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Das Land Steiermark

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IEA Bioenergy – Webinar Series

BEST Bioenergy and Sustainable Technologies

RWC – Towards Low Emission Systems

Real life test methods for log wood and pellet stoves

May 6, 2021

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Introduction

Why we have to look at test methods?

- What is the **purpose** of test methods?
- 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 methods **loose** their reliability?

Source: https://greennews.ie/irelands-own-dieselgate-the-dieselisation-of-irelands-car-fleet-amidst-global-decline/ (accessed April 2021)

Objectives & Approach

- For **firewood** and **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 firewood and pellet stoves & identification of most **relevant parameters** for emission and efficiency performance
  - Evaluating a **newly developed lab testing methods** 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. **Existing test standards**
2. **Novel test concepts: "*beReal*" – Firewood & Pellet**
3. **Test results:** Comparing lab with field

Information

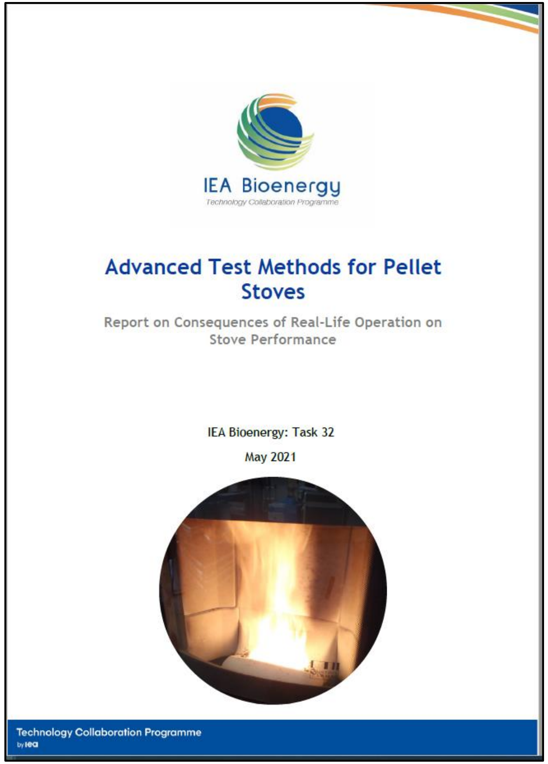
Detailed information about this topic focusing on firewood stoves is already available:

- **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 May 2021)

Outlook

Detailed information about this topic focusing on pellet stoves will be available <u>soon</u>:

- **<u>Title:</u>**
  - "Advanced Test Methods for Pellet Stoves – Report on Consequences of Real-Life Operation on Stove Performance"
- **<u>Link/ Download:</u>**
  - https://www.ieabioenergy.com


IEA Bioenergy
Technology Collaboration Programme

Advanced Test Methods for Pellet Stoves

Report on Consequences of Real-Life Operation on Stove Performance

IEA Bioenergy: Task 32

May 2021

Technology Collaboration Programme
by iea

Results

Overview of existing test standards

- **Firewood Stoves**
  - International draft – **ISO/DIS 13336**
  - Australian/ New Zealand Standards – **AS/NZS 4012 – 4014**
  - British recommendations for testing – **PD 6434**
  - Canadian Standard – **CSA B415.1-10**
  - European Standards – **EN 13240; EN 13229, EN 15250, EN 12815, EN 15821, EN 16510-1**
  - Norwegian Standards – **NS 3058, NS 3059**
  - United States Standards – **US EPA method 28 (5G & 5H)**

- **Pellet Stoves**
  - Australian/New Zealand Standards – **AS/NZS 5078, 4886, 4014.6**
  - Canadian Standard – **CSA B415.1-10**
  - United States Standards – **ASTM E2779-10**
  - European Standard – **EN 14785**

Results

Main findings and differences

- **Firewood Stoves**
  - Testing under optimal conditions (e.g. EN) or evaluation of maloperating aspects, too (e.g. US EPA/ CSA) – Some examples of different characteristics:
    - **Fuel**: Hardwood or softwood, firewood or squared timber
    - **Batch mass** defined by manufacturers or by combustion chamber volume
    - **Natural** draft conditions or **controlled** draft conditions
    - Number of tested **load settings** (burn rates)
    - PM sampling: “hot” (**undiluted**) or “cold” (**diluted**) flue gas
    - Thermal efficiency: **Direct** (calorimeter room) or **indirect** (i.e. evaluation of losses)
- **Pellet Stoves**
  - Number of tested load settings, repetitions of measurements, respected emissions and PM measurement procedure – Some examples of different characteristics:
    - **Preconditioning** before testing required or not
    - Number of tested **load settings** (burn rates)
    - PM sampling: “hot” (**undiluted**) or “cold” (**diluted**) flue gas
    - Testing of appliances which are **controlled** by room thermostats

Results – Firewood Stoves

Parameters influencing real-life performance

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

Chimney

- Material
- Dimensions
- Temperatures
- Weather conditions
- …

User

- Fuel selection
- Air settings
- Ignition technique
- Recharging (Frequency & Instant of time, batch mass)
- …

Source: TFZ Straubing

Technology

- Design of combustion chamber
- Materials and mass
- Combustion air supply (e.g. air staging concept)
- Leakage rate
- Integrated secondary emission abatement technologies (e.g. catalyst)
- …

Focus of EN test standards

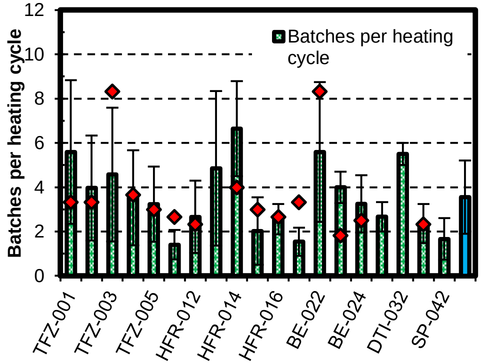
Results – Firewood Stoves

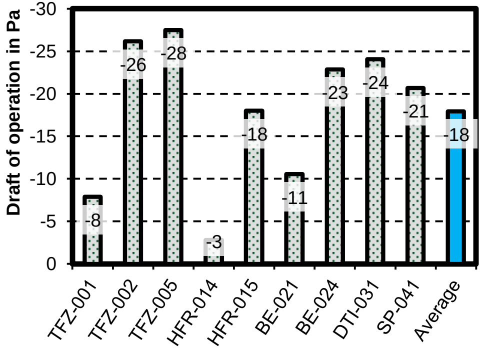
How are firewood stoves operated in real-life?

- **European user survey** (Source: REICHERT/WÖHLER et al. 2016)
  - ~80% uses firewood from hardwood used
  - > 60% uses bottom-up Ignition technique

- **Field monitoring** (Source: REICHERT et al. 2016)
  - Number of batches per heating cycle typically between 2 and 6 (Range; 1 – 9; Ø 4)
  - Draft conditions in the range of 3 Pa to 28 Pa

➢ **Realistic testing** of firewood stoves should include **ignition batch**, **nominal** and **part** load batches and also **cooling down** phase





Results – Firewood Stoves
Impact factors on emissions and thermal efficiency

- **Ignition** (Source: REICHERT et al. 2017)
  - Tests with two different roomheaters: Kindling material (spruce of beech) has not a significant effect, but top-down ignition method not best for both stoves
  - ➢ **Optimal ignition technique should be specified by manufacturer**
- **Draft conditions** (Source: REICHERT et al. 2017)
  - Tests with three different roomheaters: Varied draft levels: 12 Pa, 24 Pa and 48 Pa
  - ➢ **Correlation of draft conditions and gaseous emission depend on the appliance specifics** (increase up to 60% or decrease up to 45%); **no significant effect observed for PM emissions**
  - ➢ **Higher draught conditions result in lower thermal efficiency** (6%-11%, absolute)
- **Effect of cooling down phase** (Source: REICHERT et al. 2016 & 2017)
  - Exemplary test with a roomheater (air valve settings open or closed after heating operation)
  - ➢ **Cooling down phase & air settings can significantly affect thermal efficiency**

Results – Firewood Stoves

"*beReal*" – A novel test concept for firewood stoves (Source: REICHERT et al. 2016)

- **Test cycle** including eight consecutive batches (1-5: 100% batch mass/ 6-8: 50% batch mass) and a certain time of the cool down phase
- **Best practice heating operation** should be specified by a obligatory Quick-User-Guide (by text and pictures)

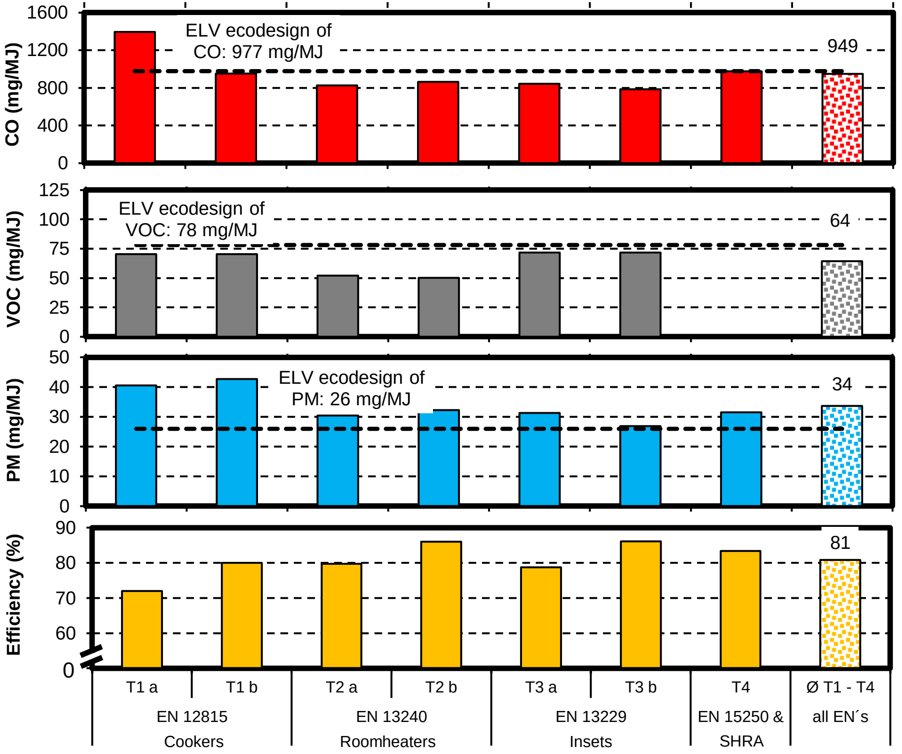
Action	Ignition	Recharg-ing	Recharg-ing	Recharg-ing	Recharg-ing	Recharg-ing	Recharg-ing	Recharg-ing	
Batch number	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8	Cool down
Operation mode	Nominal load	Nominal load	Nominal load	Nominal load	Nominal load	Part load	Part load	Part load	
Emission measurements	Continuous CO and VOC emission measurement								
	Gr. PM-s.		Gr. PM-s.		Gr. PM-s.		Gr. PM-s.		

Source: KLAUSER et al. 2018, adapted

Results – Firewood Stoves

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

- Data from the study SCHIEDER et al. 2013:
  - CO: n = 941
  - VOC: n = 219
  - PM: n = 996
  - Efficiency: n = 1577
- Similar results between the single technologies
- Future ecodesign ELVs…
  - …met for CO (977 mg/MJ) & VOC (78 mg/MJ)
  - …not achieved for PM (26 mg/MJ)



a…conventional technologies / b…modern technologies /
--- ELV ecodesign (CO: 1500 mg/m³; OGC: 120 mg/m³, PM: 40 mg/m³ (STP, 13 vol.-% O_2, dry) → transferred to mg/MJ

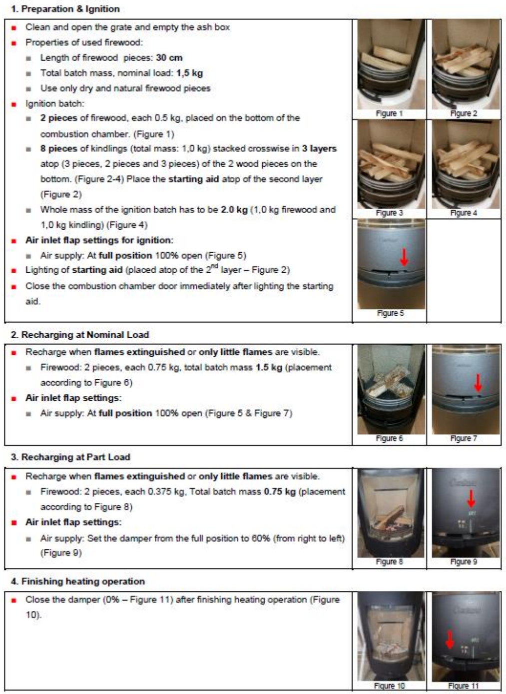
Results – Firewood Stoves

Lab versus field

Evaluation of real-life relevance: New test method („*beReal*“) compared to current test method (EN 13240) with 13 serial production appliances (Source: RÖNNBACK et al. 2016)

- **Official type test**
  - Official type test of the used stove models
- **Tests in the lab**
  - RTD type test (EN 13240)
  - “*beReal*” test cycle for firewood stoves
- **Field tests**
  - Operation acc. to the users own habits
  - Operation acc. to a Quick-User-Guide
  - “*beReal*” test cycle for firewood stoves

Same 13 appliances



1. Preparation & Ignition

- Clean and open the grate and empty the ash box
- Properties of used firewood:
  - Length of firewood pieces: **30 cm**
  - Total batch mass, nominal load: **1,5 kg**
  - Use only dry and natural firewood pieces
- Ignition batch:
  - **2 pieces** of firewood, each 0.5 kg, placed on the bottom of the combustion chamber. (Figure 1)
  - **8 pieces** of kindlings (total mass: 1,0 kg) stacked crosswise in **3 layers** atop (3 pieces, 2 pieces and 3 pieces) of the 2 wood pieces on the bottom. (Figure 2-4) Place the **starting aid** atop of the second layer (Figure 2)
  - Whole mass of the ignition batch has to be **2.0 kg** (1,0 kg firewood and 1,0 kg kindling) (Figure 4)
- **Air inlet flap settings for ignition:**
  - Air supply: At **full position** 100% open (Figure 5)
- Lighting of **starting aid** (placed atop of the 2nd layer – Figure 2)
- Close the combustion chamber door immediately after lighting the starting aid.

Figure 1 Figure 2 Figure 3 Figure 4 Figure 5

2. Recharging at Nominal Load

- Recharge when **flames extinguished** or **only little flames** are visible.
  - Firewood: 2 pieces, each 0.75 kg, total batch mass **1.5 kg** (placement according to Figure 6)
- **Air inlet flap settings:**
  - Air supply: At **full position** 100% open (Figure 5 & Figure 7)

Figure 6 Figure 7

3. Recharging at Part Load

- Recharge when **flames extinguished** or **only little flames** are visible.
  - Firewood: 2 pieces, each 0.375 kg, Total batch mass **0.75 kg** (placement according to Figure 8)
- **Air inlet flap settings:**
  - Air supply: Set the damper from the full position to 60% (from right to left) (Figure 9)

Figure 8 Figure 9

4. Finishing heating operation

- Close the damper (0% – Figure 11) after finishing heating operation (Figure 10).

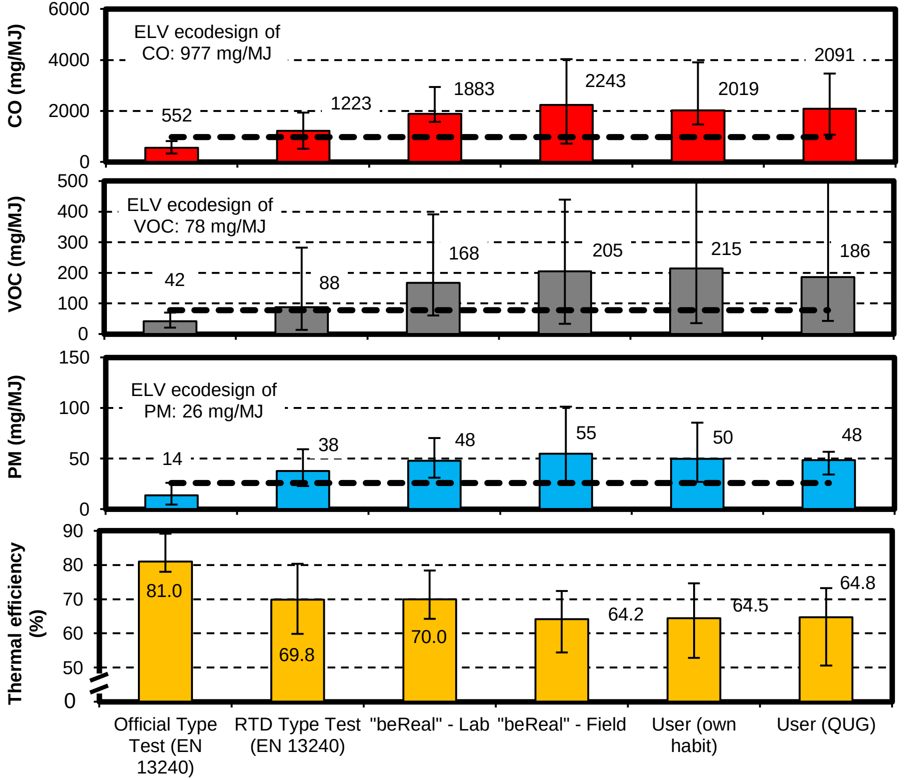
Figure 10 Figure 11

Example of a Quick-User-Guide
Source: BEST GmbH

Results – Firewood Stoves

Lab versus field – Evaluation of real-life performance

- RTD partners achieved **significant different test results** with serial production stoves → no retested appliance met the future European emission limit values (ELV)
- Official type test results far away from field performance
- "*beReal*" test protocol: **good real life relevance** for emissions
- Thermal efficiency of lab tests significantly higher compared to field results



ELV ecodesign (CO: 1500 mg/m³; OGC: 120 mg/m³, PM: 40 mg/m³ (STP, dry, 13 vol.-% O_2) → transferred to mg/MJ

Results – Pellet Stoves

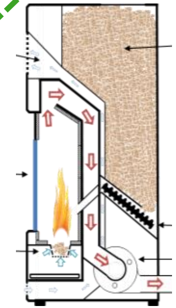
Parameters influencing real-life performance

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

Focus of EN 14785 test standard

Technology

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



Source: WÖHLER 2017a

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

Operating conditions

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

Fuel

Results – Pellet Stoves
How are pellet stoves operated in real-life?

- **European user survey** (<u>Source:</u> 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** (<u>Source:</u> 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 – Pellet Stoves

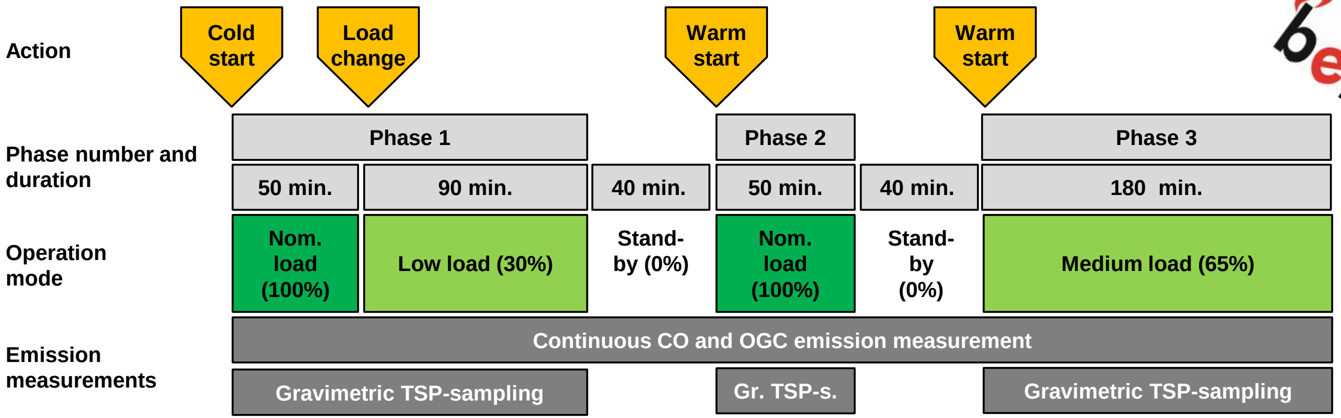
Impact factors on emissions and thermal efficiency

- **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 **PM** 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 – Pellet Stoves

"*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



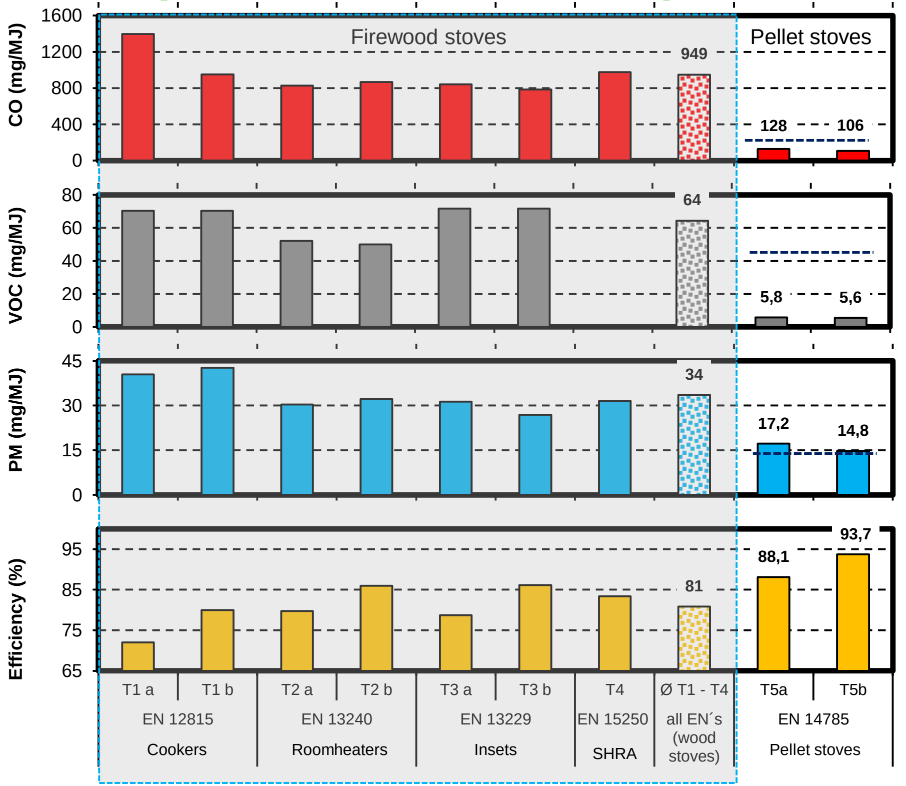
Source: KLAUSER et al. 2018, adapted

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

Results – Pellet Stoves

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

- Data from the study SCHIEDER et al. 2013:
  - CO: n = 941
  - VOC: 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) & VOC (42 mg/MJ)
  - …not achieved for PM (14 mg/MJ)



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

Results – Pellet Stoves
Lab versus field

Evaluation of real-life relevance: New test method („*beReal*“) compared to current test method (EN 14785) with 4 serial production appliances (Source: RÖNNBACK et al. 2016)

- **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

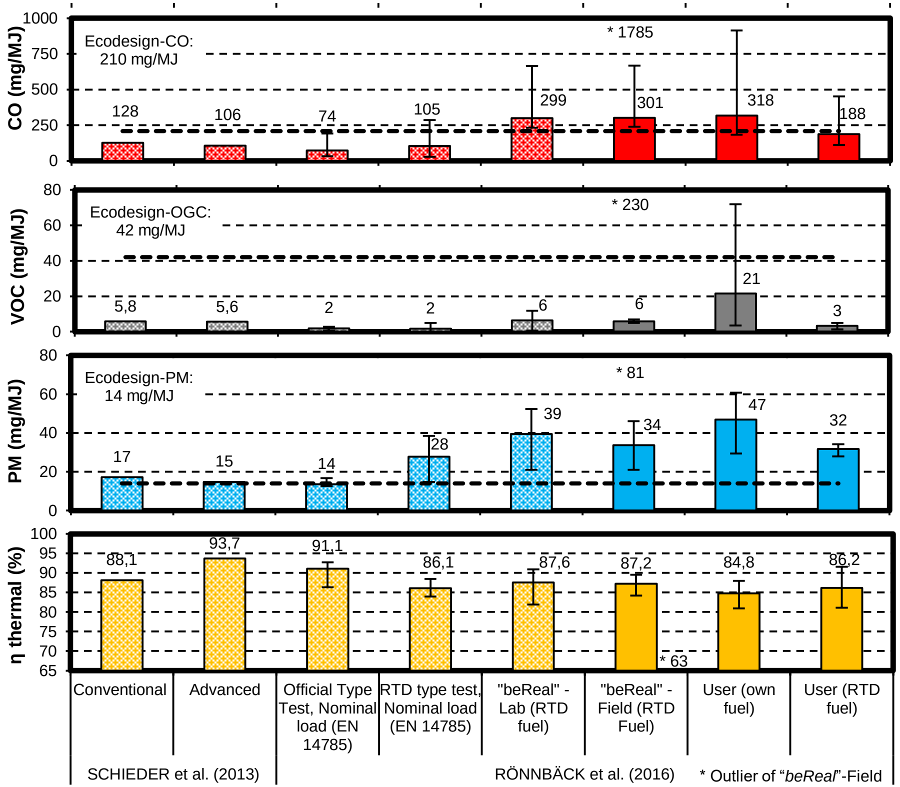
Source: BEST GmbH

Source: RÖNNBACK et al. 2016

Results – Pellet Stoves

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)
- VOC 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

Summary & Conclusions

- <u>Generals</u>
  - 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,** (e.g. ignition, load changes and cleaning intervals, cooling down/ standby)
    - ➢ **Advanced test methods** should also include those phases to push technological development into the right direction
- <u>Firewood</u>
  - Users should be guided towards **best-practice** use
    - ➢ **Technological development** should focus on the **user** and **real-life operation**
- <u>Pellets</u>
  - **The fuel** has an **significant influence** on emissions (even when using certified pellets)
    - ➢ **Further research** about relevant fuel parameters or technology restrictions which cause such variations is needed

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Standards – Firewood Stoves

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Results – Firewood Stoves

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

IEA Bioenergy – Webinar Series

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