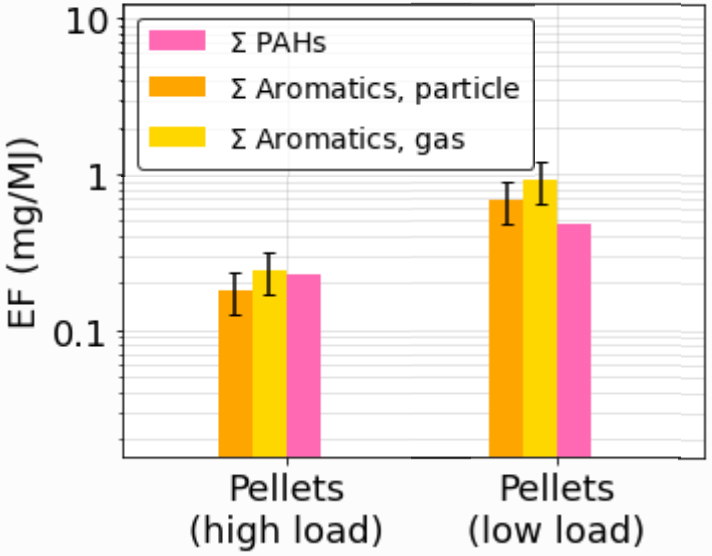
The lower pellet loading is more polluting than the higher loading

Lowering the load



- Less complete combustion
  - More organic material remains
  - Greater contribution to particle mass
- Particles become more optically absorbing i.e. browner
- Greater PAH and BC emissions suggests lack of O_2
  - Indicates O_2 injection not optimal

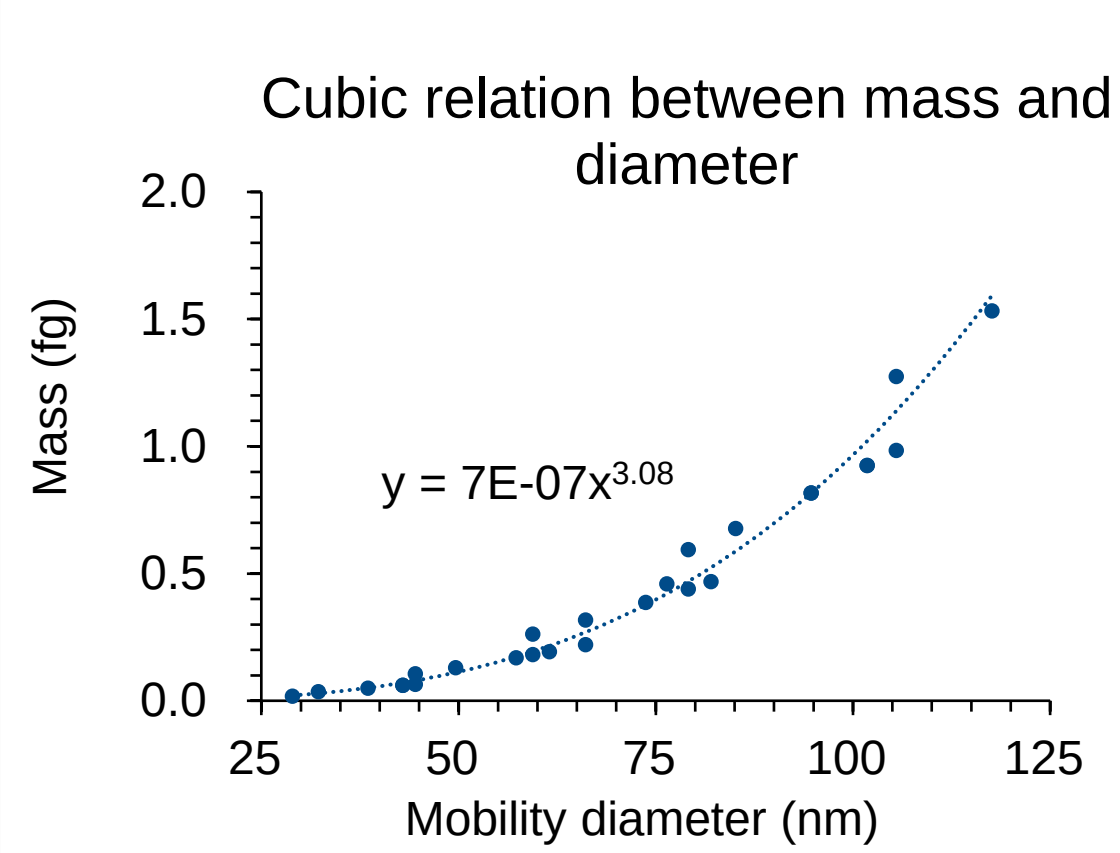




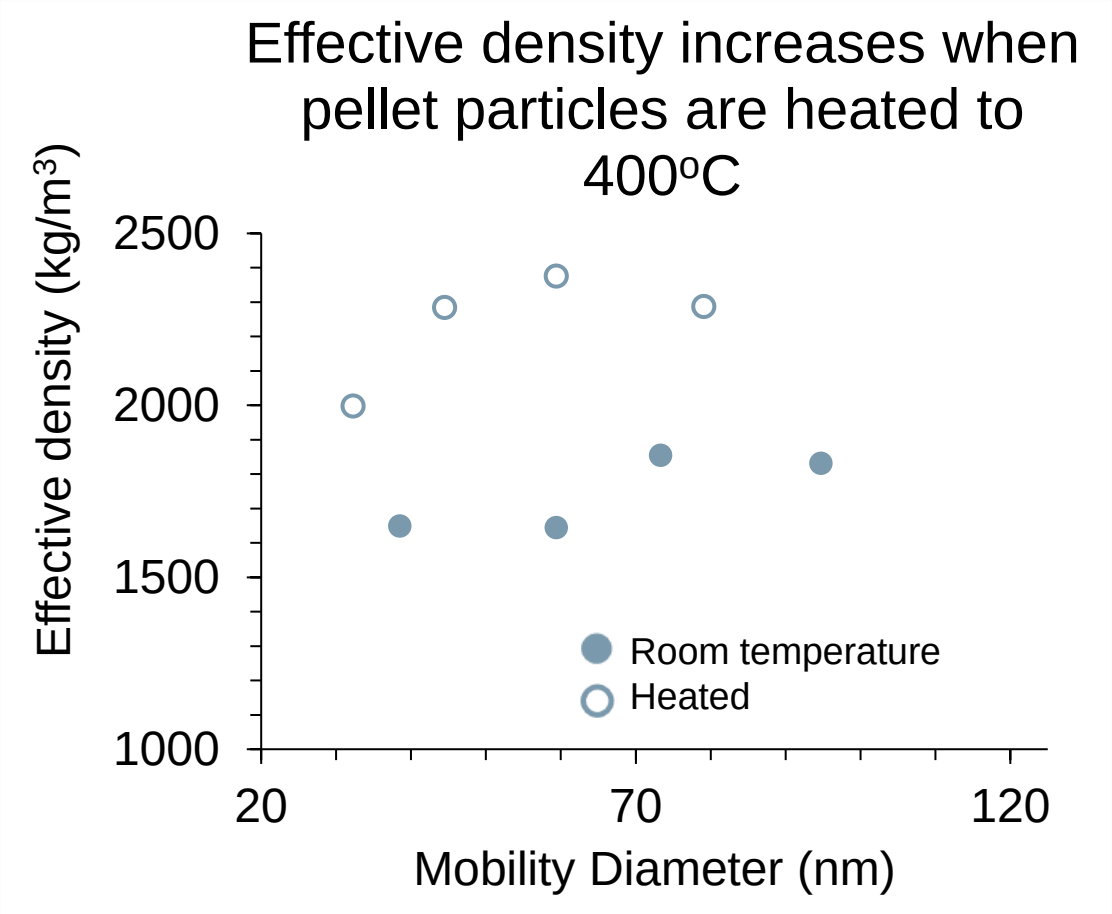
Conclusions

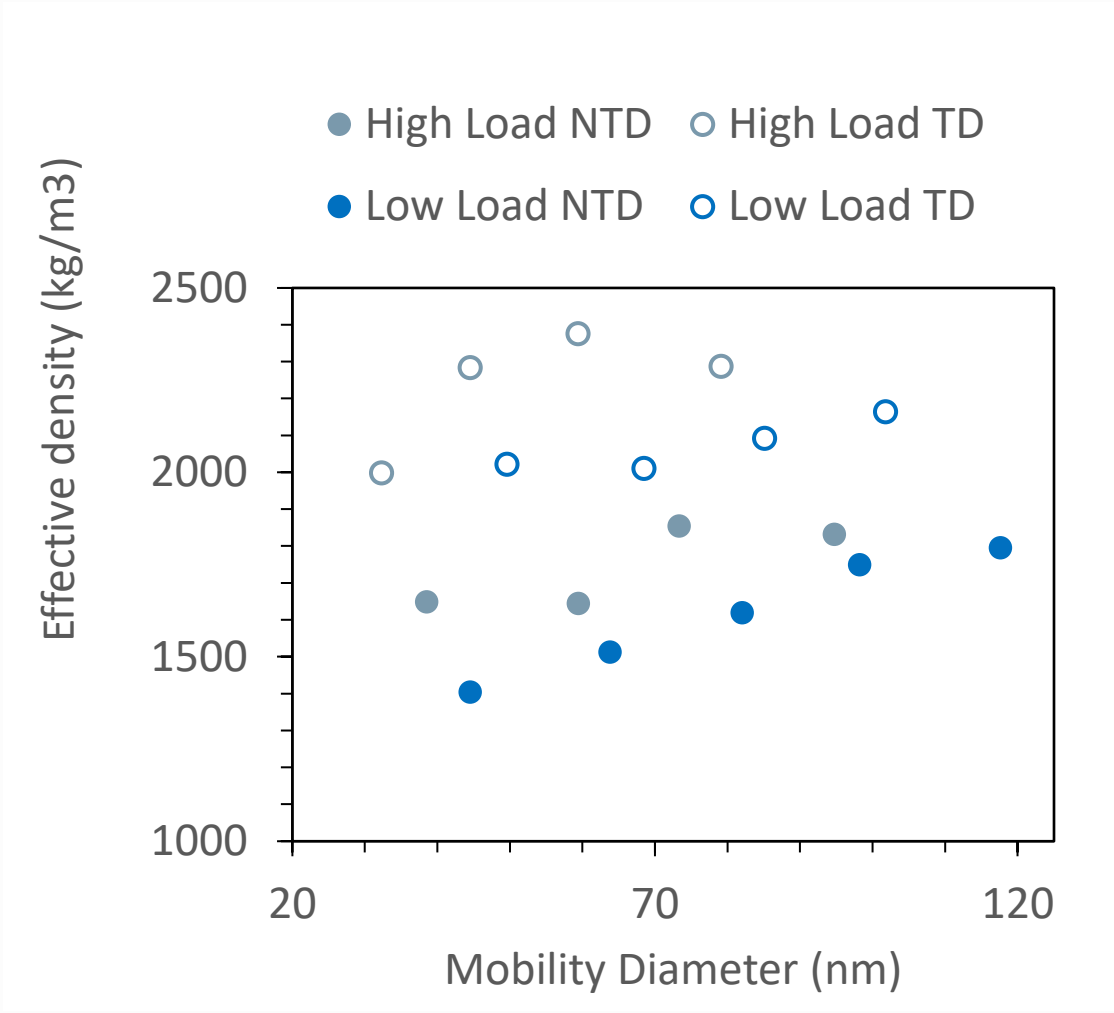
- RWC is a **significant** source of air pollution
- Comprehensively **characterized emissions** from two RWC appliances
  - Morphology, optical and chemical properties
- Emitted **particles are very different** depending on RWC appliance
- Wood **log stoves emit more** material than pellet stoves
- Pellets stoves **become more polluting** as loading decreases
- Studies on **ageing**
  - E.g. SOA formation, BrC bleaching
- **Toxicological effects** of different particle characteristics
- **Reporting** emission factors
  - Less than optimum conditions
  - Additional species

Pellet particles



Pellet particles

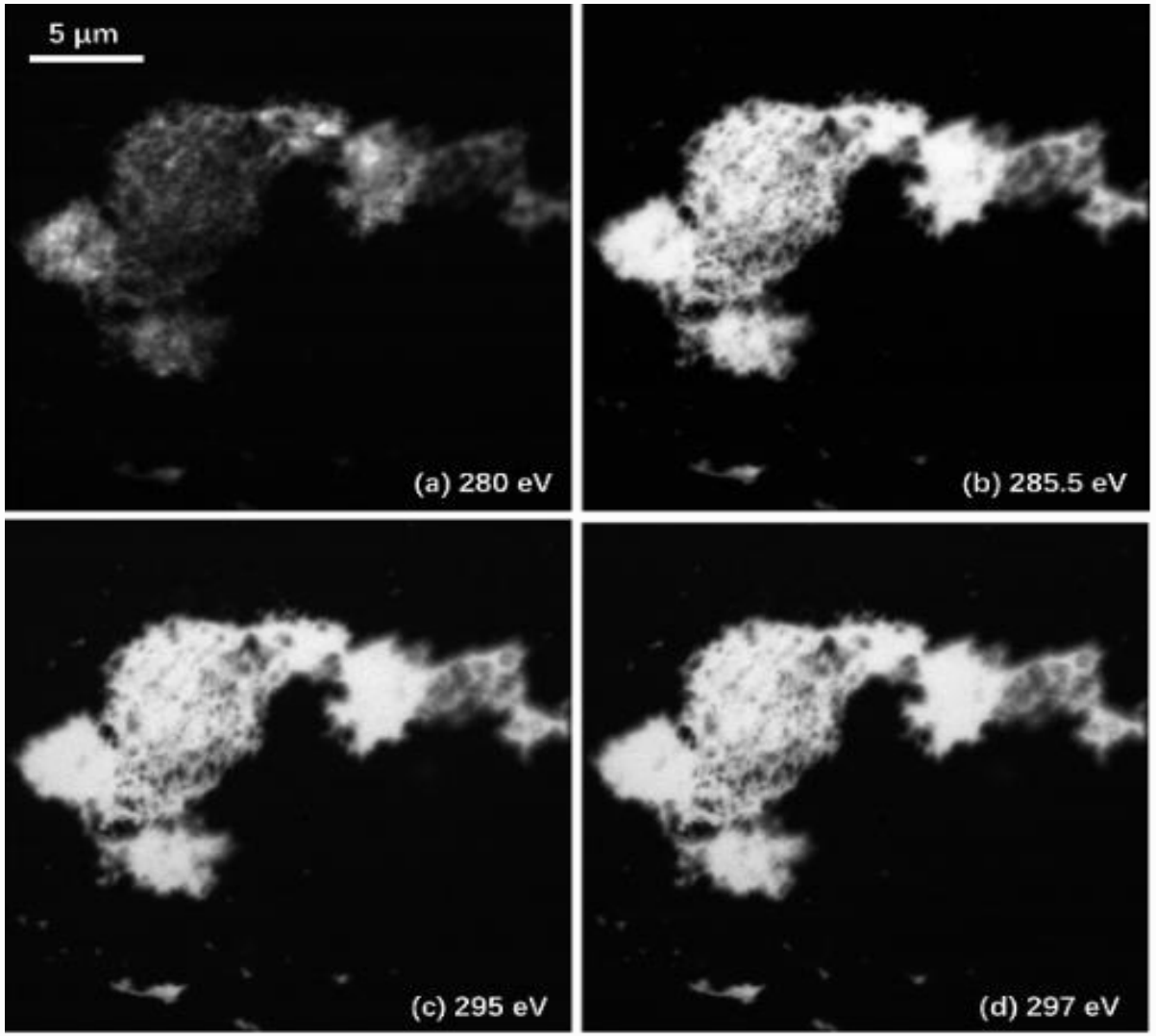




Log particles

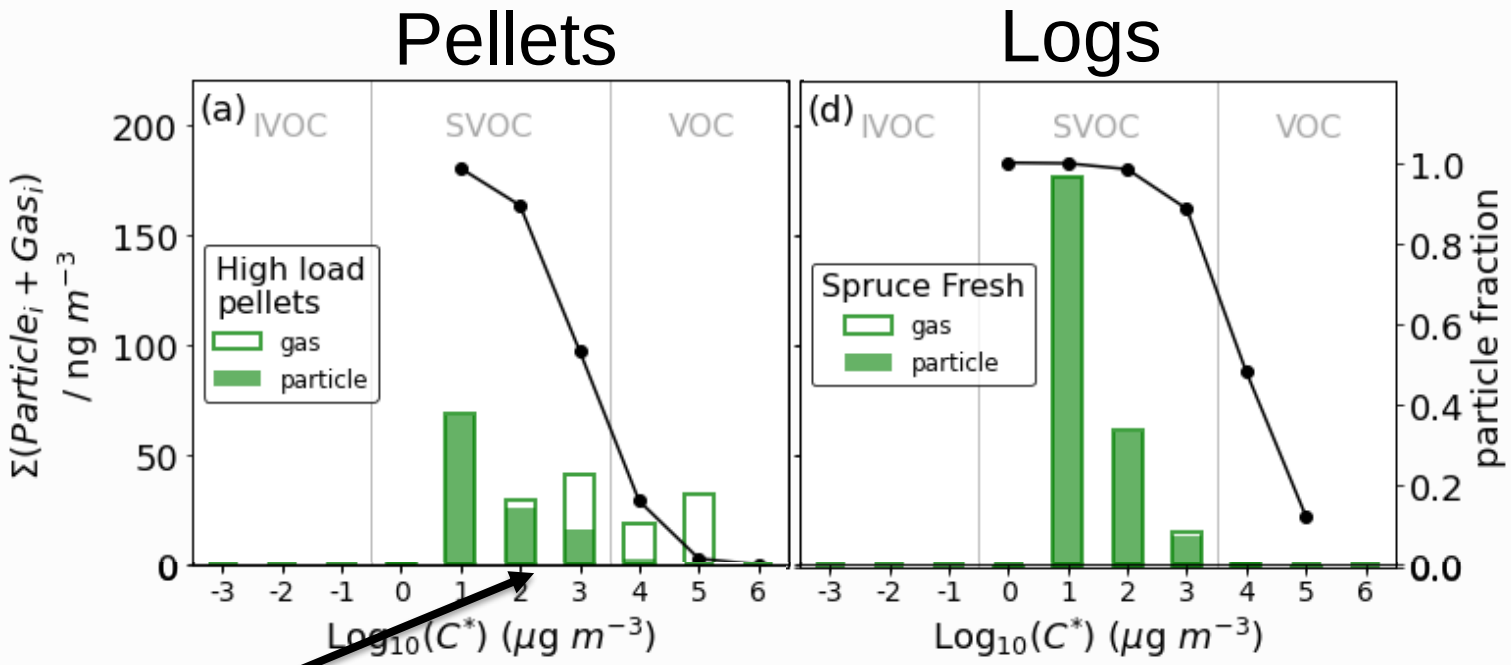
Scanning transmission xray microscopy (STXM)

Various states of carbon



Volatility

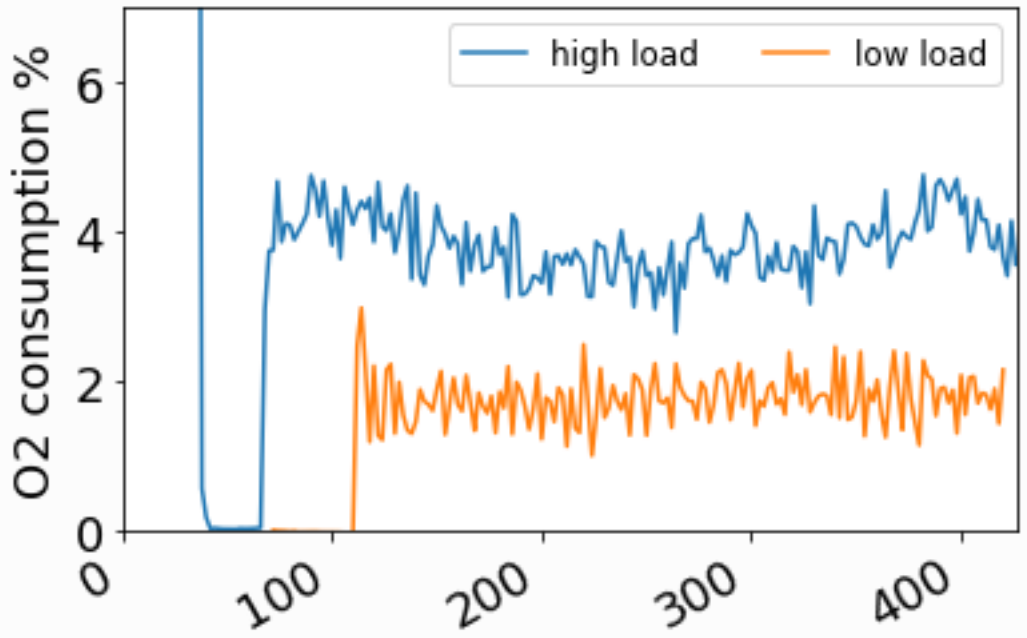
Compounds are grouped by their volatilities (C_i*)



Greater gas phase component

Increasing volatility

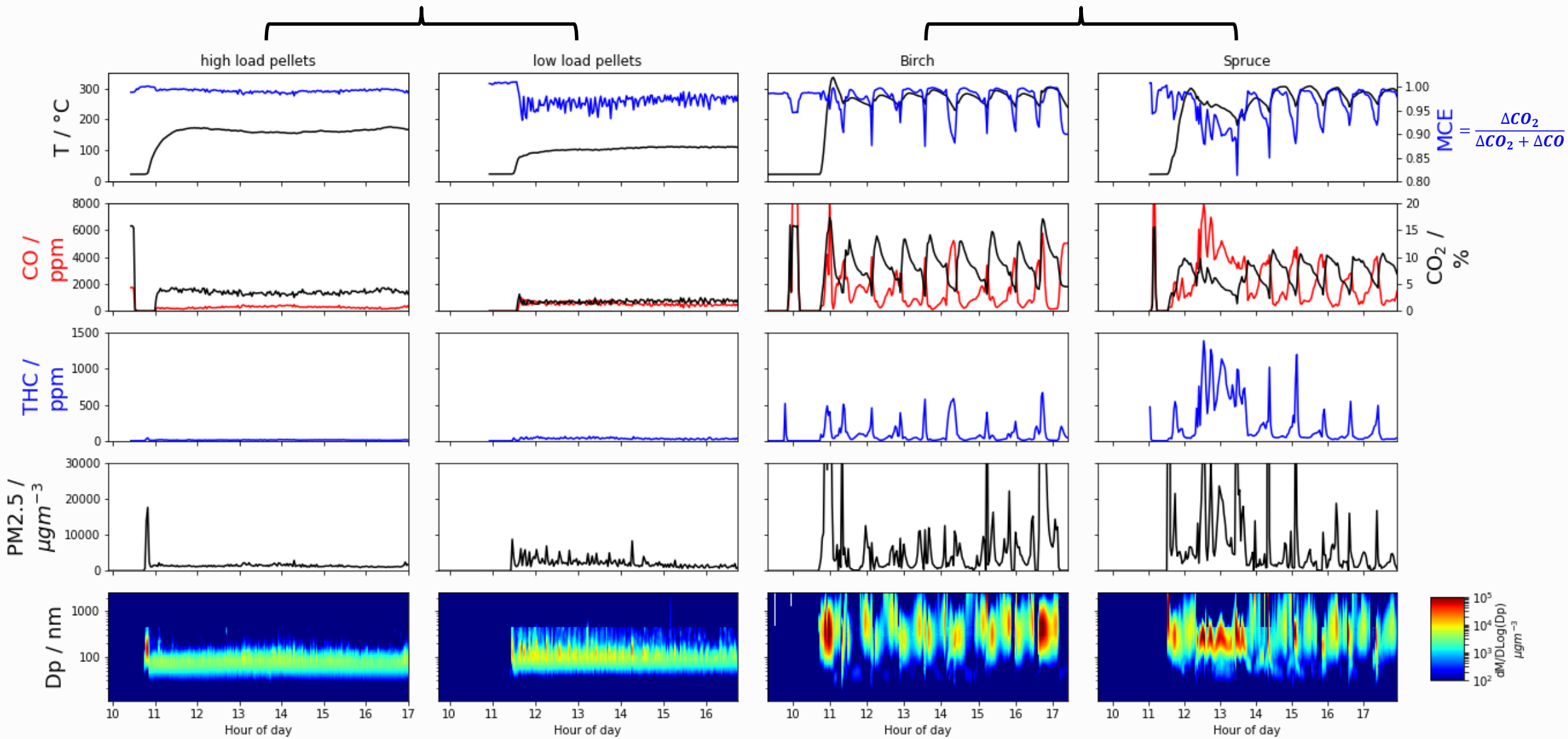
Fuel and O2 consumption



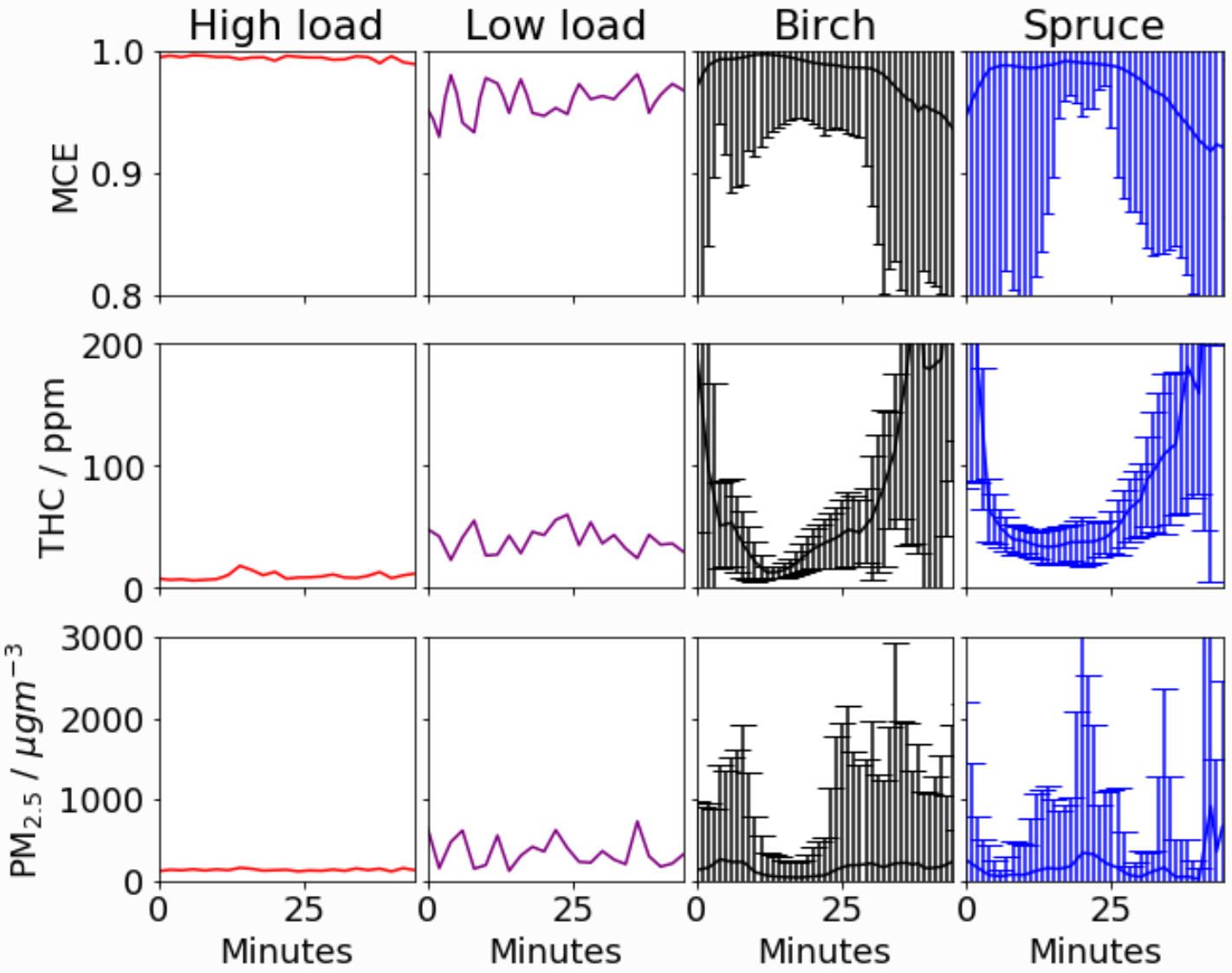
Fuel consumption

- low load 0.69 kg per hour
- high (full) load 1.16 kg per hour

Overview


Pellets
Wood
high load pellets
low load pellets
Birch
Spruce
T / °C
MCE
$= \frac{\Delta CO_2}{\Delta CO_2 + \Delta CO}$
CO / ppm
CO_2 / %
THC / ppm
PM2.5 / $\mu g m^{-3}$
Dp / nm
dM/DLog(Dp) $\mu g m^{-3}$
Hour of day

Overview


High load
Low load
Birch
Spruce
MCE
1.0
0.9
0.8
THC / ppm
200
100
0
$PM_{2.5}$ / μgm^{-3}
3000
2000
1000
0
0
25
Minutes

Human health and associated costs of RWC

Revealed: air pollution may be damaging 'every organ in the body'

Exclusive: Comprehensive analysis finds harm from head to toe, including dementia, heart and lung disease, fertility problems and reduced intelligence

Damian Carrington
Environment editor
Fri 17 May 2019 11.00 GMT

Air pollution may be damaging every organ and vi
human body, according to a comprehensive new g

The research shows head-to-toe harm, from heart
diabetes and dementia, and from liver problems a

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Health impacts of wood burning cost EU and UK €17 billion a year

Wood-based home appliances are responsible for 63 per cent of the health costs from air pollution related to heating and cooking in homes in the European Union and UK

HEALTH 30 March 2022

By Michael Le Page

epha european public health alliance

ABOUT US POLICY CLUSTERS CAMPAIGNS ACTIONS

Replacing fossil fuels and biomass with cleaner alternatives in residential heating and cooking can decrease the social health costs, say researchers

by European Public Health Alliance | Mar 31, 2022 | Clean Air | Publications

"Total **health-related costs** *to society of outdoor air pollution due to residential heating and cooking activities by households in Europe amounted to* **€29 billion** *in 2018."*

"A conservative estimate of the current contribution of biomass smoke to **premature mortality** *in Europe amounts to at least* **40,000 deaths per year**."