The "beReal" Project
-
Scientific Highlights

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SEVENTH FRAMEWORK PROGRAMME

Objectives

Providing **insights** & **highlights** of the **development process** of the „beReal" methods for firewood and pellet stoves

Firewood Stoves*

- Suction pyrometer – Effect on (indirect) efficiency determination
- Thermal efficiency – Direct vs. indirect determination & the effect of cooling down
- Effect of ignition mode on combustion performance
- Effect of draught conditions on combustion performance

* Tests performed by BE2020+ and TFZ

Firewood Stoves

Suction pyrometer – Effect on (indirect) efficiency determination

a) Tests from an accredited test institute (experiments of a previous project):

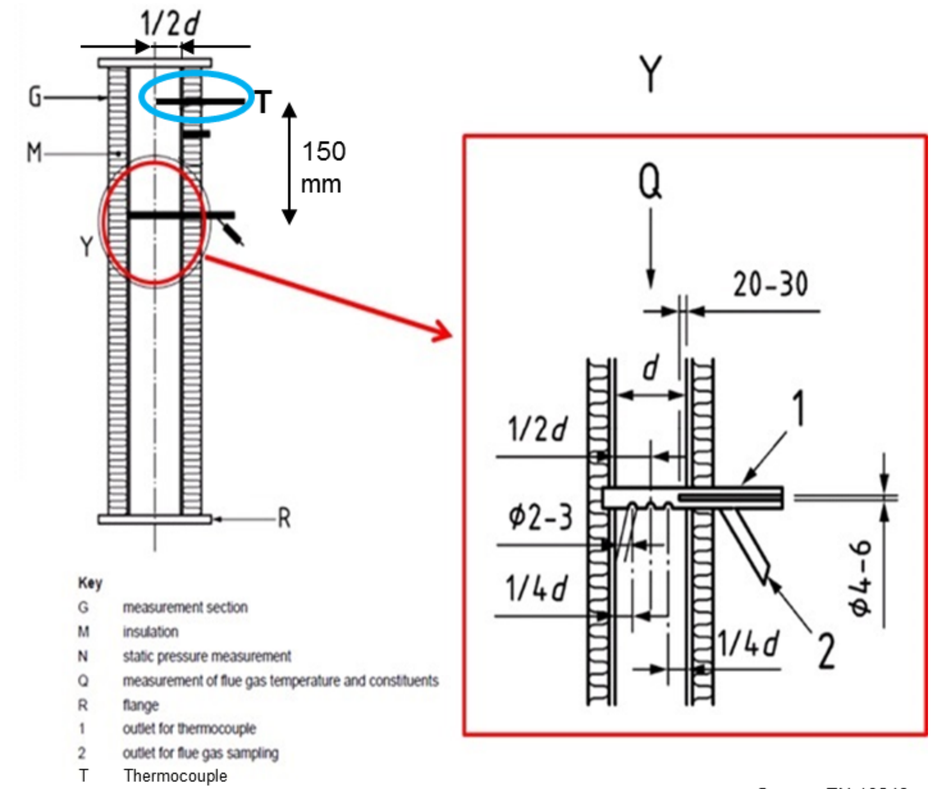
- 3 Roomheaters according to EN 13240 (A, B, C) → thermal efficiency (indirect)

$$\eta = 100 - (q_a + q_b + q_r)$$

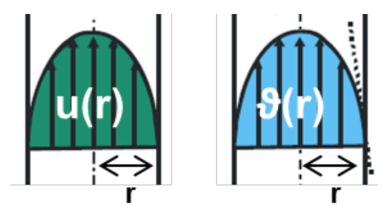
- Thermal (q_a) & chemical (q_b) flue gas losses & losses due to unburnt material (q_r)

b) Comparative combustion tests

- 1 Roomheater acc. to EN 13240
- Flue gas temperature measurement:
  - Suction pyrometer (different suction velocities)
  - Thermocouple (centrally placed in the flue gas pipe)
- Evaluation of measured temperature differences and their impact on indirect thermal efficiency determination
- Variation of flue gas velocities in the suction pyrometer



Source: EN 13240

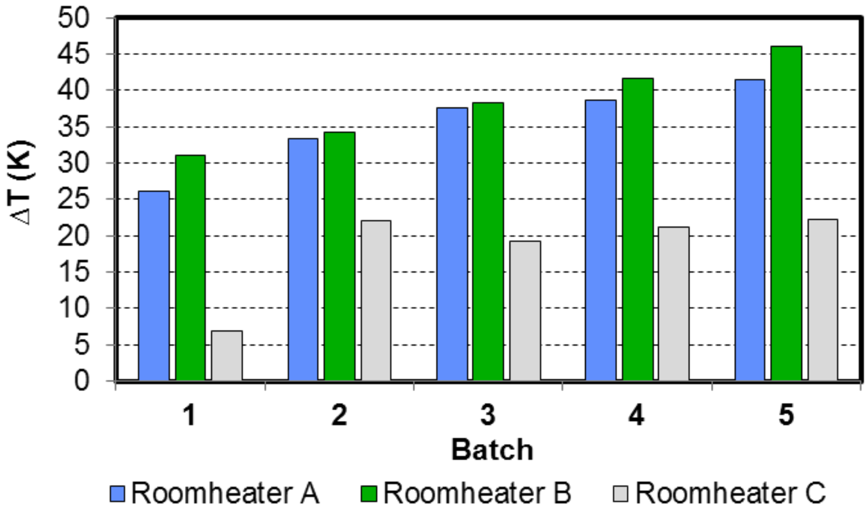


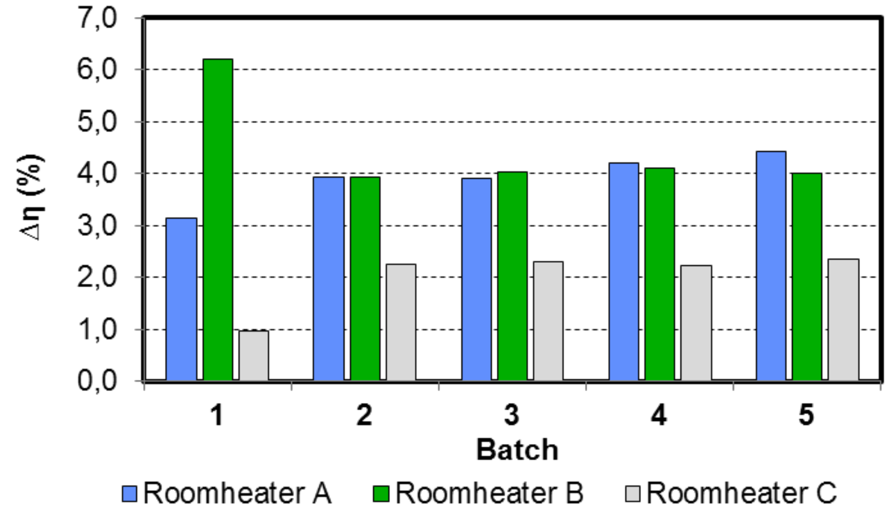
Velocity u(r) and temperature ϑ(r) profile depend on flow conditions in the flue gas pipe

Firewood Stoves

Suction pyrometer – Effect on (indirect) efficiency determination

Results **a) Tests from an accredited test institute** (experiments of a previous project)





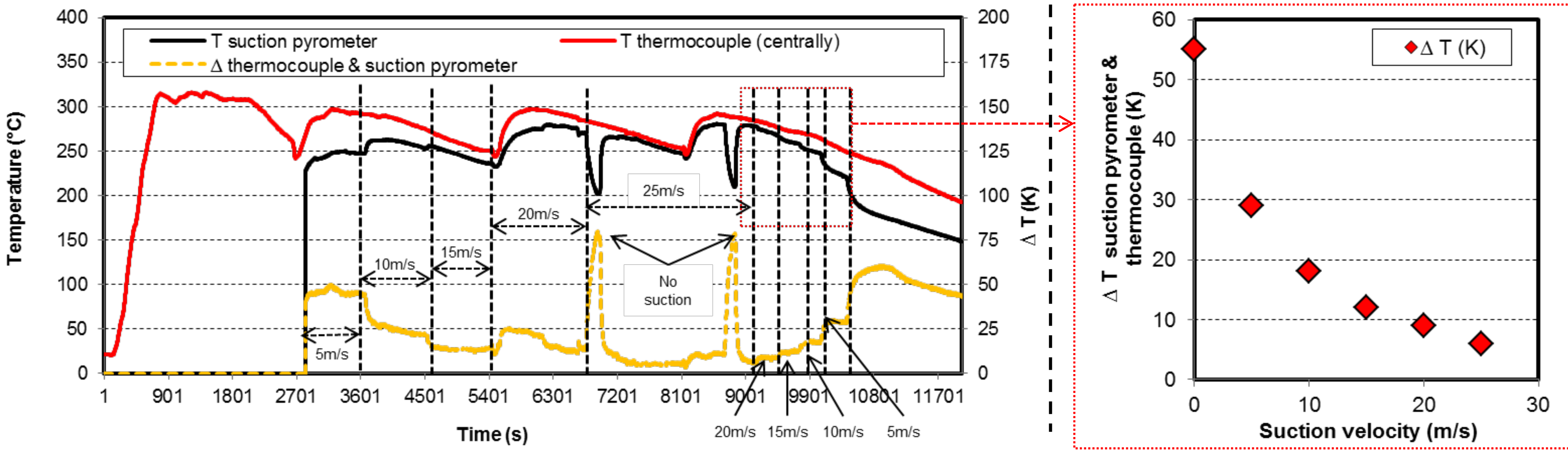
- **Clear differences** between suction pyrometer and core temperature (thermocouple) obvious (for all three tested roomheaters) → Higher temperatures measured with the thermocouple (**7K – 46K**)
- Consequently differences of **thermal efficiencies** varied from **1 % to 6.2 % (Ø 3.5 %).**
- The required flue gas velocity in the suction pyrometer (20-25 m/s) is **not/ hardly** reached when only gas analyzers are used for flue gas suction.

➢ Flue gas temperature measurement is essential for thermal efficiency determination

Firewood Stoves

Suction pyrometer – Effect on (indirect) efficiency determination

<u>Results</u> b) Comparative combustion tests



- Correlation of suction velocity and measured temperature with suction pyrometer clearly evident
- Highest impact of suction velocity on temperature difference between 0 to 15 m/s
- Differences between thermocouple and suction pyrometer was around 5 to 10 K (even when suction velocity was ≥ 20 m/s).

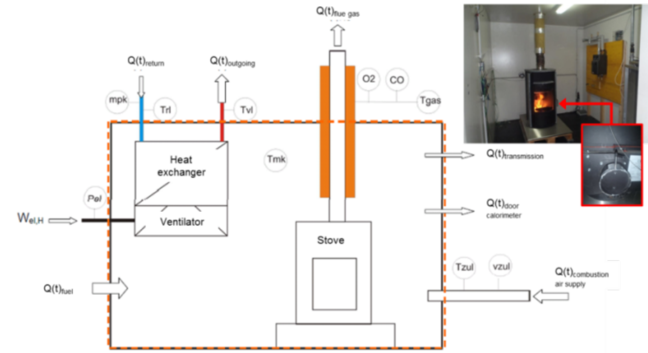
- Thermocouple measurement less error-prone compared to the suction pyrometer measurement
- <u>Relevance for the beReal test method:</u> Flue gas temperature measurement will be done with a thermocouple centrally placed in the flue gas pipe

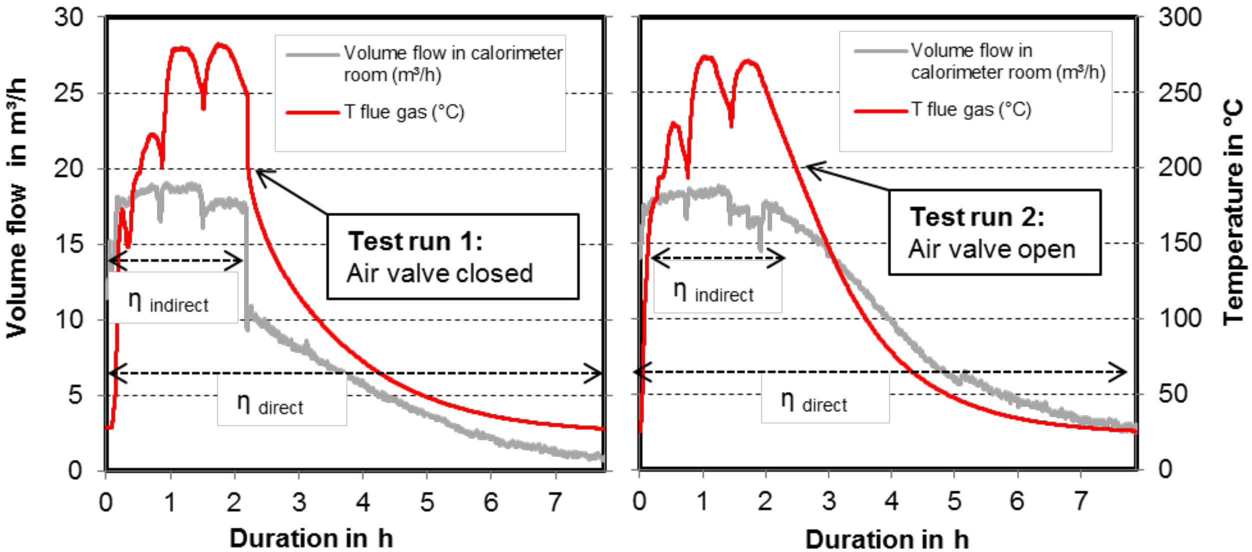
Firewood Stoves

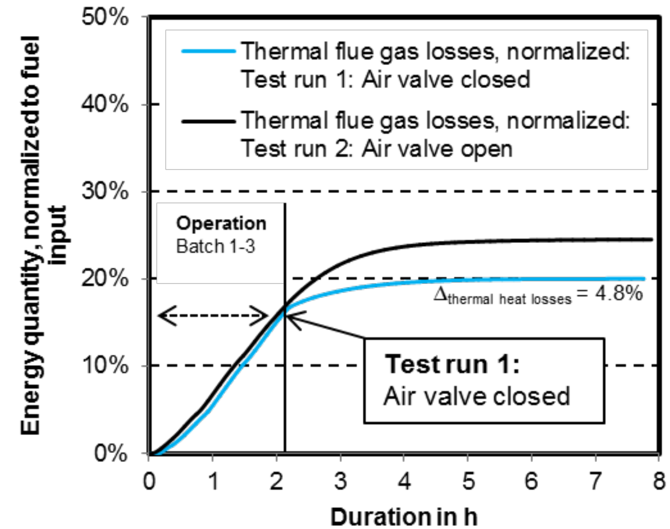
Thermal efficiency – Direct vs. indirect & the effect of cooling down

Approach

- Comparative assessment of thermal efficiency using the **indirect** (EN 13240) and **direct** (calorimeter room) approach
- Comparative test with a roomsealed roomheater (3 batches per test cycle)







Results

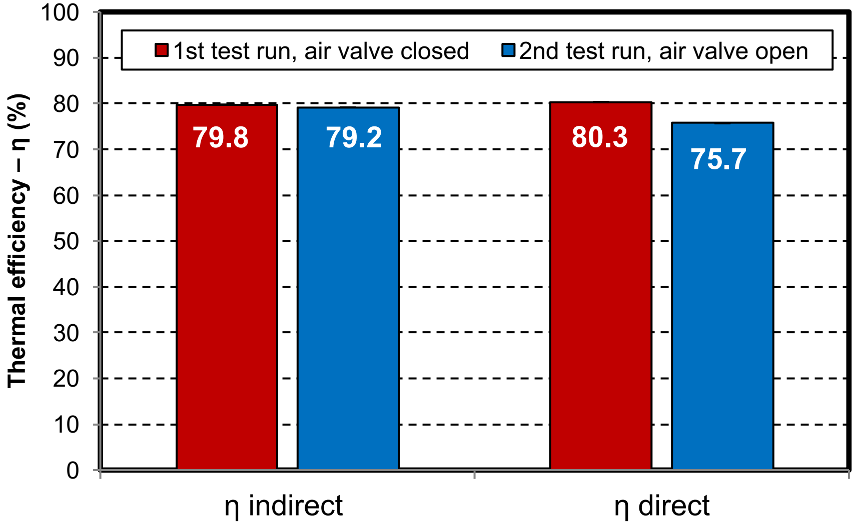
- **Cooling down process** & **air valve settings** after heating operation influence thermal efficiency performance → should be respected in the beReal test procedure
- ➢ Important aspect for avoiding emissions and low efficiency in real-life operation (**Quick-User-Guide!**)

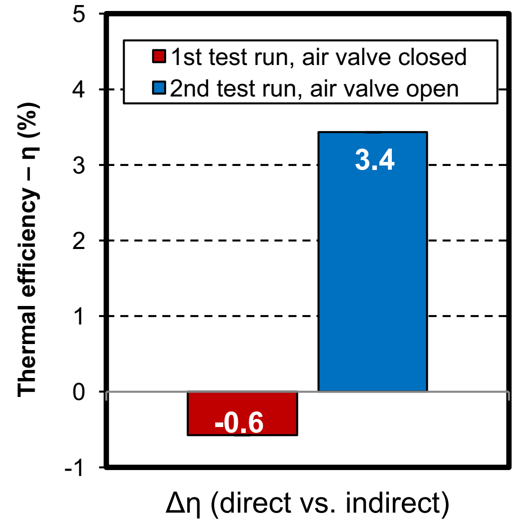
Firewood Stoves

Thermal efficiency – Direct vs. indirect

$$\eta_{direct} = \frac{Output}{Input} = \frac{E\ Heat\ exchanger\ (kWh) + E\ Transmission\ (kWh) - E\ Ventilator\ (kWh)}{E\ Fuel\ input\ (kWh)} \times 100\%$$

$$\eta_{indirect\ EN13240} = (1 - thermal\ losses - chemical\ losses - 0.005) \times 100\%$$





Results:

Test-run 1: Air valve closed - after heating operation

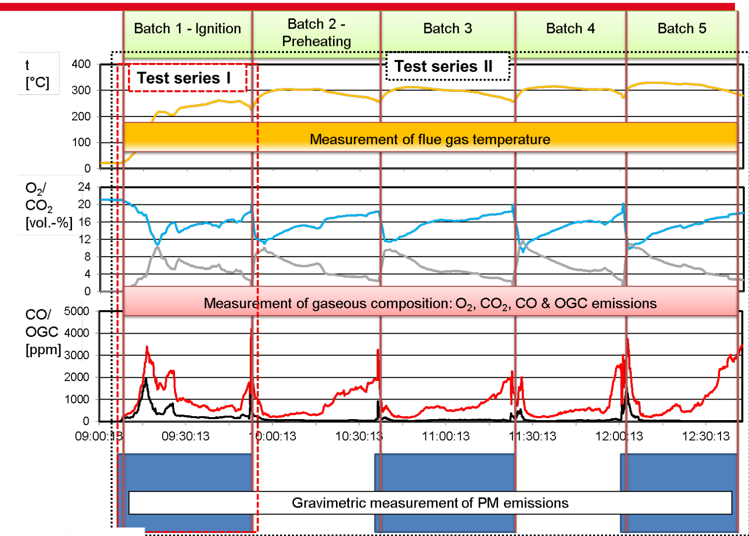
- **Negligible differences** between direct and indirect efficiency determination

Test-run 2: Air valve open - after heating operation

- Higher differences of efficiency (direct vs. indirect)
- ➢ Reason: **Thermal losses of cool down phase** are not respected in the indirect efficiency determination process

Firewood Stoves

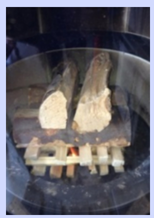
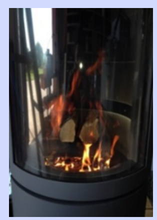
Effect of ignition mode and draught conditions



Approach

Ignition tests (Test series I)

- Start from cold conditions
- Three test runs for each variation / two roomheaters (A, B)

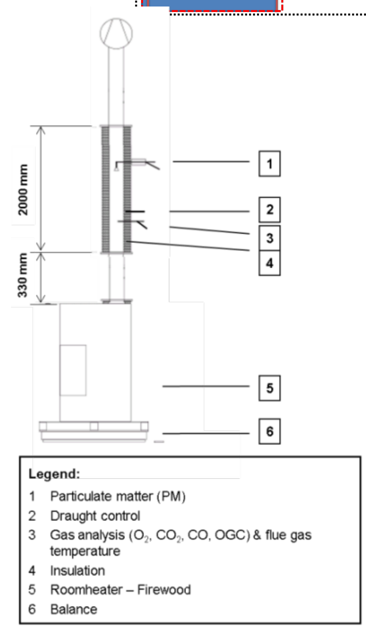
Top-down ignition mode		Bottom-up ignition mode	
			
Variation 1	**Variation 2**	**Variation 3**	**Variation 4**
Spruce kindling (Spruce + Beech)	Beech kindling (Beech + Beech)	Spruce kindling (Spruce + Beech)	Beech kindling (Beech + Beech)

Beech

Spruce

Effect Draught conditions (Test series II)

- One test cycle for each draught level – 12Pa, 24Pa, 48Pa
- 5 batches per test cycle with three roomheaters (A, B, D)



Firewood Stoves

Effect of ignition mode

Bottom-up vs. top-down

- Kindling material: Impact in general very low

Roomheater A:

Bottom-up ignition mode less CO and PM emissions

- CO: ~ 12% / PM: ~ 20%
- BUT: Lowest OGC emissions achieved by top-down ignition

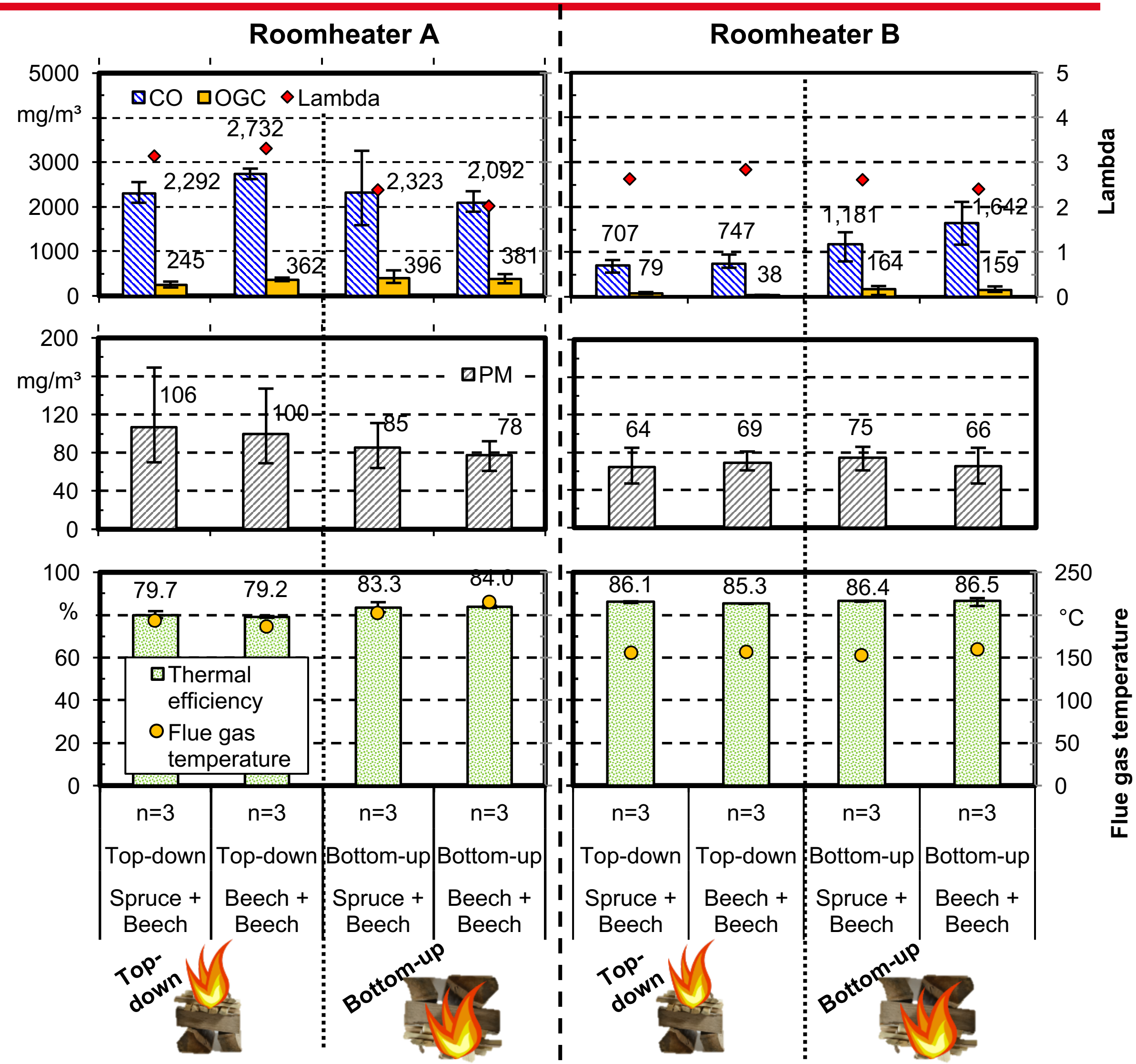
Roomheater B:

Lower CO and OGC emissions for top-down ignition mode

- CO: ~ 50% / OGC: ~ 65%
- PM: only marginal differences

- Best thermal efficiencies achieved by bottom-up ignition mode

➢ **Ignition mode** is an **obligatory** part of the **Quick-User-Guide**

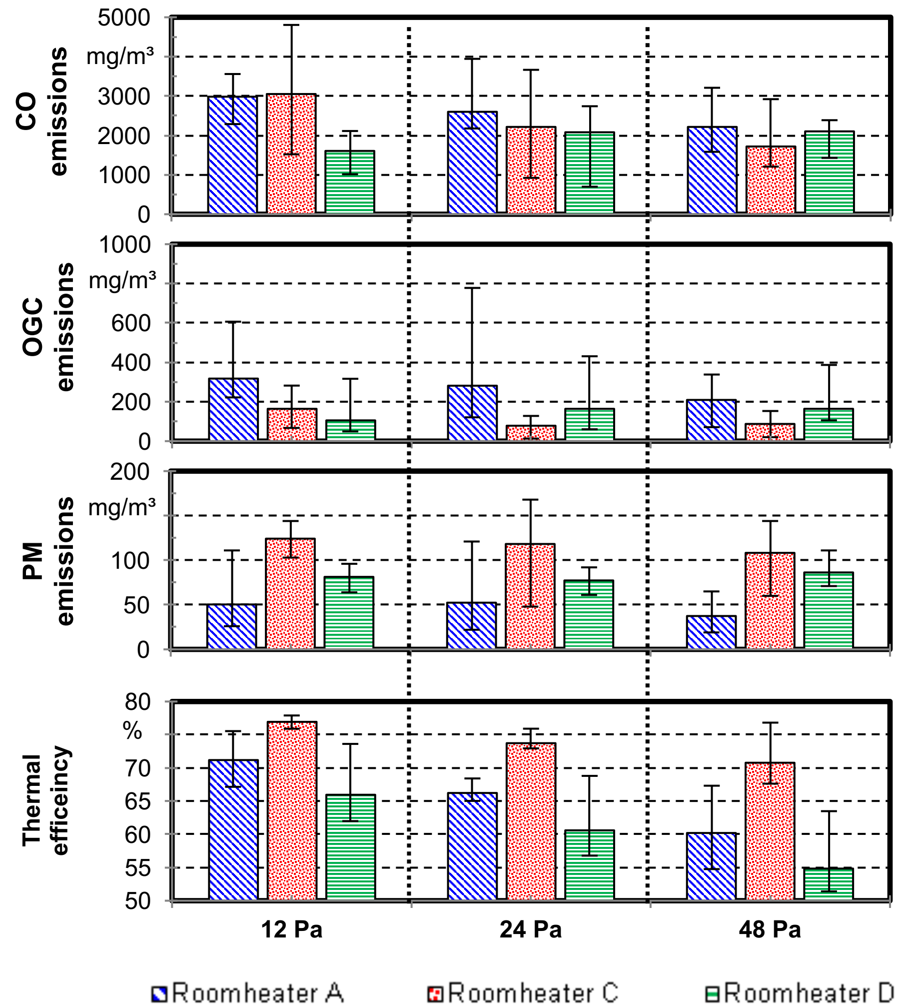


- all emission concentrations in mg/m³, at STP conditions, dry, transferred to 13 vol.-% O_2

Firewood Stoves
Effect of draught conditions

- Trends of impact of increased draught on CO & OGC were investigated (but: statistically not significant)
  - Stove A & C: Emissions **decreased**
  - Stove D: Emissions **increased**
- **Correlation** of draught conditions and gaseous emission depend on the **appliance specifics**
- No effect of draught conditions on PM emissions → **no correlation**
- **Decrease** of **thermal efficiency** at higher draught level for all three roomheaters → **Correlation statistically significant**

➢ **Higher draught** conditions result in **lower thermal efficiency**



- all emission concentrations in mg/m³, at STP conditions, dry, transferred to 13 vol.-% O_2

Objectives

Providing **insights** & **highlights** of the **development process** of the „beReal" methods for firewood and pellet stoves

Pellet Stoves*

- Fuel quality: A screening on pellet quality from Europe
- Pellet quality and combustion performance
- Effect of cleaning process on emissions and thermal efficiency

* Tests performed by TFZ

Pellet Stoves

Fuel quality: A screening on pellet quality from Europe

Motivation

- Varying qualities of wood pellets & search for suitable test fuels for pellet stoves

Approach

- Pellets considered in screening: Wood pellets in bags/ 42 samples in total
  - 20 samples from Germany, 22 samples from all over Europe (Austria, Switzerland, Sweden, France, Estonia, Denmark, UK, Belgium, Poland, Czech Republic, Italy)
  - Quality label: 27 with EN_{plus}, 22 with DIN_{plus}, 8 samples without label
  - Some pellet samples from different factories but same producer

Analysis program

- Combustion properties: Ash & moisture content, net calorific value
- Physical properties: Bulk density, mechanical durability, share of fines
- Chemical composition: Nitrogen, sulfur, chlorine content, ash forming elements

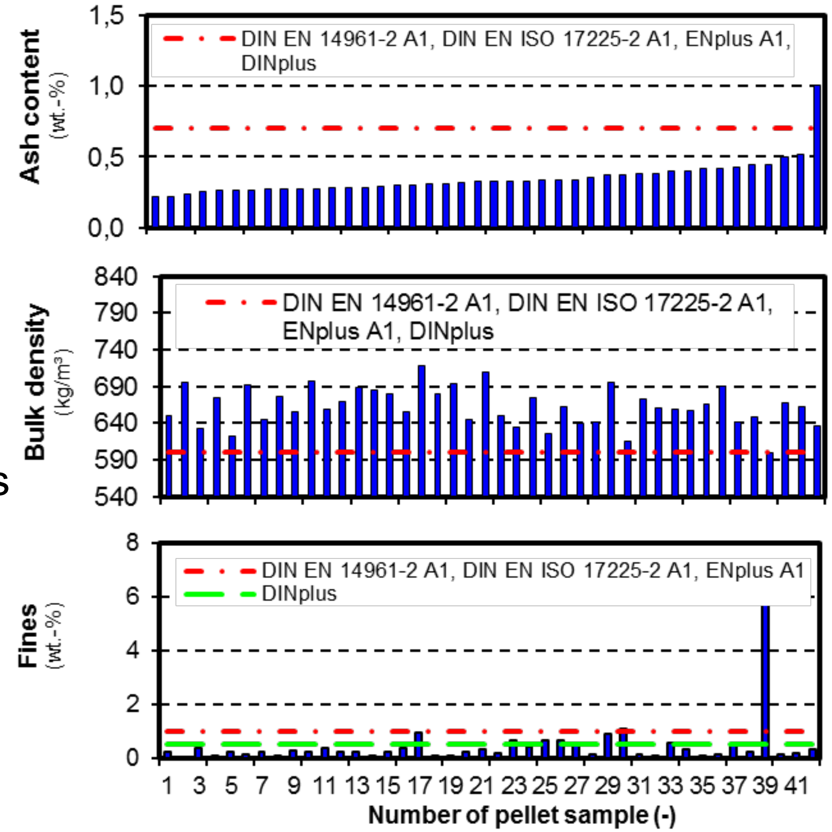
Pellet Stoves

Fuel quality: A screening on pellet quality from Europe

Results

Combustion properties:

- **Ash content**: All samples with increasing ash content (@ 550°C); Only one sample (# 42) does not fulfil requirements of A1 quality
- **Moisture content**: Only one sample (# 39) does not fulfil requirements of A1 quality (<10%)
- **Net calorific value**: All samples fulfil the requirements regarding net calorific value (Ø 18,956 $kJ/kg_{d.b.}$)



Physical properties:

- **Bulk density**: Only one pellet sample does not meet the requirements but is very close to the value (599 versus 600 kg/m³). Average bulk density of 662 kg/m³ (range: 599 to 717 kg/m³)
- **Mechanical durability**: Two samples do not meet the requirement of > 97.5 (# 23 and # 39)
- **Share of fines**: DIN_{plus} has stricter limits on fines for bagged pellets compared to EN_{plus} and ISO. Two samples do not meet the ISO-requirements (# 30 and # 39)

Fuel quality: A screening on pellet quality from Europe

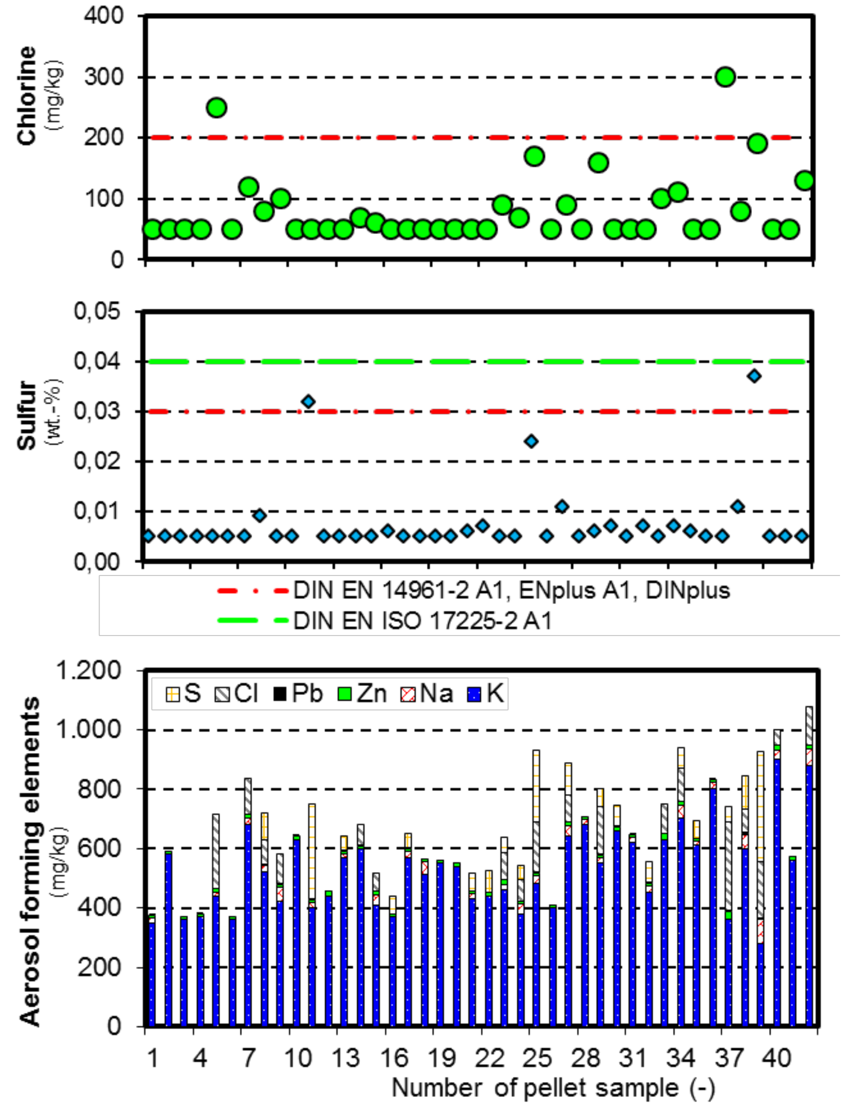
beReal

Results

Chemical composition:

- **Nitrogen content**
  - All samples meet the requirements on nitrogen content (DIN EN ISO 17225-2 A1 & EN_{plus}: < 0.3 wt.-%).
- **Sulfur content**
  - All samples meet the new ISO standard. Lower values for certified pellets
- **Chlorine content**
  - Two samples exceed the limiting values of 0.02 wt.-% (# 5 and # 37)
- **Aerosol forming elements**
  - Aerosol forming elements are dominated by K content (280 - 900 mg/kg; Ø 528 mg/kg)

➢ **Positive results** for **quality** of wood pellets on the German and European market



TFZ

SEVENTH FRAMEWORK PROGRAMME

Pellet Stoves
Pellet quality and combustion performance

Motivation

- Impact of different fuel characteristics during operation in one conventional pellet stove (8 kW)

Approach

- Serial combustion of 12 selected pellet fuels from the pellet screening
- 3 PM samples, each over 15 minutes per fuel, using plane filters
- All 12 selected fuels are EN_{plus}-certified wood pellets

After preheating the pellet stove for at least 1 hour

1.
Refilling the storage tank with the next fuel → 15 min to burn the previous fuel completely

2.
Execution of 3 PM samples with a duration of 15 min per sample

3.
Cleaning the storage tank and the stoker screw completely with a vacuum cleaner

Pellet Stoves

Pellet quality and combustion performance

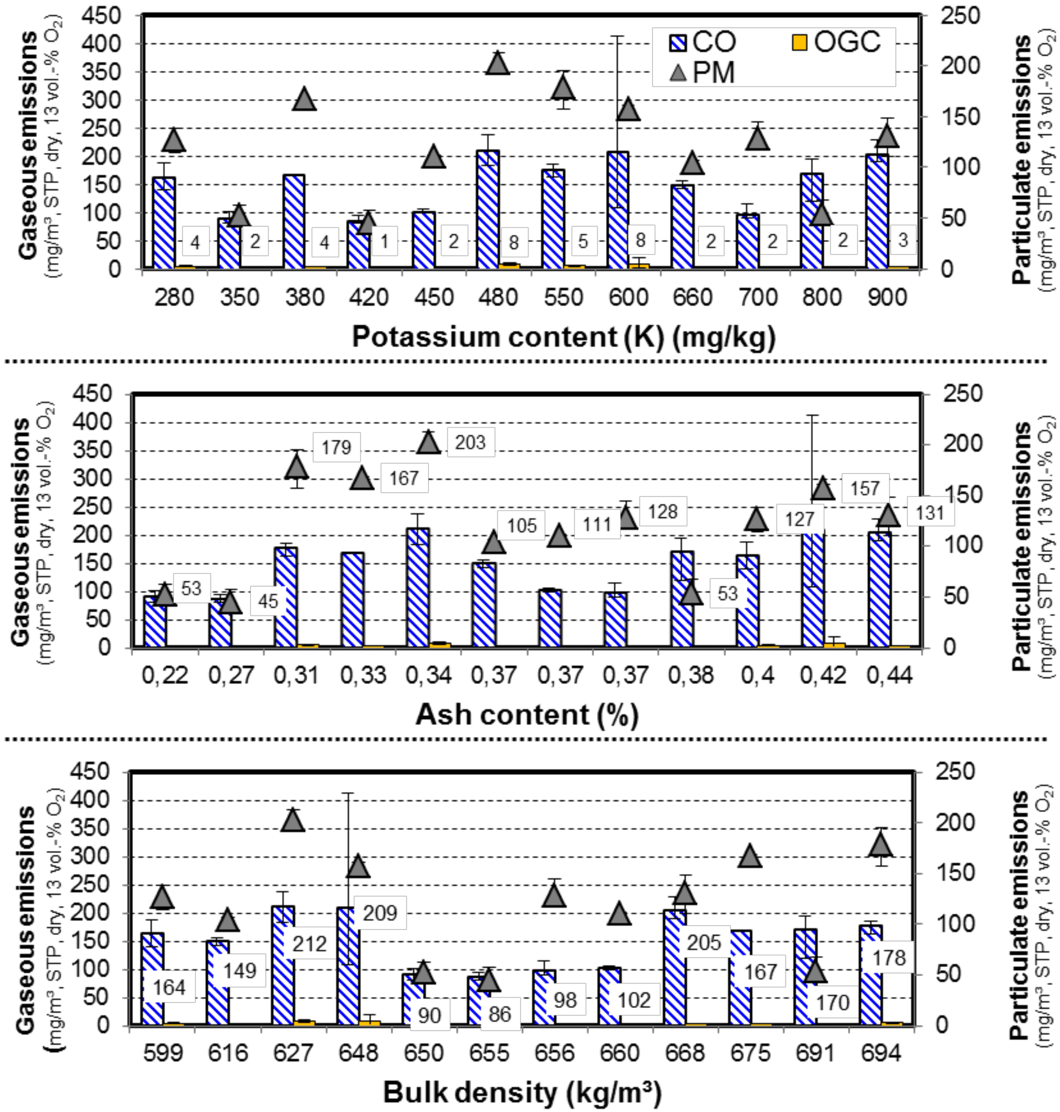
Results

- Different EN_{plus}-certified pellets can cause **very large emission variations** with one pellet room heater.
- There is **no clear trend** showing the emissions as function of **ash** content, **potassium** content, **bulk density** etc.
- Multiple regression analyses has brought no further knowledge (many more testing replications would be required).

➢ Yet unknown pellet properties need to be investigated

➢ Picking up the best suitable fuel can lead to big advantages

➢ beReal: Test fuel has to be provided by the testing institute



Pellet Stoves

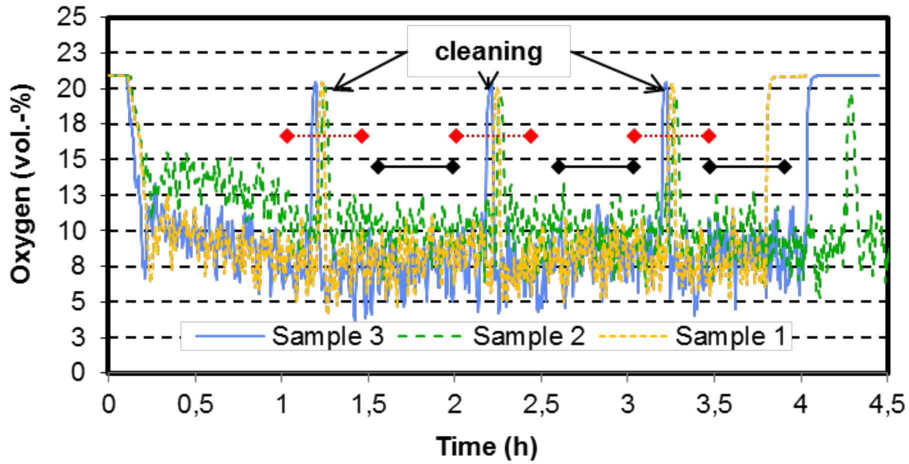
Effect of cleaning process on emissions and thermal efficiency

Motivation

- Impact of **cleaning process** on combustion performance

Approach

- Evaluation of gaseous and particulate emissions **with** (◆⋯◆) and **without** (◆—◆) the cleaning interval (30 min)
- Tests were carried out with three different pellet samples (Sample 1 – 3)
- One commercial pellet stove (EN 14785) was used (Nominal load: 8 kW)



Number of Sample	1	2	3
			
Producing country	Austria	Belgium	Poland
Certification	EN Plus A1	DIN Plus	-
Description	wood pellets	pinewood without bark	100 % wood
Diameter [mm]	6	6	6
Heating value [kJ/kg]	18790	18893	19330
Ash content [%]	0.26	0.28	0.33
Moisture content [%]	7.3	7.4	3.3
Bulk density [kg/m³]	622	669	709
Mechanical strength [%]	98.9	99.2	98.9
Fines [%]	0.25	0.24	0.33
C [Ma.-%]	51.0	50.1	51.3
H [Ma.-%]	6.1	6.1	6.2
O [Ma.-%]	42.8	43.7	42.4
N [Ma.-%]	0.10	0.09	0.10
S [Ma.-%]	0.005	0.005	0.006
S [mg/kg]	<5	<5	6
Cl [mg/kg]	250	<50	<50
K [mg/kg]	440	440	430
Na [mg/kg]	13	<10	17
Zn [mg/kg]	10	15	9
Sum of aerosol formers [mg/kg]	718	520	512

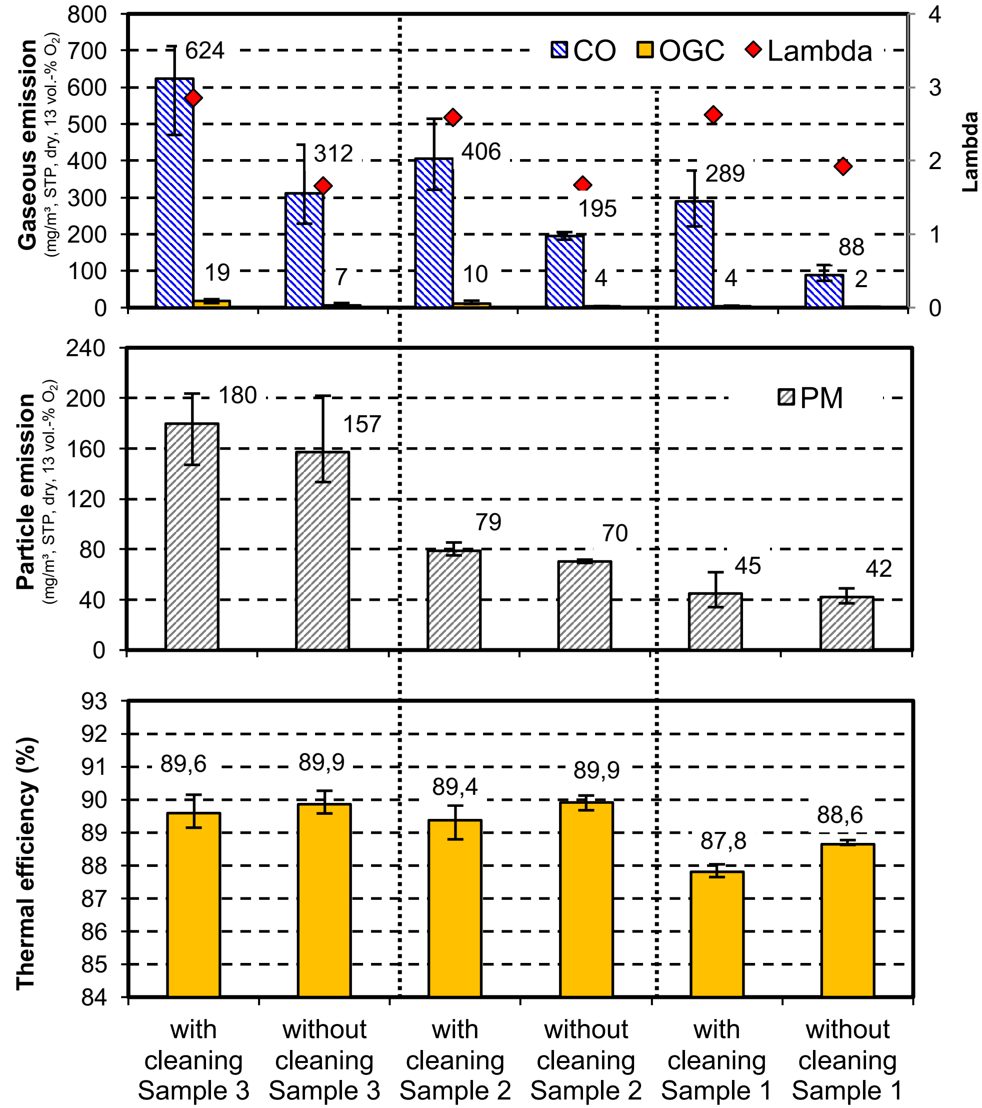
Pellet Stoves

Effect of cleaning process on emissions and thermal efficiency

Results

- **Different emissions** for the three fuel samples (same finding compared to the previous test series in another stove)
- **Gaseous emissions** “with cleaning” **significantly higher** compared to “without cleaning” for gaseous emissions
- Average **PM emissions lower** for intervals “without cleaning” compared to “with cleaning”
- **Lower thermal efficiency** when the cleaning process is considered, but: In general, the effect of the cleaning process on thermal efficiency was low

➢ **Cleaning phase** has to be **considered** in the beReal test method. The cleaning interval was included in the testing and data evaluation of beReal



Acknowledgements

Associations

Company partners

Subcontractor

Acknowledgements
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Thanks for listening !

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