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6th Central European Biomass Conference

Advanced Test Methods for Pellet Stoves –

A Technical Review

24.01.2020, Graz, Austria

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Introduction

Why we have to look at test methods?

- What is the **purpose** of test protocols?
- They should guarantee the …
  - Product **quality**
  - Product **safety**
  - Product **reliability**
- They should push **technological development** further!
- They should reflect the "**truth**" or the "**real-life**" performance
- What could happen, if test protocols **loose** their reliability?

Source: https://greennews.ie/irelands-own-dieselgate-the-dieselisation-of-irelands-car-fleet-amidst-global-decline/ (accessed Jan. 2020)

Objectives & Approach

- For **pellet stoves** the testing concepts shall become more real-life relevant. Therefore, the objectives are…
  - Comparing **existing testing protocols** worldwide
  - Evaluating the **real-life use** of pellet stoves & identification of most **relevant parameters** for emission and efficiency performance
  - Evaluating a **newly developed lab testing method** focusing on real-life performance (“*beReal*”)
  - Analyzing **real-life relevance** of testing results based on existing EN standard and the advanced testing method (“*beReal*”)

→ **Literature review**

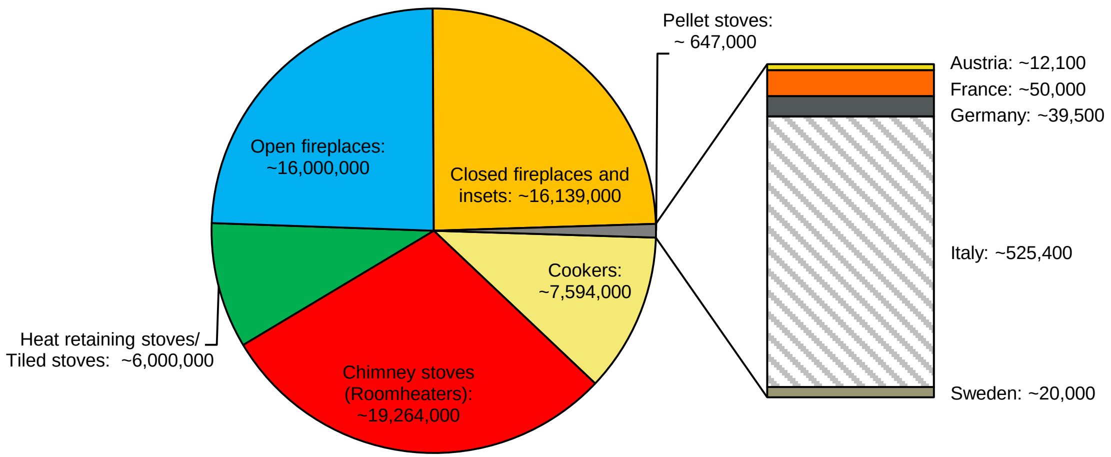
1. **Relevance of pellet stoves:** Stock and market
2. **Existing test standards & Novel test concept “*beReal*”**
3. **EN test results:** Official type test results (also in comparison to wood stoves) & Comparing lab with field

Results

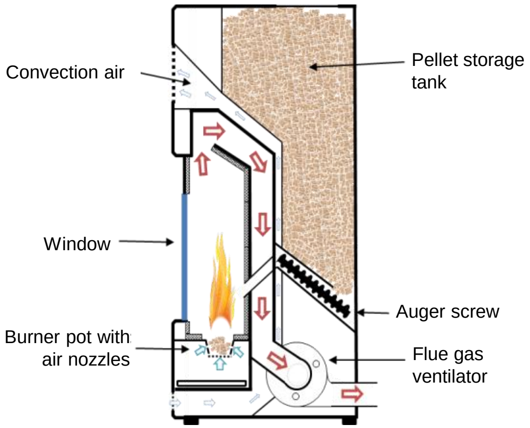
Overview of stock & main features

- Pellet stoves refer to the category **direct room heating** appliances – their main features are the **automatic fuel supply** and the typical use of a **flue gas ventilator**
- Compared to manual fired stoves their stock number is **small** (~ 1%)

Stock of direct room heating appliances in the EU (2007)



Source: EC DG TREN, Lot 15, Numbers referring to 2007

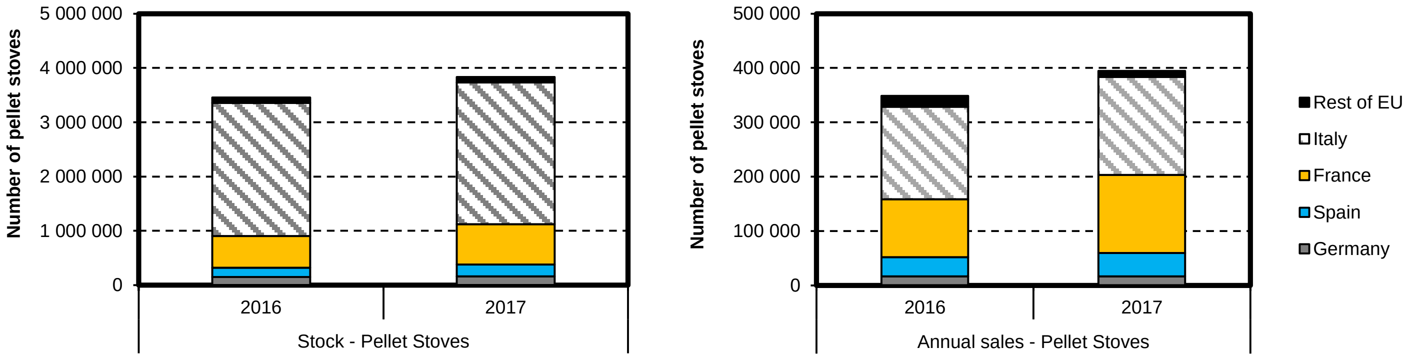


Source: WÖHLER 2017a (translated in English)

Results

Trend of stock and market

- However, compared to 2007 the **stock** has **increased** by almost **600%**
- This growth illustrates their increasing **popularity** and **relevance** among direct room heating systems, especially in **Italy** and **France**
- **Annual sales** ranged around **10%** of the stock in 2016 and 2017



Source: EPC survey 2018, Bioenergy Europe, Statistical report 2018

➢ It can be expected that the stock of pellet stoves and their share among direct room heating appliances will further **increase** in **future**!

Results

Overview of existing test standards

- **Australian/New Zealand test protocol – AS/NZS**
  - AS/NZS 5078:2007 – Domestic solid fuel burning appliances – Pellet heaters – Method for determination of power output and efficiency
  - AS/NZS 4886:2007 – Method for determination of flue gas emission
  - AS/NZS 4014.6:2007 – Wood Pellets

- **Canadian test protocol – CSA**
  - CSA B415.1-10 (2010) – Performance testing of solid-fuel-burning heating appliances

- **US standards – ASTM**
  - ASTM E2779 – 10 (2017): Standard Test Method for Determining Particulate Matter Emissions from Pellet Heaters

- **European test protocol – EN**
  - DIN EN 14785:2006 – Residential space heating appliances fired by wood pellets – Requirements and test methods

AS/NZS 5078:2007

Australian/New Zealand Standard™

Domestic solid fuel burning appliances—Pellet heaters—Method for determination of power output and efficiency

B415.1-10

Performance testing of solid-fuel-burning heating appliances

Designation: E2779 – 10 (Reapproved 2017)

Standard Test Method for Determining Particulate Matter Emissions from Pellet Heaters

DIN EN 14785

Residential space heating appliances fired by wood pellets – Requirements and test methods

Results

Overview of existing test standards: AS/NZS 5078:2007, AS/NZS 4886:2007 and AS/NZS 4014.6:2007

- **Preconditioning**
  - Tested stoves have to be operated before testing by **two separate burn periods**, each of them lasting at least **8 h** at the **maximum** burn rate (time in between at least 4 h)
- **Fuel**
  - Wood pellets, moisture content in range of 4% to 8%, bulk density (≥ 640 kg), ash ≤ 0.5%, H_u:18 – 21 MJ/kg, Pellet size: Ø max. 10 mm and length ≤ 38 mm
- **Test burn period** (**two** test runs for each burn rate mandatory, at least 2 h per burn rate)
  - Ignition and operation until the respective burn rate is achieved (within ±10%) (one or more hours) → Test of **three burn rates** ("**high**" = maximum, "**low**" = minimum, "**medium**" = ± 10% of midpoint of high and low) using a **calorimeter room** → **PM sampling** during the whole test run (in **diluted** flue gas)
  - Appliances without controlling options are only tested at high burn rate; thermostatic controllers for heating operation in accordance with room temperature must be disabled
- **Results**
  - **Average particulate emission factor** based of each of the tested burn rates in "**g/kg dry fuel**"
  - **Thermal efficiency** based on two consecutive test burn periods which deviates ≤ 5%

Results

Overview of existing test standards: CSA B415.1-10 (2010)

- **Preconditioning**
  - Tested non-catalytic stoves have to be operated before testing for **10 hours** (**medium** burn rate)
- **Fuel**
  - Wood pellets of each specified grade by the manufacturer have to be tested, moisture content ≤ 8%; Potential types of allowed other fuels (e.g. wood chips, corn) have to be tested, too
- **Test run** (**three** test runs for each burn rate mandatory, at least 2 h per burn rate)
  - Ignition and 1 h operation at the high burn rate → Test of **4 burn rates** (≤ 30%, 44%, 65%, 100%)
  - **PM sampling** during the whole test run (in **diluted** flue gas)
  - For stoves that are automatically controlled, e.g. by a room thermostat: **artificial manipulation** of the controls (on-off operation)
- **Results**
  - **Average particulate emission rates** including the required test runs in "**g/h**" or "**g/MJ of heat output**" are calculated (special procedure, **weighted** by the burn-rates of all test runs)
  - **Average thermal efficiency** and **average carbon monoxide** emissions are calculated (special procedure, **weighted** by the burn-rates of all test runs)

Results

Overview of existing test standards: US standards – ASTM E2779 – 10 (2017)

- **Preconditioning**
  - Tested stoves have to be operated before testing for **48 hours** (**medium** burn rate)
- **Fuel**
  - All types of allowed fuel have to be tested; in case of different fuel grades: the lowest grade has to be used
- **Integrated test run** (at least **one** mandatory)
  - Ignition and 1 h operation at the high burn rate → Test at **maximum** (60 min, maximum achievable), **medium** (120 min, ≤ 50% of maximum) and **minimum** (180 min, minimum achievable) burn rate
  - **PM sampling** during the whole integrated test run (in **diluted** flue gas) → **load changes** included
  - For stoves that are automatically controlled, e.g. by a room thermostat: **artificial manipulation** of the controls (high burn-rate: 60 minutes-on; medium burn-rate: two cycles of 30 minutes-on and 30 minutes-off; low burn rate: three cycles of 20 minutes-on and 40 minutes-off)
- **Results**
  - **Average particulate emission rates** over the whole test run in "**g/h**", "**kg/dry kg of fuel burned**" or "**g/MJ of heat output**" (if the optional thermal heat output is measured)

Results

Overview of existing test standards: DIN EN 14785:2006

- **Preconditioning**
  - No special requirements
- **Fuel**
  - **Commercial** wood pellets with most relevant parameters: moisture content ≤ 12%, ash ≤ 0.7%, H_u:16.9 – 19.5 MJ/kg, Pellet size: Ø 4 mm – 10 mm and length ≤ 50 mm
- **Test run** (at least **one** test run including nominal and partial load)
  - Ignition and preheating (at nominal load) → Start of test run when **stationary conditions** are achieved (flue gas temperature is stable ± 5K)
  - Nominal load = defined by manufacturer; Partial load = minimum
  - Test of the appliance at **nominal** (≥ 3 h) and **partial load** (≥ 6 h)
  - Partial load testing after nominal load test possible or as single test run after ignition and preheating
- **Results**
  - **Average CO emissions** (mg/m³, STP, dry, 13 vol.-% O_2) and **thermal efficiency** mandatory (average of **two test intervals**, e.g. 30 minutes, for **nominal** and **partial load**, respectively)
  - No respective procedure for PM emissions (however, up to now PM is measured most frequently acc. to CEN/TS 15883: Gravimetric measurement in **hot** and **undiluted** flue gas)

Results

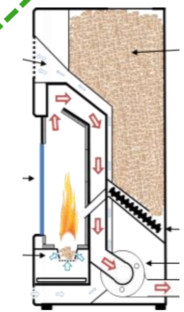
Parameters influencing real-life performance

- **Pellet stoves** – What are or might be the main influencing factors on emissions and thermal efficiency in real-life operation?

Technology

- Design of burner pot
- Used material
- Controlling system of combustion air supply
- Air staging concept
- Leakage rate
- …

Focus of EN 14785 test standard



Source: WÖHLER 2017a

Operating conditions

- Start-and stop phases
- Load settings and load hanges
- Integration in the residential heating system
- Cleaning intervals
- …

Fuel

- Chemical composition
- Moisture and ash content
- Bulk density
- Distribution of length of pellets
- …

Results

How are pellet stoves operated in real-life?

- **European user survey** (Source: WÖHLER et al. 2016)
  - Most pellet stoves are used as **secondary** heating system
  - Heating operation of pellet stoves is either controlled by a **room thermostat** (36%), or **directly** by the users (35%) or by a **clock timer** (25%)
  - **Thermal heat output** is **typically adjusted** by the users during heating operation
  - **Highest power** is only **marginally** used (10%), **predominantly** the stoves are operated at a **reduced power level** or in a mixed operation of different power levels (90%)
- **Field monitoring** (Source: OEHLER et al. 2016, HARTMANN & OEHLER 2017)
  - Also field monitoring revealed a **high share** of **partial load** operation and the significance of **cold** and **warm starts** of the total heating operation time of pellet stoves

➢ **Realistic testing** of pellet stoves should include **different load settings**, **load changes** as well as **cold** and **warm starts**

Results

Impact factors on emissions and thermal efficiency

Most relevant findings – up to now!

- **Cleaning interval** (Source: REICHERT et al. 2017)
  - The automatic **cleaning of the grate increases** gaseous and particulate emissions and **reduces** thermal efficiency
- **Fuel** (Source: REICHERT et al. 2017)
  - Experimental tests showed that there could be **large emission variations** when different pellets are used (even when only EN_{plus} certified pellets were used)
- **Pellet length** (Source: WÖHLER et al. 2017)
  - Results showed a reduced **fuel mass flow** (up to 36%) into the combustion chamber for long pellets (Ø 22,6 mm) compared to short pellets (Ø length 17,5 mm)
  - **CO** and **TSP** emissions of one stove **increased** for **long pellets** compared to **short pellets** from 185 mg/m^3 to 882 mg/m^3, and from 27 mg/m^3 to 37 mg/m^3 respectively (nominal load operation).

Results

“*beReal*” – A novel test concept for pellet stoves (Source: REICHERT et al. 2016)

- **Preconditioning** of the stove by at least **6 h** of operation before “*beReal*” testing
- Test cycle of 7.5h duration and including **3 phases** with different **load settings** (one cold start and two warm starts) as well as one **load change** and two **stand-by** phases

Action	Cold start	Load change		Warm start		Warm start
Phase number and duration	Phase 1			Phase 2		Phase 3
	50 min.	90 min.	40 min.	50 min.	40 min.	180 min.
Operation mode	Nom. load (100%)	Low load (30%)	Stand-by (0%)	Nom. load (100%)	Stand-by (0%)	Medium load (65%)
Emission measurements	Continuous CO and OGC emission measurement					
	Gravimetric TSP-sampling			Gr. TSP-s.		Gravimetric TSP-sampling

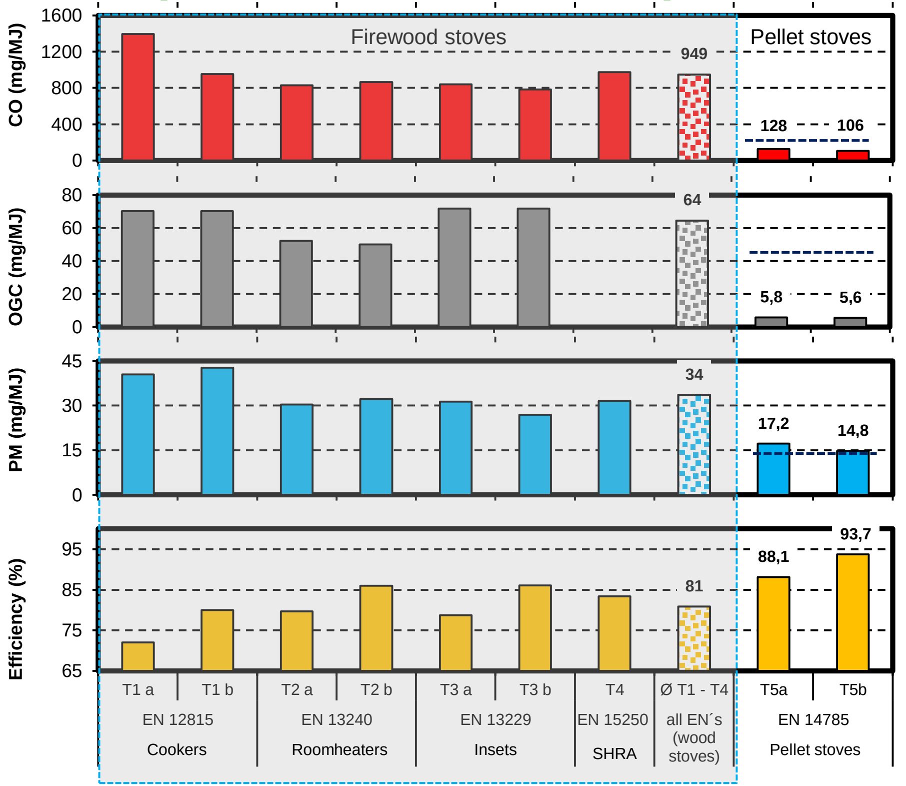
Source: KLAUSER et al. 2018, adapted

- **Cleaning intervals** of the stove are included in the test cycle

Results

Database on official type test results (ott, EN test standards)

- Data from the study SCHIEDER et al. 2013:
  - CO: n = 941
  - OGC: n = 219
  - PM: n = 996
  - Efficiency: n = 1577
- Official type test results for pellet stoves **show better performance** in terms of emissions and thermal efficiency compared to wood stoves
- Future ecodesign ELVs…
  - …met for CO (210 mg/MJ) & OGC (42 mg/MJ)
  - …not achieved for PM (14 mg/MJ)



a…conventional technologies / b…modern technologies /
--- ELV ecodesign (CO: 300 mg/m³; OGC: 20 mg/m³, PM: 20 mg/m³ (STP, 13 vol.-% O_2, dry) → transferred to mg/MJ

Results

Lab versus field

Evaluation of real-life relevance: New test method („*beReal*“) compared to current test method (EN 14785) with 4 serial production appliances

- **Official type test**
  - Official type test of the used stove models
- **Tests in the lab**
  - RTD type test, nominal load (EN 14785)
  - “*beReal*” test cycle for pellet stoves
- **Field tests**
  - Operation acc. to the users own habits (own fuel)
  - Operation acc. to the users own habits (same fuel as used by RTD institutes)
  - “*beReal*” test cycle for pellet stoves

beReal Same 4 appliances

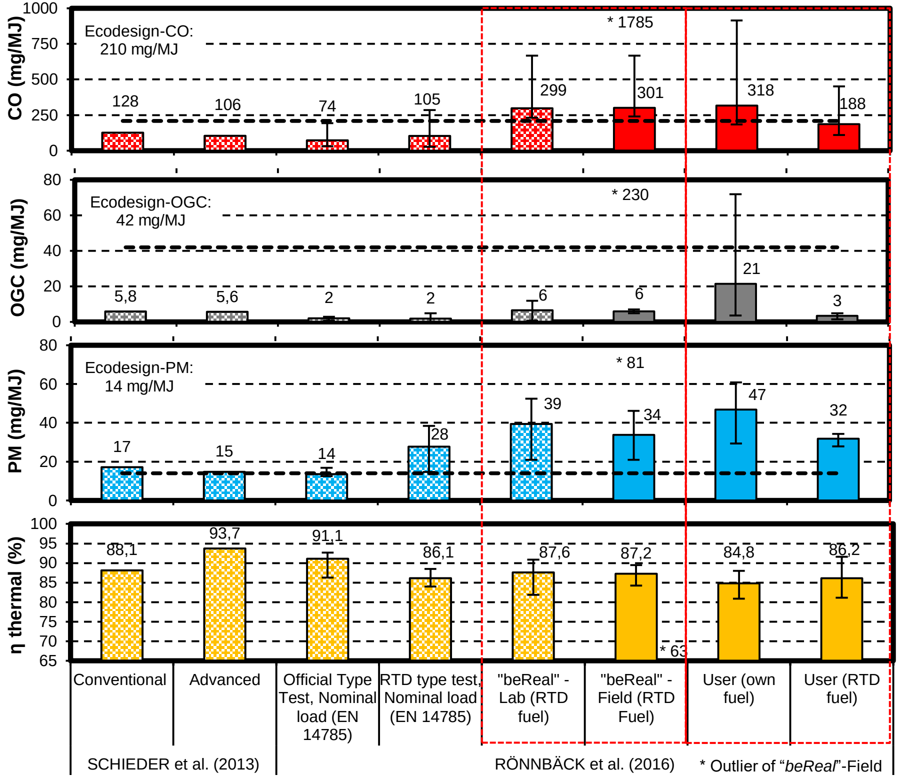
Source: BEST GmbH

Source: RÖNNBACK et al. 2016

Results

Lab versus field – Evaluation of real-life performance

- **Higher** emissions for CO and PM as well as **lower** thermal efficiency during **RTD type tests** observed
- Emissions of field performance about **300% higher** for **CO** and about **100%** for **PM emissions** (i.c. to ott results)
- OGC emissions **very low**
- Thermal **efficiency** around **85%** in real-life operation
- "*beReal*" tests in the field were in a **good agreement** with "*beReal*" tests in the lab as well as with the user´s heating operation → <u>But:</u> **Fuel impact** is obvious

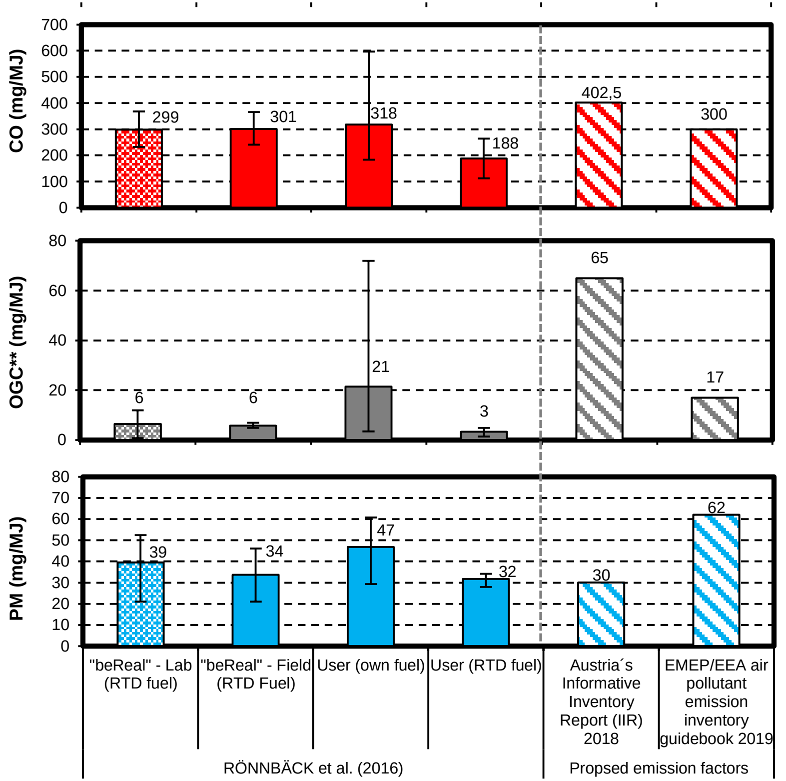


--- ELV ecodesign (CO: 300 mg/m³; OGC: 60 mg/m³, PM: 20 mg/m³ (STP, dry, 13 vol.-% O_2) → transferred to mg/MJ

Results

Field and lab test results compared to emission factors

- Both types of emission factors (EFs) **clearly deviate** for OGC and PM emissions
- Field test results are in general **in the range** of the proposed emission factors
  - **CO** – both types of EFs fit quite well
  - **OGC** – EFs by trend higher compared to field performance, (AIIR-EF in general too high)
  - **PM** – AIIR-EF fits good to field results; EMEP/EEA-EF for PM (TSP) of pellet stoves was increased from 31 mg/MJ (2016) to 62 mg/MJ (2019)
- “***beReal***” test appears to be a promising concept to **evaluate EFs** on the test bench



** OGC emission factors calculated based on proposed NMVOC-EF, assuming 40% methane in the flue gas

Summary & Conclusions

- Most relevant **differences** of **testing concepts**: Number of tested load settings, repetitions of measurements, respected emissions and PM measurement procedure
  - **International standardization (ISO)** however seems feasible and would strongly support industry.
- The comparison of **lab** and **field** test results showed **higher emissions** and **lower thermal efficiency** in field operation compared to official type test results
- Important factors on **real-life operation** performance are load settings as well as **transient phases,** like ignition, load changes and cleaning intervals
  - **Advanced test methods** should also include those phases to push technological development into the right direction
- **The fuel** has an **significant influence** on emissions (even when using certified high quality pellets)
  - **Further research** about relevant fuel parameters or technology restrictions which cause such variations is needed

Detailed information available soon: IEA Bioenergy Report – "***Advanced Test Methods for Pellet Stoves***"

Information

Detailed information about this topic focusing of firewood stoves is already available:

- **Title:**
  - "Advanced Test Methods for Firewood Stoves – Report on consequences of real-life operation on stove performance"
- **Link/ Download:**
  - https://www.ieabioenergy.com/wp-content/uploads/2018/11/IEA_Bioenergy_Task32_Test-Methods.pdf (accessed Jan. 2020)

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- More information about the “*beReal*” project available: http://www.bereal-project.eu/

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Thank You For Attention

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