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beReal: Advanced Testing Methods for Better Real Life Performance of Biomass Room Heating Appliances

Final publishable summary report

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report

beReal

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1 Introduction

In the last years standard type test methods for biomass room heating appliances have driven technological development tremendously towards low emissions and high efficiency. However, they are not applicable to reflect real-life operation performance since operating conditions and the user habits are not sufficiently included in the test procedure. Consequently, there is the need to optimize the combustion performance of these technologies significantly in future, especially in real-life operation. Advanced test procedures implemented in normative standards or labels are effective instruments to assess product quality and to push forward technological development.

The EU project ‘beReal’ (full title: Advanced testing methods for Better Real Life Performance of Biomass Room Heating Appliances, grant agreement no. 606605) was funded under FP7, Research for SME associations. The consortium included three SME-AGs with associated SC-10 industry partners, five RTD-partners and five partners from stove industry

The development process as well as the definition of the advanced beReal test method for firewood and for pellet roomheaters based on several work items which comprised:

- An assessment of typical user behaviour and frequency of use by an European survey with more than 2000 respondents were carried out. Additionally, an investigation of real life operating conditions (i.e. typical heating duration, draught) by long term field monitoring (flue gas temperature & draught) during one heating season at 20 firewood and nine pellet room heaters in Italy, Germany, Austria, Sweden and Denmark was carried out.
- For method development the effect of different operation characteristics, for example the ignition mode or load changes, draught conditions and fuel characteristics, were assessed and evaluated at different types of firewood and pellet room heaters. The test concept and test procedure was validated regarding practicability and repeatability at five different European RTD institutes using nine different types of firewood room heaters and five types of pellet room heaters.
- A standardized QuickUserGuide (QUG) as basis for testing as well as for optimization of real life operation was established. Further, a web-based calculation tool for standardized data calculation and documentation of test results was developed.
- A beReal coefficient was developed, in order to evaluate the flue gas emissions as well as the installation’s thermal efficiency of pellet and firewood room heaters. A striking beReal label has been designed and a possible beReal framework was shaped.
- Field tests were performed using 13 different firewood and 4 different pellet room heaters to evaluate the beReal method’s real life impact by comparing beReal test results in the lab with those in the field at the same appliance. Additionally, EN type tests were performed by the respective RTD performer to compare the respective results with the new beReal test concept.

- To evaluate the beReal method's reproducibility, a Round Robin Test was conducted at one pellet and one firewood room heater. Participants comprised six test institutes (notified bodies and RTD performers in Austria, Germany, Sweden and Denmark).
- The prepared dissemination plan is a strategy to identify and organize activities in order to increase the project influence and to support commercial and other exploitation of the project results. To communicate the project idea, results and progress, different target groups were identified and addressed using appropriate communication means and tools. These groups included the project partners, public stakeholders, expert audience or standardization bodies and the general public.

The beReal project generated basically the following results:

- An advanced test methods better reflecting real life performance of biomass room heating appliances
- A common web-based measurement data analysis and evaluation tool
- Labelling schemes that allow to differentiate biomass room heating appliances according to their real life performance

The most likely case for an appropriate economic strategy for the deployment of the label were the cooperation with existing label suppliers or Europe wide associations with relevant experience. Beyond a label several other exploitation possibilities were identified:

- The beReal testing procedure could have a positive influence on the type testing method as it may provide a reliable guideline for future standards or regulations.
- For industry partners the internal use of the beReal method might serve to further optimize their stoves in a more holistic way than it is possible with the type testing methods.
- The use of the method to revise the (rather theoretic) factors for the calculation of national emission inventories.
- The positive influence of the QuickUserGuide (QUG) on the end user behaviour became evident.

The beReal test results show a much higher differentiation between poor and excellent products than current type testing does. This will stimulate the further development of existing products to the benefit of customers and the environment.

2 Work package 2 – Market and framework analysis

2.1 Survey (HFR)

The BeReal survey was used to investigate the real life operation behaviour of biomass room heating appliance users in Europe. The knowledge about the actual way how users operate their heating appliance was the basement for the development of a real life correlated testing method. Therefore the development of the survey was conducted with a strong focus on necessary results for WP 3.

Based on these requirements a list of questions were developed and discussed in various meetings and feedback loops of all BeReal WP2 partners. Finally the questionnaire was translated by project partners into Danish, Dutch, French, German, Italian and Swedish was and implemented into an online survey application ("LimeSurvey" version 2.05[1]).

The following links show the final survey. There are specific links for each language available.

http://www.bereal-project.eu/survey.html

Within the survey the user is guided automatically through the questionnaire. The individual set of questions is based on the user input (e.g. users of pellet stove are faced only with pellet related questions). The questions are mandatory or voluntary. For all questions either a selection of responses are given (closed questions) or a number input is possible. All completed questionnaires have been saved in the online system and can be transferred into various data evaluation programs.

The BeReal survey was launched on 25th March 2014. All project partners were asked to distribute the link to the survey. Among others, the survey was distributed via newsletters, websites, social media and the BeReal website:

The survey ended after 14 weeks by the end of June. The results of the questionnaire were summarized by the used online application in one database for all used languages. Microsoft Excel and IBM SPSS Statistics 22 were used for data analysis. Only completed questionnaires were analysed.

Finally 2,205 questionnaires were completed and saved in the online system. Completed questionnaires from 21 countries were received. Figure 1 shows the distribution of all answers in Europe. The majority of response of 92 % came from Italy (38 %), followed by Germany (33 %), Austria (11 %) and Sweden (10 %). Beside Denmark (2.5 %) and Belgium (2.0 %) the remaining answers were distributed with low share on other 15 countries.

[1] available at https://www.limesurvey.org/en/

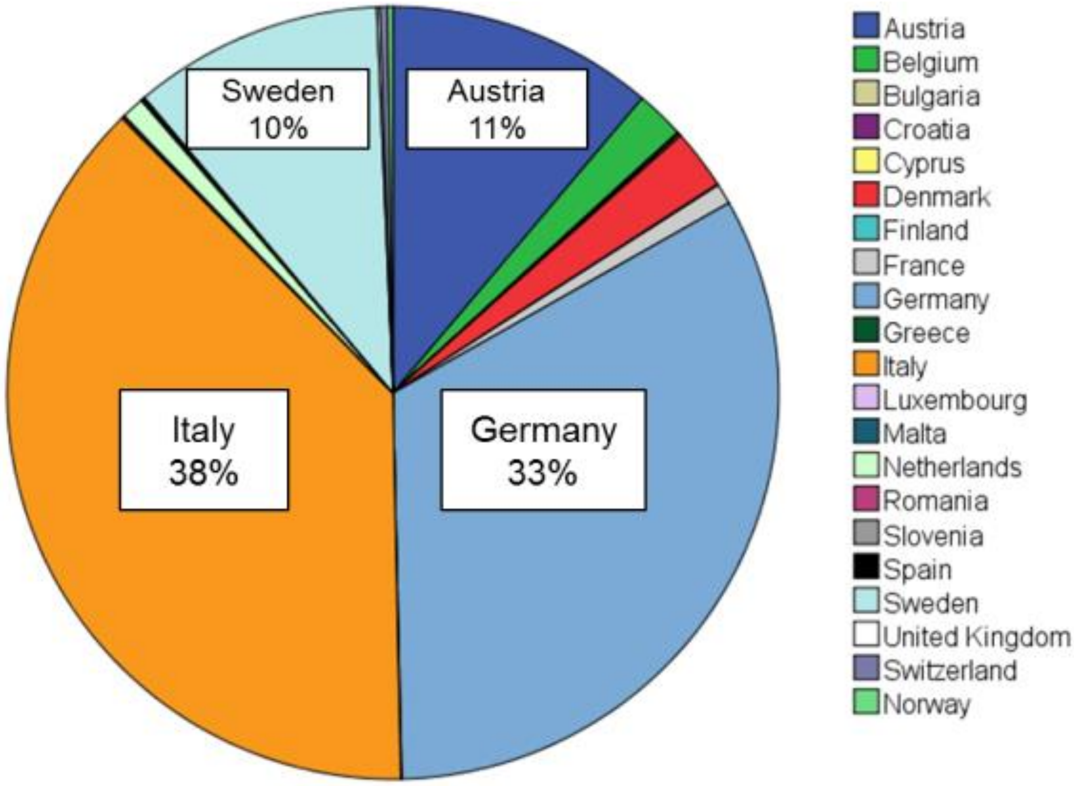


Figure 1: Distribution of BeReal survey participants

The BeReal survey is until now the most comprehensive study about the practical use of biomass room heating appliances in Europe. The challenging requirements of the survey such as high amount of answers and a good geographical distribution were achieved. The results were used for the development of the BeReal testing method. Detailed information about the survey of the firewood stove users is already published here:

Wöhler, M.; Andersen, JS.; Becker, G.; Persson, H.; Reichert, G.; Schön, C.; Schmidl, C.; Jaeger, D.; Pelz, S. (2016): Investigation of real life operation of biomass room heating appliances – Results of a European survey.
Applied Energy. doi:10.1016/j.apenergy.2016.01.119 2016; 169:240–9.

2.2 Field observation (TFZ)

Simultaneously to the online survey, field monitoring was conducted at 20 firewood room heaters and 9 pellet room heaters (5 installations without water jacket, 4 with water jacket) of which some were used as main heating installation and some as additional heating installation. The stoves observed had an age of 1 to 8 years and featured a heat output of 8 kW to 15 kW.

On average, the monitoring duration lasted over a three months period in the 2014 heating season to cover both, a winter and a spring heating period. The monitoring's aim was to collect operational data focusing on the identification and the assessment of real life conditions and operational patterns that shall be considered within the method development.

Monitoring was carried out by determining the flue gas temperature with a surface thermocouple attached to the flue gas pipe. Additionally, a chimney draught measurement was installed only at some selected room heaters (10 firewood room heaters and one pellet room heater) over a period of two to four weeks to derive information on the behaviour of the stove and the state and quality of the combustion process.

These measurement parameters provided information regarding number of heating cycles/ heating phases per observation period, number of batches/ combustion phases performed per heating cycle, the duration of defined operation states, the flue gas temperature during the respective phases as well as the duration above a certain temperature threshold at pellet room heaters. With this particular time frame and the respective temperature level in correlation to the maximum temperature the load level and its respective duration were estimated.

The field monitoring covered a wide range of typical heating days during a heating season. A user profile of the recorded flue gas temperature monitored over three days of operation at a pellet room heater (left) and at a firewood room heater (right) are given in Figure 2.

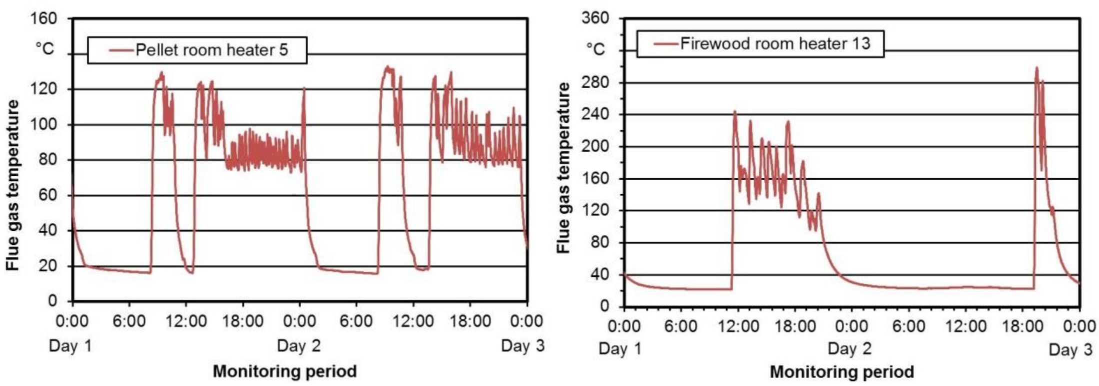


Figure 2: Exemplary user profile over a three days observation period at a pellet room heater (left) and a firewood room heater (right)

When evaluating the user profiles at pellet room heaters the estimated load level displays that nominal load duration accounts for only about 10 % of the total operation time while operation in low partial load regime (load in the range of 30 % to 65 %) amounts to about 51 % and high partial load (load in the range of 65 % to 90 %) amounts to about 39 % of the operation time (Figure 3).

General observations gained at pellet room heaters comprise that a large variety of different operational conditions prevail at various types of installations: regularly occurring cold and warm starts, operation in nominal and in partial load, load changes with transient phases or modulating operation mode. It becomes obvious that a consistent operational mode does not exist and the profiles are highly user dependent according to personal needs.

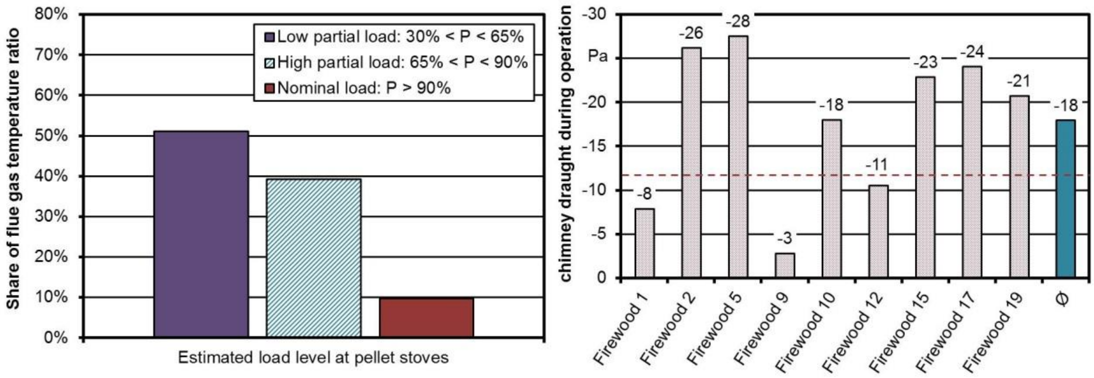


Figure 3: Left: Evaluation of mean operation time in estimated load levels at pellet room heaters – Right: Mean chminey draught during operation at firewood room heaters

The evaluation of the mean chimney draught during operation at the respective installations is given in Figure 3 (right). In average the chimney draught during operation sums up to -18 Pa, but with results gained in the range of -3 Pa to -28 Pa a high variability was determined. Obviously most of the appliances are not operated under type testing conditions respectively at the optimum value of -12 Pa (red dashed line) as specified by most of the manufacturers.

The overall findings at firewood room heaters comprise, that a mean number of approximately 4 batches (3.6 ± 1.7) seem to describe the "usual" behavior in the monitoring appropriately. Nevertheless high deviations in the range of only one batch per heating cycle up to 15 batches per heating cycle indicate the high variability of the user’s behavior. Additionally significantly lower flue gas temperatures clearly indicate frequently occurring part load operation.

Basic assumptions in terms of considering only a steady state operation, excluding the ignition phase or disregarding part load operation at firewood room heaters at as it is the case in current test standards does not reflect real life operation and therefore need to be questioned.

3 Work package 3 – Measuring methods and testing procedures

Measurements at small-scale appliances according to standard test procedures require predefined well controlled stable combustion processes at constant conditions without any transient phases. Since stable and real life operation differ largely when evaluating a stove's performance, type testing procedures which focus only on steady state operation while also disregarding the ignition phases need to be considered insufficient to reflect real life stove operations.

3.1 Pellet stove method (TFZ)

From the data gathered in the online survey, the field monitoring and on the test stand, an advanced real life testing procedure for pellet stoves, the ‘beReal method’, was derived. It aims at a high transferability from real life operation to test stand measurements and therefore at reflecting typical user habits more appropriately by applying a scheme which considers ignition and stop phase, load changes and different load levels. The time frames for periods on a given load level as well as the respective load level values were defined as they had been observed in real life. Additionally, the load level periods were chosen appropriately long enough as it was found necessary that also regular cleaning cycles should occur during the measurement phase, but also stable conditions with presumably decreased gaseous and PM emissions compared to transient phases should be reached.

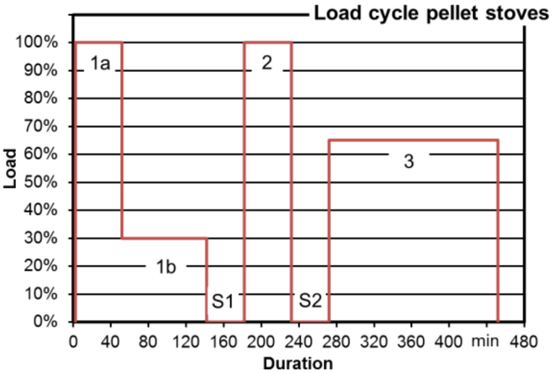
It was defined that in the first stage the method is only applicable for stoves without water jacket and that appliances tested shall be end user marketed products. Automatic controls as room thermostats shall remain activated during the beReal test, this is also true for automatic cleaning or de-ashing operations. Additionally, certain load levels were defined which shall be implemented in the operational procedure by manual adjustment.

Intending to fulfil requirements as derived from the survey and field testing and therefore to represent typical user behaviour, the real live test cycle at its current state was defined as follows:

- It consists of four combustion phases: 1a, 1b, 2, 3 (Table 1).
- The cycle exhibits ignition phases with one cold start (at phase 1a) and two warm starts (at phases 2 and 3) as well as three burn-out phases (after phases 1b, 2, and 3).
- Load change operation occurs from phase 1a to 1b.
- Three defined load levels are applied: 100 % or the maximum user-settable load level, 65 % or the mean settable load level between minimum and maximum load, 30 % or the lowest settable load level.
- Two intermediate standby phases are included and enable to perform warm starts: S1 between phases 1b and 2 and S2 between phases 2 and 3.

The test cycle is depicted in Table 1 together with operational mode, load level and duration of each phase.

Table 1: Scheme of load cycle of the beReal method for pellet stoves and operational mode, load level and duration of the load cycle



Phase	Operational mode	Load level	Duration
1a	Cold start	Nominal load: 100 %	50 min
1b	Load change	Partial load: 30 %	90 min
S1	Standby	0 %	40 min
2	Warm start	Nominal load: 100 %	50 min
S2	Standby	0 %	40 min
3	Warm start	Partial load: 65 %	180 min
			Σ: 7.5 h

Several boundary conditions were precisely defined to secure a measurement procedure that is less prone to misuse and variable interpretation.

- Measurement section as given in Figure 4
- Flue gas temperature measured by centrally placed thermocouple.
- Flue gas velocity measured continuously.
- Continuous flue gas sampling during total measurement cycle.
- PM sampling: gravimetric out stack measurement of total PM emissions in hot undiluted flue gas, sampling volume flow proportional to flue gas volume flow.
- PM sampling period starts with starting the pellet stove and lasts until O_2 content in the flue gas has reached 20 % after turning off the pellet stove after phases 1b, 2, and 3.
- Always the same evaluation period is considered for determining emissions and thermal efficiency.
- Calculation of average values by weighting the results derived in the single measurement phases according to their produced flue gas volumes.
- Duration of the respective phases 1a, 2 and 3 starts at a flue gas CO concentration of 10 ppm.

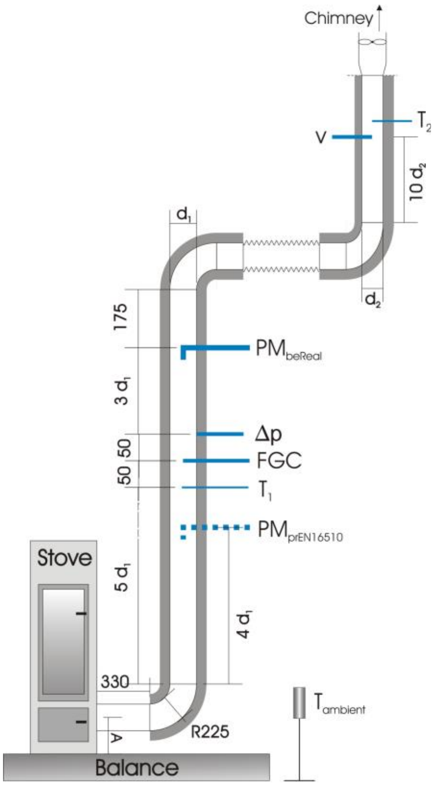


Figure 4: Sketch of the measurement section as considered for beReal method

3.2 Firewood stoves (BE2020)

Based on the findings of the user survey and long term measurements (WP2) an experimental development process in the lab was carried out (WP3). In detail, following aspects were investigated:

- Influence of draught conditions on emissions (CO, OGC, PM) as well as thermal efficiency
- Comparative evaluation of top-down and bottom-up ignition mode
- Effect of air settings and cooling down-phase on thermal efficiency
- Comparison of temperature measurements using a suction pyrometer or an unshielded thermocouple
- Comparison of direct (determination of usable thermal heat via a calorimeter room) and indirect (determination of losses) efficiency determination.

Increased draught conditions up to 48 Pa revealed only limited effect on gaseous emissions and no effect on PM emissions. However, increased draught conditions led to a significant decrease of thermal efficiency. Top-down ignition mode did not lead to significant better results in each case. Thermal efficiency of the ignition batch was even better when using the bottom-up ignition mode. Open air settings after finishing heating operation indicated a clear effect on thermal heat losses during cooling down. The comparative assessment of flue gas temperature measurement using a suction pyrometer or an unshielded thermocouple showed that the thermocouple measurement is less error prone. For temperature measurement with the suction pyrometer it is essential to comply with the required flue gas velocity (≥ 20 m/s) in the suction pyrometer, which can be usually not guaranteed when using only conventional gas analysers for flue gas suction. Direct efficiency determination using a calorimeter room requires a high effort. Direct and indirect efficiency determination reveals good conformity when respecting only the heating operation time without cooling down phase. Details about the above mentioned experiential development tests are published in Reichert et al. 2016 [2].

Finally, after finishing the experimental development process test conditions and test procedures of "beReal-Firewood" were defined.
The "beReal-Firewood" test method is represented by a heating cycle including eight consecutive batches and a certain time of the cooling down phase (Figure 5).The first five batches represent nominal load (100% batch mass), batch six to batch eight represent part load (50% batch mass). The cooling down phase is defined until the measured flue gas temperature (T1) reaches 50°C. As fuel the use of hardwood (beech or birch) is required. The mass of the first fuel batch for ignition has to be at least 80% of the fuel mass representing nominal load. As kindling material hardwood or softwood can be used. The total mass of kindling material is limited at 25% of the total batch mass. For lighting the ignition batch the use of specific bio

[2] Reichert et al. „beReal" – Development of a new test method for firewood roomheaters reflecting real-life operation, 24th European Biomass Conference and Exhibition, 6 -9 June 206, Amsterdam, The Netherlands

based starting aids is required. The use of paper or liquids as starting aids is not allowed. The total mass of starting aids is limited at 3% of the total batch mass.

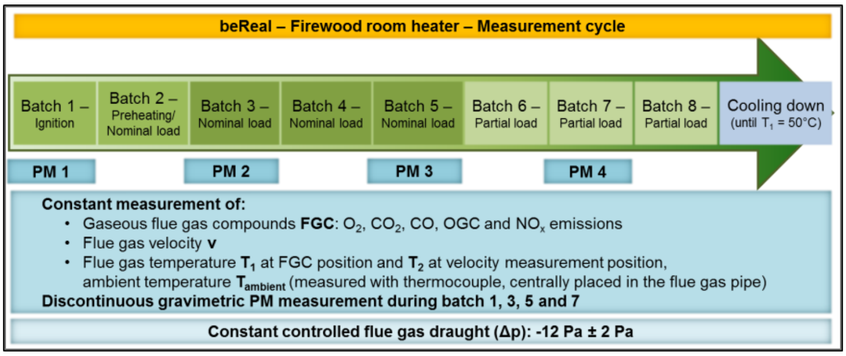


Figure 5: “beReal –Firewood” – test procedure and measurements

The instant of time for refilling a new fuel batch is defined according to the CO_2 flue gas measurement. If the maximum CO_2 flue gas content of the respective batch is >16 vol.-% refilling is required at 4 vol.-% CO2. If the maximum CO_2 flue gas of the respective batch is <12 vol.-% refilling is required at 3 vol.-% CO_2. In all other cases refilling is required at a CO_2 flue gas content representing 25% of maximum CO_2 flue gas content. This criterion represents the quantitative criteria for the qualitative criteria “flames extinguished” or “only little flames visible”. If combustion devices offer a signal indicating the instant of time for refilling, this signal is used.

The adaption of air settings is limited to four different settings for stoves with manually controlled combustion air supply:

1. Ignition and (if necessary) preheating (Batch 1 and (2)),
2. Nominal load (batch (2) 3-5),
3. Part load (Batch 6-8)
4. and end of heating operation (after batch 8).

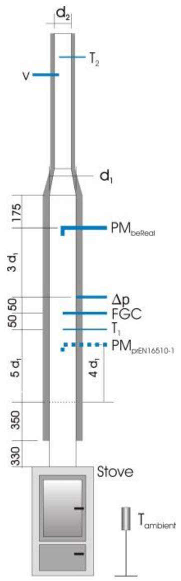


Figure 6: Test set-up for “beReal-Firewood”

If the test appliance offers an automatically controlled combustion air supply the adaption of air settings is done by the automatic control system. Basis for heating operation is an obligatory Quick User Guide” (QUG) (see WP4).

Flue gas composition (FGC) is evaluated by O_2, CO_2, CO, NO_x and OGC (measured as THC) measurements. Thermal heat losses are calculated based on the flue gas temperature (T1) measured with a thermocouple that is centrally located in the flue gas pipe. Gravimetric PM measurements are performed during batch 1, 3, 5, and 7. PM sampling over the entire batch starting before opening the combustion chamber door for refilling (or lighting – batch 1) is required. The flue gas velocity (v) and a second flue gas temperature (T2) measurement is necessary for calculation of thermal and chemical flue gas losses and for volume weighted data evaluation.

4 Work package 4 – Data evaluation and documentation

4.1 Online tool and Quick user guide (BE2020)

A web based online tool was developed to guarantee standardized data evaluation of the beReal test cycles for firewood room heaters and pellet stoves.

For accession to the online tool a login is mandatory (Figure 7). Therefore, the administrator provides an username and a password to the respective user (e.g. a testing body). Subsequently, the user have to do a registry process. During registration relevant data about the respective company as well as potential contact persons are provided by the user.

Figure 7: Login interface of the beReal online tool for standardized data evaluation

After the login all tests that were done by this user are listed and a new test can be generated. Before a new test is started the tested product need to be specified. Relevant data on the stove's characteristics (e.g. name and customer of the stove, thermal heat output,…) need to be provided by the user. After submission of the stove's data a new test can be generated.

Starting such a new test all relevant data on the measurement and test parameters (measurement systems, date, ambient conditions, PM sampling,…), characteristics of fuel and the measured raw data (as CSV-file) have to be uploaded and filled in the respective forms. When the data is submitted completely and correctly, the results can be calculated. Then a list of gaseous (CO, OGC, NOx) and particulate (PM) emission as well as efficiency results are displayed and a report (PDF-file, Figure 9) can be downloaded. This report is generated automatically and includes all relevant data on the test and stove parameters. Moreover, the calculated results are given and the time dependent values of the respective measured parameters are printed in graphs. Pictures can be included either.

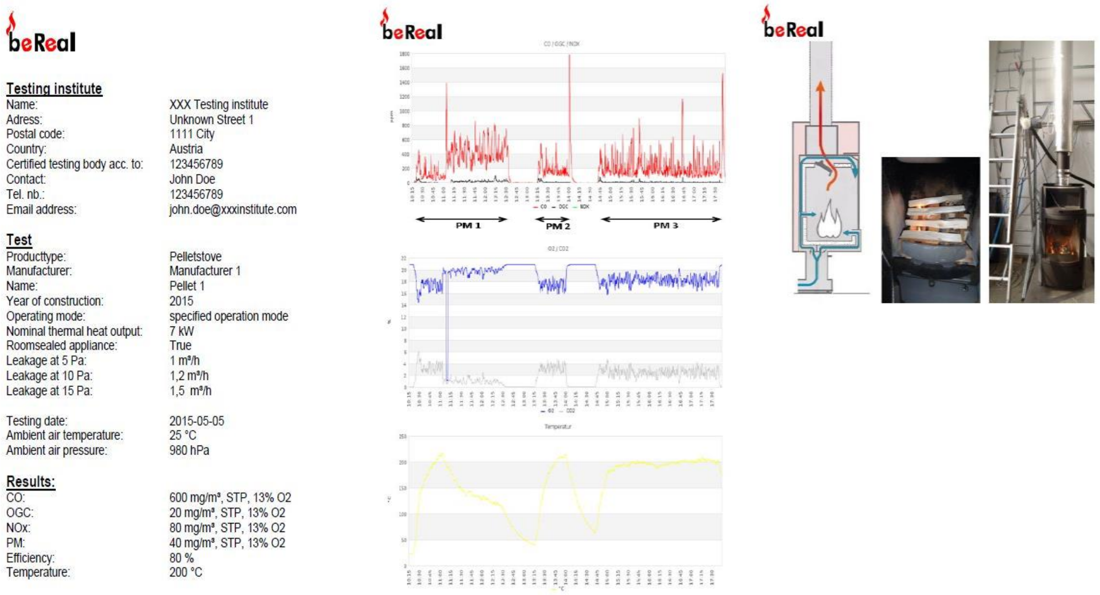


Figure 9: Standardized report of test results of the evaluation via the beReal online tool

For quality assurance some security queries are implemented in the web based online tool. Obligatory fields are marked with an asterisk and logical errors or missing values are detected and an information message of the respective error is given to the user (Figure 8). These errors need to be corrected for the submission of all data, otherwise the calculation of the test results is not possible.

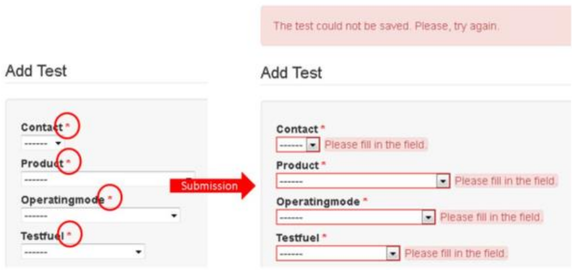
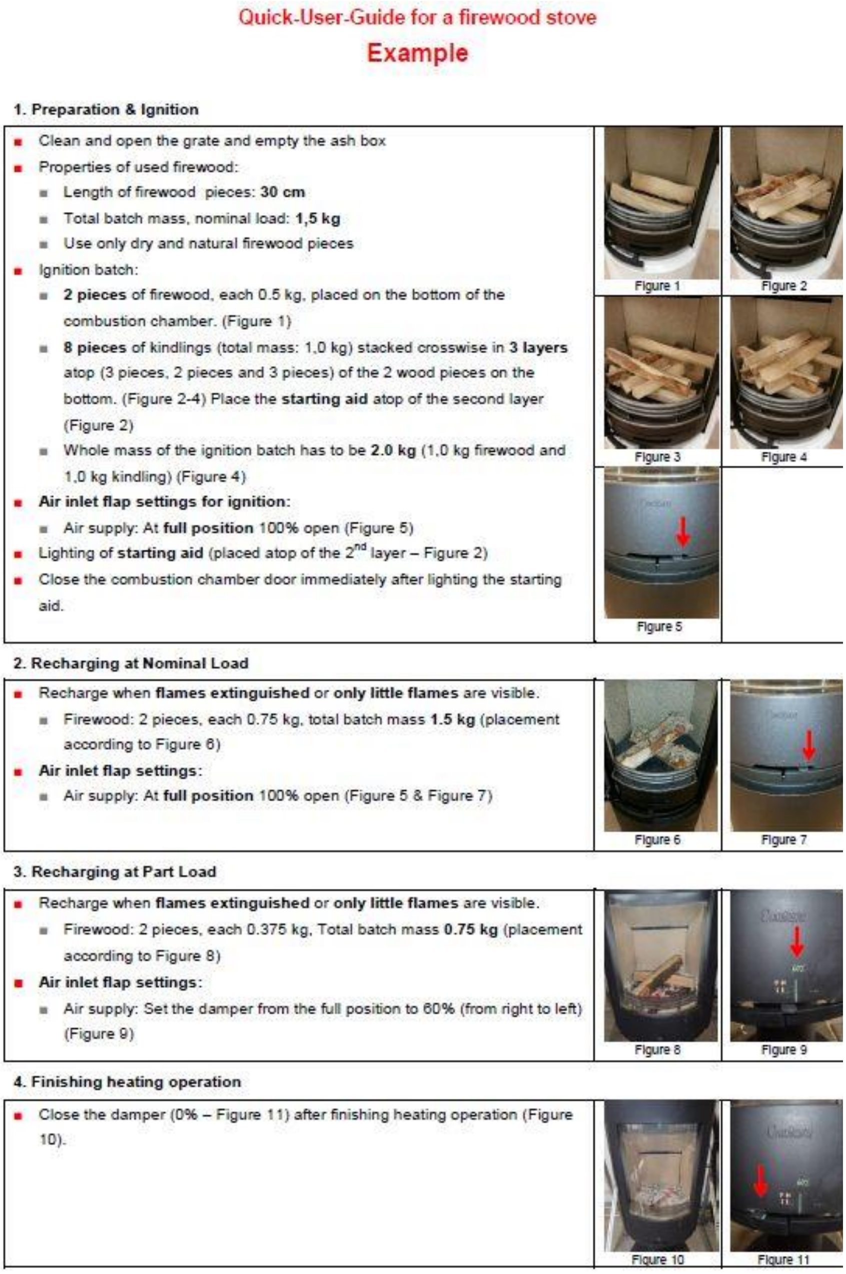


Figure 8: Red asterisk (left) for obligatory fields and error messages (right) as quality assurance measure at the beReal online tool

The beReal method requires an so called “Quick User Guide” (QUG). It is meant as a short description of the heating operation. The QUG should provide information about the “appliance specific” best-practice-heating-operation to the testing body as well as to the user in the field.

Thereby, operation modes for ignition, refilling and shut down of the stove are described with text and pictures, obligatory (Figure 10). This one page manual should give support and information on parameters like fuel specifications (type, size and amount), placement of fuel in the combustion chamber, air valve settings, etc. These instructions are given for ignition, nominal and part load operation as well as for the end of the heating operation, the cool down phase.

The QUG is the basis for the beReal testing procedure. The test is done exactly according to the QUG, which needs to fulfil all requirements of the beReal method. Additionally, the QUG is meant as a short manual for the end user in real life.



Quick-User-Guide for a firewood stove

Example

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

Figure 10: Example of the Quick User Guide (QUG) for firewood room heaters

5 Work package 5 - Validation

Validation measurements were conducted with the purpose of identifying weak points in the description of the procedure and in the performance of the measurements. Thereby the focus was on the feasibility and the repeatability of the new test method compared to the existing type testing method.

At six different pellet stoves (appliances according to DIN EN 14785) on four test benches (RTD partners and notified bodies from Austria, Germany and Sweden) the respective method was validated. All appliances were typical installations representing the current state-of-the-art. The heat output was in the range of 6 kW to 10 kW. At all installations comparative measurements as described in standard methods (DIN EN 14785) were conducted by performing three measurement repetitions at nominal load operation and three repetitions at partial load operation (minimum settable load) each lasting over a 30 min period under constant conditions. Measurements with the test cycle according to the new beReal test method were evaluated according to the respective method concept with one volume-weighted average value calculated for the complete cycle. The mean values were calculated out of three repetitions of the method measurement. Repeatability was evaluated by calculating the coefficient of variation *r* ($r = \frac{s}{\bar{x}} * 100$ with standard deviation s and mean value x̄).

5.1 Validation pellet stove method (TFZ)

A comparison of the results from official type test values (results from notified body that were provided by the stove manufacturer – 'official type test'), comparatively performed type test measurements at RTD partners ('RTD type test') and measurements according to the beReal method ('beReal test') from 6 tested stoves can be derived from a graphical overview over the CO results as given in Figure 11. Mean values on CO and thermal efficiency are illustrated in 12.

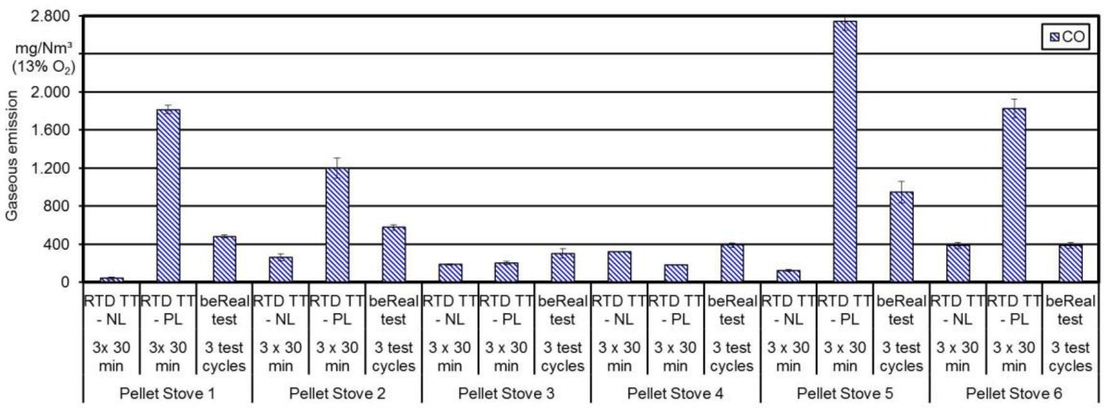


Figure 11: Mean values of validation measurements for RTD type tests at nominal load ('RTD TT – NL'), partial load ('RTD TT – PL'), and with beReal method ('beReal') for CO results at all 6 pellet stoves investigated (n = 3 repetitions)

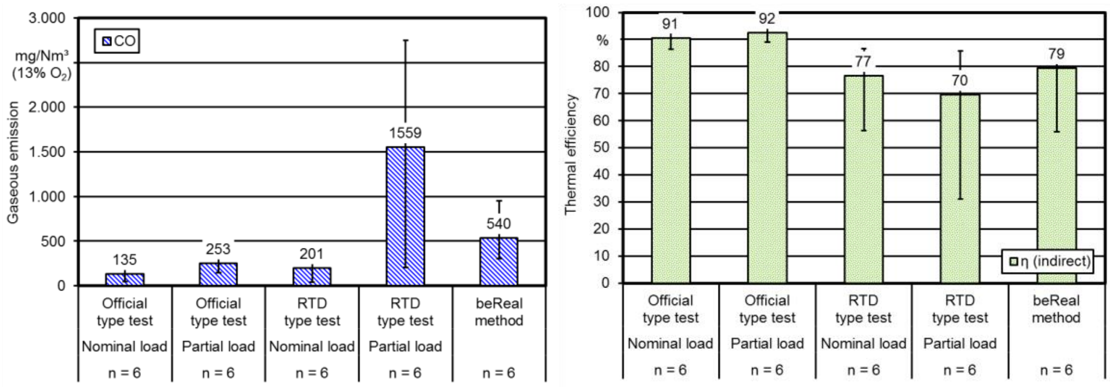


Figure 12: Mean values of validation measurements for CO (left) and thermal efficiency *η* (right) for official type tests, RTD type tests, and beReal tests (n = 6 stoves)

It becomes obvious that the RTD partner's type tests showed mostly higher results compared to official type test results which were e.g. exceeded by up to 49 % for CO for nominal load and by up to 515 % for CO for partial load. This underlines the difficulty of repeating the type test measurement accurately. Results of measurements according to the beReal method exhibited usually higher values than those for RTD type tests at nominal load, but values were lower compared to RTD type tests at partial load. This indicates that the beReal method might reflect various operational conditions not worse than the current standard procedure. Nevertheless, there is no repeated ratio between type test result and beReal result and therefore, no constant factor can be calculated which could be applied to the type test result to indicate the beReal result.

In terms of coefficient of variation r it became apparent that for measurements according to the beReal method the validation revealed a high repeatability with mean r below 10 % for CO, NOx, and PM emissions and thermal efficiency. Only for OGC emissions a lower repeatability with an increased coefficient of variation of 15 % was seen. These results are given in Figure 13.

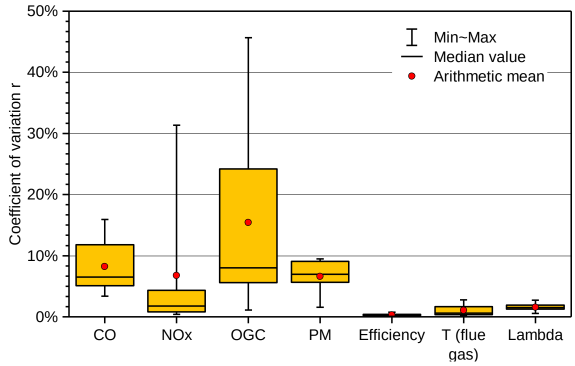


Figure 13: Coefficient of variation *r*: Mean values reached in beReal tests (n = 6 stoves)

5.2 Validation firewood stove method (BE2020)

During the method validation the difference between a nominal load test cycle (5 batches) and a test cycle containing nominal (5 batches) and part load operation (3 batches) was evaluated. It was seen, that the differences are very stove dependent. Figure 14 shows the differences for the tested firewood room heaters for the parameters CO, OGC, NOx and lambda. As a result of this comparison part load batches were included in the beReal test cycle (5 nominal batches followed by 3 part load batches).

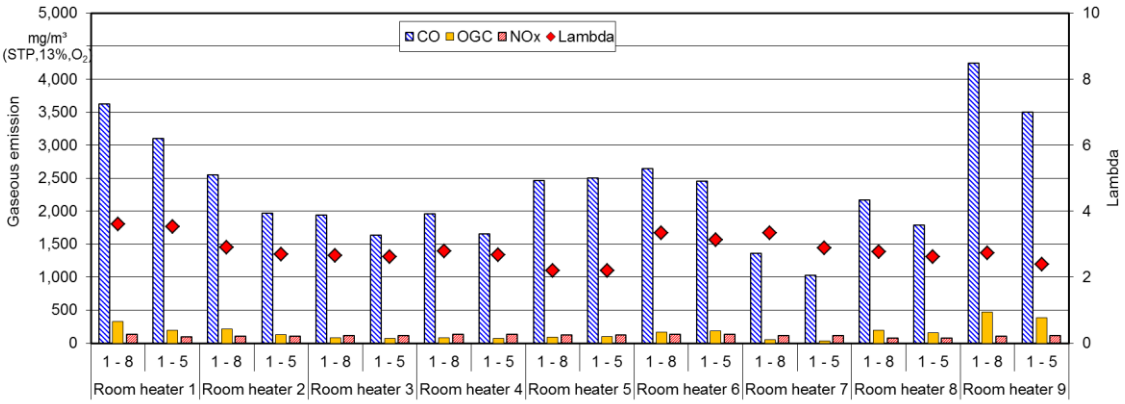


Figure 14: Mean values of validation measurements for beReal tests, evaluated for nominal load batches (1-5) and nominal and part load batches (1-8), for CO, OGC, NOx and lambda at all 9 firewood room heaters (n = 3 repetitions)

Moreover, further investigations on the following testing aspects should be done after the validation process:

- Refilling criteria: In some cases the “25 % criteria” was not appropriate for reigniting the following batch. Therefore, further tests should be done.
- q_r factor: The ash analysis during the validation procedure showed very different factors for the combustible amount in the residues, in contrast to the fix factor of q_r of 0.5 % of the standard evaluation according to DIN EN 13240. Further analysis was necessary for a definition of the analysis of this parameter.
- Leakage rate of appliance: In order to guarantee that the stove is not changing during the testing procedure, a leakage test before and after the beReal test was required.

The results of the comparative tests showed that official type testing results couldn’t be reached. In Figure 15 it can be seen that the type testing method at the RTD partners (“according type testing”) showed PM values up to 414 % higher. CO and OGC values exceeded the official values by up to 223 % and 183 %, respectively. On average, type testing at the RTD partners lead to worse results than the official type testing, but at nominal load to better results than for beReal testing (8 batches) (Figure 15, left). Part load testing at the RTD partners lead to worse results than for beReal (8 batches) (Figure 15, right). This indicates that the beReal method including 8 batches is a good indicator for a combined method of nominal and part load operation.

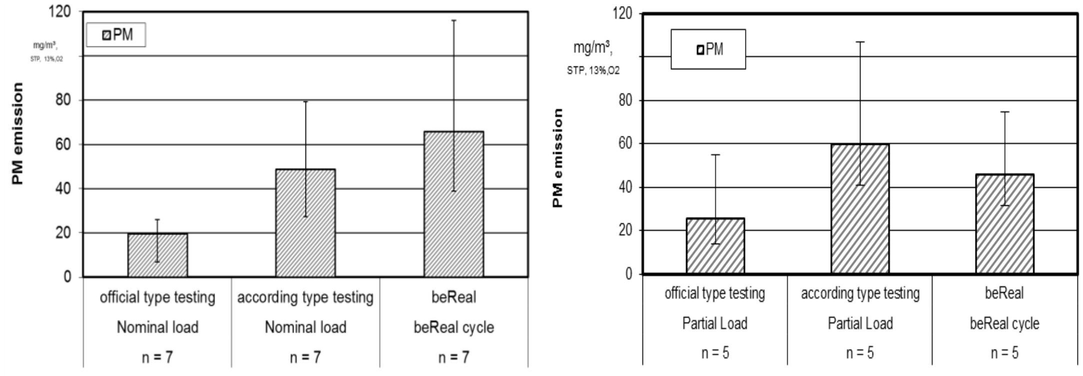


Figure 15: Mean values of official type testing, comparative type testing and beReal results for PM, for nominal load (left) and part load (right) operation (only at type testing method) (n = number of stoves)

In terms of repeatability the results of the coefficient of variation *r* showed results towards good repeatability (< 11 % on average) for CO, NOx, PM, efficiency as well as flue gas temperature, lambda and test duration. Only OGC showed a higher coefficient of variation (22 % on average) which seems to be the most critical measured parameter. Nevertheless, the repeatability is still satisfying. The results of the coefficient of variation are shown in boxplots in Figure 16.

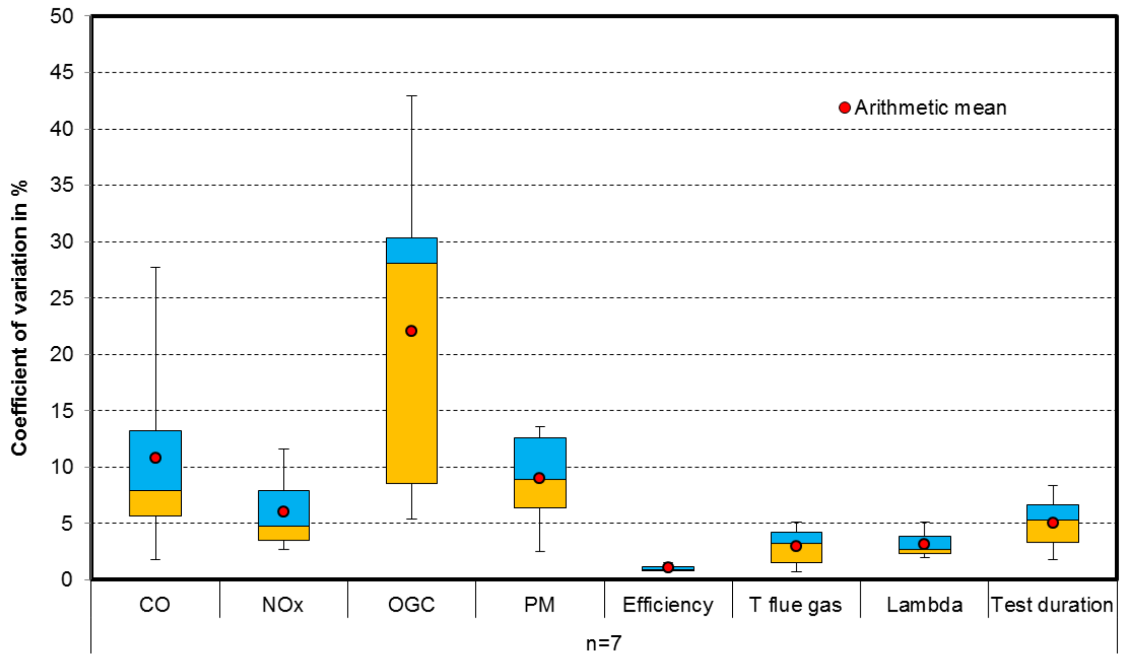


Figure 16: Coefficient of variation r for all tested parameters in the validation process (n = 9 stoves)

6 Work package 6 – Label development

A beReal-label could be an important step for the stove industry to meet public requests of testing methods close to real life. Furthermore, this label will enable stove manufacturers to emphasize high quality products in real life. Within the work package the calculation of the beReal label coefficient was developed. Further topics were regulations of a beReal label, the design, the framework and conditions of the beReal label scheme.

6.1 Calculation of a beReal label coefficient (BE2020)

Intense discussion within the beReal consortium led to the following two calculation methods:

6.1.1 Calculation method 1

By dividing the emission values measured by the benchmark values an immediate correlation to the benchmark values is realized (for efficiency results the benchmark efficiency value is divided by the measurement value). This leads to a neutral value of 1 given the case that all tested results have the same value as the benchmarks. Lower emission values (respectively higher efficiency values) indicate better results. The following equation describes the first method of the coefficient calculation:

$$Coefficient = \boldsymbol{a} * \frac{CO_{Measured}}{CO_{Benchmark}} + \boldsymbol{b} * \frac{OGC_{Measured}}{OGC_{Benchmark}} + \boldsymbol{c} * \frac{PM_{Measured}}{PM_{Benchmark}} + \boldsymbol{d} * \frac{\eta_{Benchmark}}{\eta_{Measured}}$$

$$\boldsymbol{a} + \boldsymbol{b} + \boldsymbol{c} + \boldsymbol{d} = 1$$

$\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}$ and $\boldsymbol{d}$ represent weighting factors

Emission benchmark factors:

$$\Delta CO = \frac{CO_{Measured}}{CO_{Benchmark}}$$

$$\Delta OGC = \frac{OGC_{Measured}}{OGC_{Benchmark}}$$

$$\Delta PM = \frac{PM_{Measured}}{PM_{Benchmark}}$$

Thermal efficiency benchmark factor:

$$\Delta \eta = \frac{\eta_{Benchmark}}{\eta_{Measured}}$$

6.1.2 Calculation method 2

The second method emphasizes stove efficiency. This approach proposes that in a first step the coefficient is calculated only for emissions (including weighting parameters) and then this value is multiplied by a factor for efficiency itself, as it is given in the equation below. This would be comparable to the correlation between an emission value and an energy unit (e.g. emissions per kWh or per MJ). As in method 1 the neutral value is 1, lower values indicate better results.

$$Coefficient = \left(\boldsymbol{a} * \frac{CO_{Measured}}{CO_{Benchmark}} + \boldsymbol{b} * \frac{OGC_{Measured}}{OGC_{Benchmark}} + \boldsymbol{c} * \frac{PM_{Measured}}{PM_{Benchmark}} \right) * \frac{\eta_{Benchmark}}{\eta_{Measured}}$$

$$\boldsymbol{a} + \boldsymbol{b} + \boldsymbol{c} = 1$$

$\boldsymbol{a}$, $\boldsymbol{b}$ and $\boldsymbol{c}$ represent weighting factors.

6.1.3 Setting the benchmark

As additional criterion for the beReal label, absolute threshold values for maximum emission and minimum thermal efficiency have to be set in order to avoid very high result in one of the tested parameters. Therefore, it is suggested that gaseous emissions shall not exceed the benchmark by more than 30 %. The beReal coefficient can still be equal or lower than 1 if other emission values outweigh a small exceedance, but it needs to be in the range of the absolute threshold. As benchmarks dummy values were used to do calculations and a sensitivity analysis. For a definitive determination of the beReal benchmarks, a sufficiently large data base is required from various combustion units with measurement results according to the beReal method. Further research is required.

6.2 Label regulations (TFZ)

Any European stove manufacturer can apply for the beReal label. The manufacturer has to provide a QuickUserGuide (QUG), which shall be created in accordance with the beReal method procedure. The beReal test is executed exactly according to this QUG which is part of the user manual, any modifications need to be approved by the testing body.

The validity of the label shall be limited to four years, in order to account for changes in the production process. The label shall include an ID number and QR code which links the specific product to the test report on the label's public website. The year of issuing shall be indicated on the label, e.g. as part of the ID number.

6.3 The label design

In central position the label proposals show the beReal logo (Figure 17). It is suggested that there is a clear differentiation between the label for pellet and for logwood room heaters. The label contains space for year and number (example: 1234562016). The reference to the beReal website allows the customer to get further information (e.g. test results from database). Additionally, a QR code can be used to reach the beReal website. It is possible to count the number of QR code scans to get an impression of possible clients. The label refers to the beReal test method and summarizes the core objective of the beReal project: "Tested Under Real Life Conditions".

Figure 17: Propositions for beReal-labels (design: AIEL)

6.4 The label framework

The following chapter develops an idea of how to organize the framework for a future beReal label. Figure 18 illustrates possible administration levels.

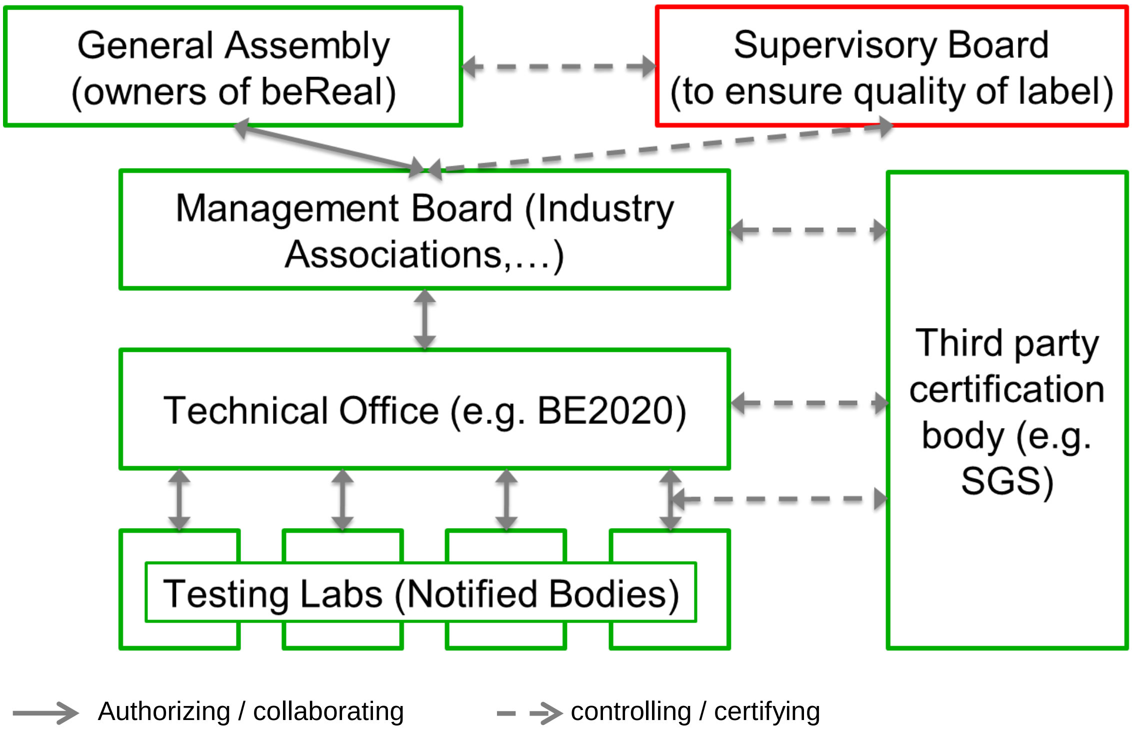


Figure 18: Draft of possible administration levels of a future beReal label

The owners of a beReal label form the General Assembly defining the general course of affairs and overall strategy within the beReal label. The Management Board is responsible for the day-to-day management of the label and cooperates with the Technical Office. The Technical Office maintains the online tool for the evaluation of the test results and publishes the test results in an online database. It takes care of data handling and quality assurance and hosts a web database with all positive tested products. The Supervisory Board is in charge of the overall supervision and oversees the implementation of the testing scheme. The members are representatives from stove industry, environmental agency representative(s), end-user representing NGOs and representative of the Notified bodies. The External Certification Body allows an independent third party certification. Therefore it should be a well-recognized worldwide operating certification organization. This will assure a high reputation of the label among industry and governments. The Testing Labs (Notified bodies) do the testing and invoice the assessment fee.

6.5 Conditions of the beReal label scheme

A variability of measures ensures the high quality and the credibility of the labelling process and the labelled products.

- The testing scheme is based on extensive research concerning new testing methods with increased repeatability and practical relevance.
- The proposed beReal framework with external certification ensures a high reputation of the label among industry and governments. Notified bodies that want to qualify for beReal testing shall be obliged to attend a training course. The test results are published in a public online data base.
- Market surveillance by obligatory random spot checks will safeguard that the tested appliances are identical to the sold appliances.
- An online tool for the beReal test evaluation allows a standardized evaluation procedure between different testing bodies.

7 Work package 7 – Field demonstration

7.1 Field demonstration (SP)

The purpose of WP 7 was to demonstrate the applicability and practical relevance of the advanced testing method reflecting real life conditions. To this aim thirteen firewood stoves and four pellet stoves were installed in the field at a natural draught system. The methods developed in WP3 ("Measuring methods and testing procedures") were used and data was documented and analyzed with the tools developed in WP4 ("Data evaluation and documentation"). The results were compared with results from the lab tests performed in WP5 ("Validation").

The appliances were installed at least a month before the field tests to ensure that the users had become familiar with the appliances and had developed their own habits before the field tests were conducted. Each RTD partner provided the necessary measurement section and replaced the existing connecting pipe during the time of measurement. If the installation was altered when installing the measurement section, e.g. due to a different length of the flue gas pipe, the flue draught might have changed as well. The end users were given a few days to adapt to any changes in operation by the installation, prior to the measurements.

The firewood stoves installed in the field were fired during three days. The first day, the end users fired the stove as they normally did, using the fuel they normally used. The RTD partners were present and performed the measurements but did not give any advice nor interfered they. The second day the QUG was handed to the end users and they were told to fire according to the guide, using the fuel they normally used. The RTD partner did not give any advices nor did they interfere. The third day, the RTD partner coached the end user to fire according to beReal and provided test fuel, i.e. the same quality they normally used at the test stand. During all field days, the total test time was approximately 7 hours, including ignition, nominal load during more than 3 hours and partial load during more than 2 hours.

The pellet stoves installed in the field were fired during three days. On day 1, the end user was told to use their normal procedure and fuel quality. RTD personnel were observing but did not interfere or instruct. On day 2, the end user was told to use their normal procedure but to use RTD supplied fuel, i.e. the same quality they normally used at the test stand. RTD personnel were observing but did not interfere or instruct. On day 3, the end user was told to use the fuel delivered by RTD (same as day 2) and was coached by the RTD personnel to fire according to beReal. All three testing days consisted of four different periods, ignition, steady state nominal load, regulated partial load (load change from nominal load to 50 % partial load) and steady state partial load (50 % of nominal load).

For firewood stoves, the three field days were compared with official type test according to EN 13240 (firewood stoves) or EN 14785 (pellet stoves), with type test performed by RTD partners according to EN13240 (firewood stoves) or EN 14785 (pellet stoves) and with beReal method performed in laboratory tests done by RTD partners.

7.2 Results and Discussion, Firewood stoves

For the emissions, the official type test results are lower than the beReal results, and the type tests performed at the RTD test stand (by RTD partners) is lower than the beReal results. Emission results are represented by CO emissions in Figure 19 and Figure 20. Results from beReal at the test stand and the three field days are on a slightly higher, but between themselves, on a comparable level.

A comparison between the beReal measurement in test stand and the end user operation, day 1, shows that emissions increase and efficiency decreases when the end users operate the stoves according to their normal procedure. A comparison of day 1 and day 2 in the field gives an indication of the possibilities to improve combustion results by instruction to and education of the end user. Day 1 shows the largest spread of results. From day 1 to day 2, the results improve in general. On day 2 the end user operates the stove according to the QUG. The spread in values is reduced for CO and PM, and the average values are reduced for CO, PM and OGC. The average value for the efficiency is the same for day 1 and day 2, and so is the spread of values.

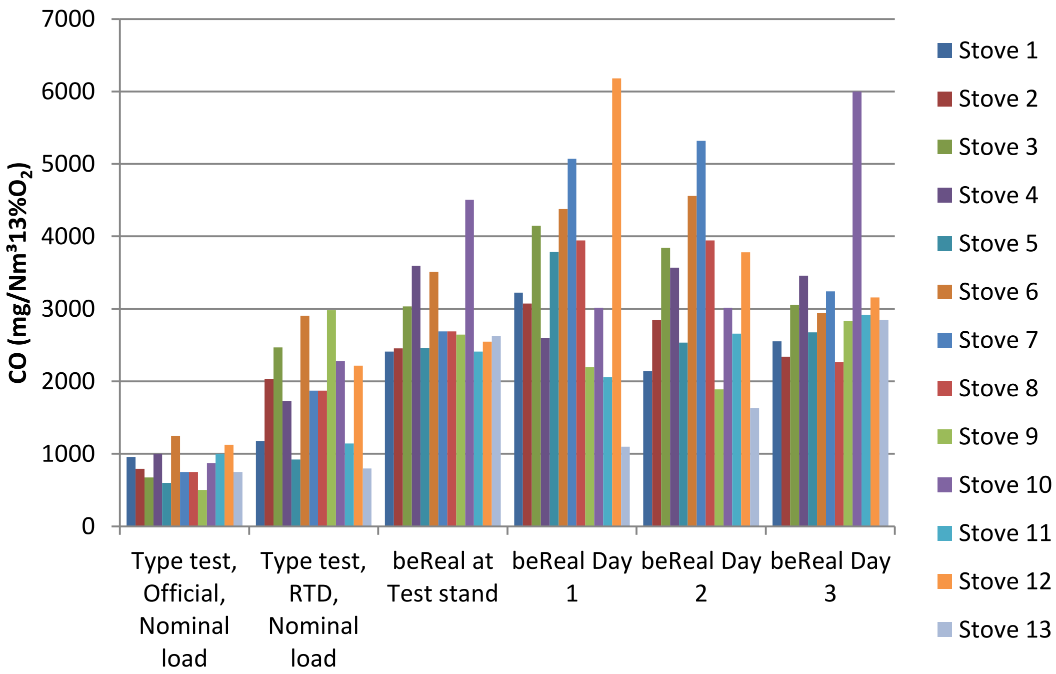


Figure 19. CO emissions from thirteen firewood stoves from different test procedures..

Day 3 for firewood stoves should be compared with the beReal result at the test stand, because the procedure and fuel is the same. The measured emission values converge these days compared to day 1 and day 3, but the efficiency is still low at day 3. For the beReal test in the field (day 3) it can additionally be seen, that the minimum and maximum values (indicated by the whiskers) are reduced significantly compared to the results from day 1 and 2.

The efficiencies are best for the official type tests. Type tests made by RTD partners and the beReal results at the test stand are the same; the beReal value in the field shows almost the same result. Results from beReal tests performed in the field using the test fuel and coached by the RTD partner (day 3) are close to results from beReal performed in laboratory and this indicates that it is possible to perform laboratory tests that truly reflect normal field conditions.

For the firewood stoves, the emissions improved between day 1 and day 2. In addition, the spread in the results diminished. During these days, the same fuel was used. This indicates that an immediate and considerable benefit is gained due to improved combustion results by giving instructions to the end user. From the results, it becomes obvious that no constant factor can be applied to the official type test result to reach the beReal result.

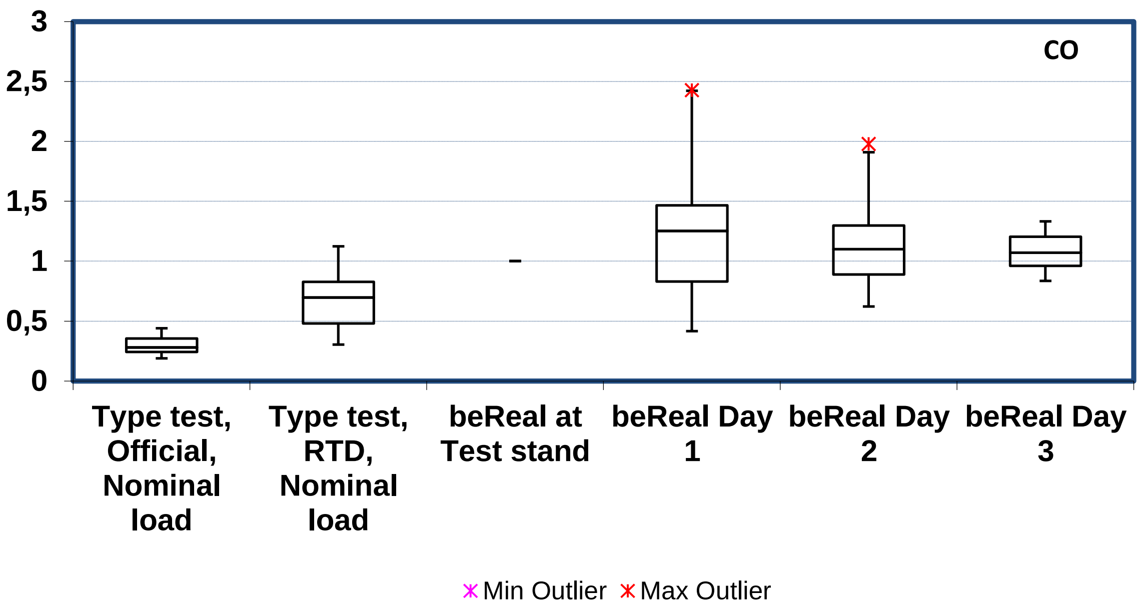


Figure 20. Box-and-whisker diagram showing CO emissions from firewood stoves. The number of values for all categories is 13. Outliers result from stove 12 on day 1 and stove 7 on day 2. All values are relative to the result gained from the beReal method measurement at the test stand. Therefore the value for beReal at test stand is 1.

7.3 Results and Discussion, Pellet stoves

For the pellet stoves, the widest spread in emission results is found for day 1 in the field, when the end users are using their normal fuel. Emission results are represented by CO emissions in Figure 21 and Table 2. The spread of results are lower on day 2 when the fuel is changed to test fuel. Results from day 3 in the field should be compared to the beReal result at the test stand because the same fuel and the beReal method are used. The difference is small. For the pellet stoves, there are few possibilities to influence the combustion and the difference between day 2 and day 3, where the end user is coached by the RTD partner, is small. The efficiencies are best for the official type test, but the differences are small.

Results from beReal tests performed in the field using the test fuel (day 3) are close to results from beReal measurements performed at the test stand and by that it is shown that it is possible to perform laboratory tests that truly reflect normal field conditions. It is clear that the choice of fuels influences the combustion result. For the pellet stoves, there is a difference between day 1 and day 2 when the fuel is changed. Obviously, pellets used by the RTD partners show improved results both in terms of emissions and in efficiency. In addition, the spread of the results is lower and the level of the median value improved compared with day 1, which indicates an optimum behaviour and increased operation reproducibility.

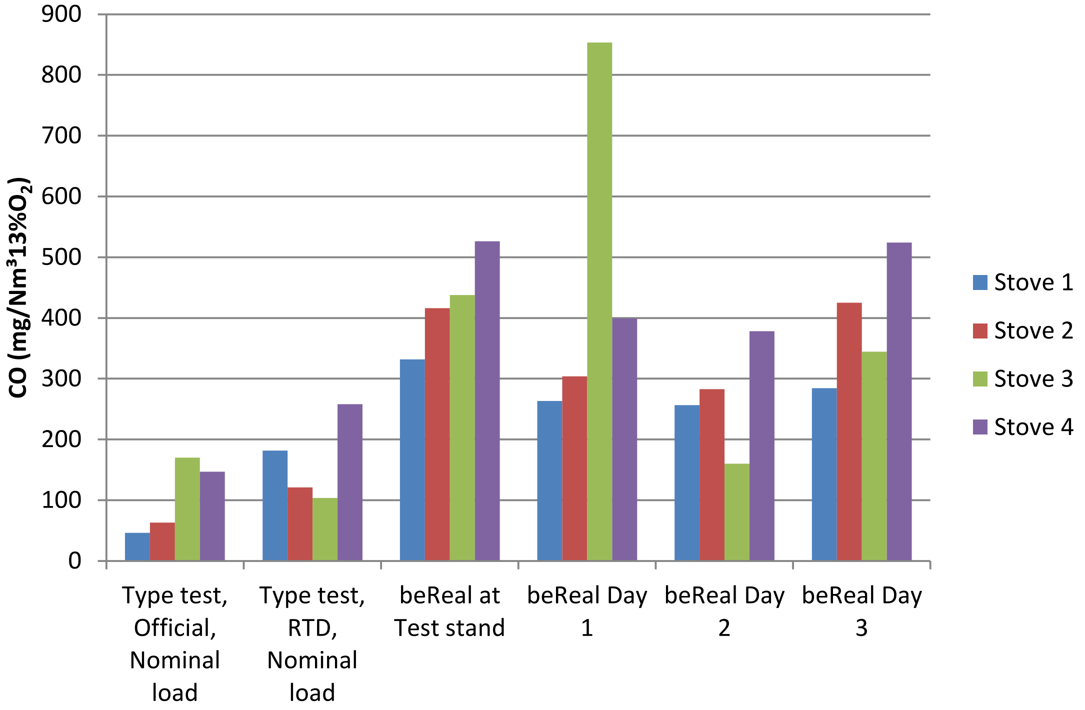


Figure 21 CO emissions from four pellet stoves from different test procedures.

Table 2. Average values for emissions and efficiencies versus procedures, firewood stoves.

	Type test, Official, Nom.al load	Type test, RTD, Nom. load	beReal at Test stand	beReal Day 1	beReal Day 2	beReal Day 3
CO ($mg/Nm^3 13\% O_2$)	848	1877	2891	3443	3211	3099
PM ($mg/Nm^3 13\% O_2$)	21	58	74	76	74	84
OGC ($mg/Nm^3 13\% O_2$)	58	130	245	310	279	297
Efficiency (%)	81	70	70	65	65	65

8 Work package 8 – Round Robin test

8.1 Round Robin (DTI)

A Round Robin was performed to provide performance data of the new beReal method in form of repeatability and reproducibility for a pellet stove and a firewood stove. Furthermore, the Round Robin was used to assess the effect of fuel quality for both pellets and firewood. Finally, the Round Robin gathered data to compare the beReal method with type testing. A total of 7 laboratories participated in the Round Robin, 3 of these laboratories where accredited for measurement of wood stoves accordingly to EN 13240/ prEN 16510 and pellet stoves accordingly to EN 14785. The remaining laboratories were experienced in measurements accordingly to the above-mentioned standards on wood stoves and pellet stoves for experimental purposes. The Round Robin schedule consisted of a period for testing wherein the initial assessment of the appliances, setup, leakage tests and all measurements should be performed (14 days). All tests were performed in the period from 16th of November 2015 until 16th of September 2016. To ensure that the different laboratories had as similar conditions as possible, one pellet stove and one wood stove was sent between the participating laboratories. Since the main focus of the Round Robin is to find the reproducibility for the method, each lab had to use its own equipment. The measurement section was developed during WP5 for both wood stoves and pellet stoves and was then used in WP 8. Each lab had to build a complete section according to this. For the wood stoves each laboratory received test fuel for three days of testing. In order to investigate how the use of local fuel influences the beReal method, measurements with the beReal method were performed with the fuel that the individual laboratory normally used. See Table 3 for an overview of the fuel used for the measurements with wood

Table 3 – Schedule of test days for firewood stoves

Day	Method	Fuel
1	beReal	Local fuel
2	beReal	HFR test fuel with bark (wb)
3	beReal	HFR test fuel without bark (wob)
4	Type test - prEN16510	HFR test fuel without bark (wob)

Wood pellets are well known as a uniform fuel with low variation in quality. Nevertheless, pellets differ in length distribution and chemical composition which influence the combustion. Therefore, the pellets for the Round Robin tests were delivered by the HFR to all partners to ensure similar fuel quality. See Table 4 for an overview of the fuel used for the measurements with pellets.

Table 4 - Schedule of test days for pellet stoves

Day	Method	Fuel
1	beReal	Local fuel
2	beReal	HFR test fuel
4	Type test – prEN16510	HFR test fuel

8.2 Validation of measurements and results

Leakage rate of the appliance was used actively to ensure that the stove didn't change during the Round Robin for example due to transportation. When a laboratory received the appliance, a leakage rate test was performed and the results were sent to SP who evaluated if it was acceptable to proceed with the measurements. After the measurement a new leakage test was performed and evaluated. To ensure that all calculations were performed identically the calculation sheet prepared for WP 5 was adjusted to be used for the Round Robin test. Each participant has then during the Round Robin campaign used the same approach and calculation sheet for calculation of results. The sheet was also adjusted so that it could be used for the type test, but accordingly to the type test the result should only be given based on the two best results. In this campaign the best results are defined by the two charges/batches with the lowest CO value. A limited number of results were identified as statistical outliers. Although no technical explanation could be found, the results were excluded in the calculation of reproducibility to reveal the potential of the method.

8.3 Reproducibility of the beReal method

WP 8 recorded and reported results of single measurements on CO, OGC, NOx, PM and efficiency, for the complete overview is referred to D7.1. Average (X), standard deviation (denoted the between laboratory standard deviation s_L), and the between laboratory coefficient of variation CV_L are calculated based on these results. In WP5 measurements were repeated within the same laboratory. Based on data from WP5 the repeatability standard deviation s_r is estimated. Finally, the reproducibility standard deviation s_R and the reproducibility coefficient of variation CV_R are calculated. The reproducibility standard deviation is calculated as $s_R{}^2 = s_L{}^2 + s_r{}^2$. See Table 5 and Table 6 for the reproducibility values.

Table 5 – Reproducibility values for the beReal method on pellet stove.

Pellet stove	CO	OGC	NOx	PM	Efficiency
		$[mg/m^3_{STP, dry, 13\% O2}]$			[%]
X	522	20	146	43	87.2
S_L	131	7	16	14	1.0
CV_L [%]	25	35	11	32	1.1
S_R	147	7	16	15	1.1
CV_R [%]	28	36	11	34	1.2

Table 6 – Reproducibility values for the beReal method on firewood stove.

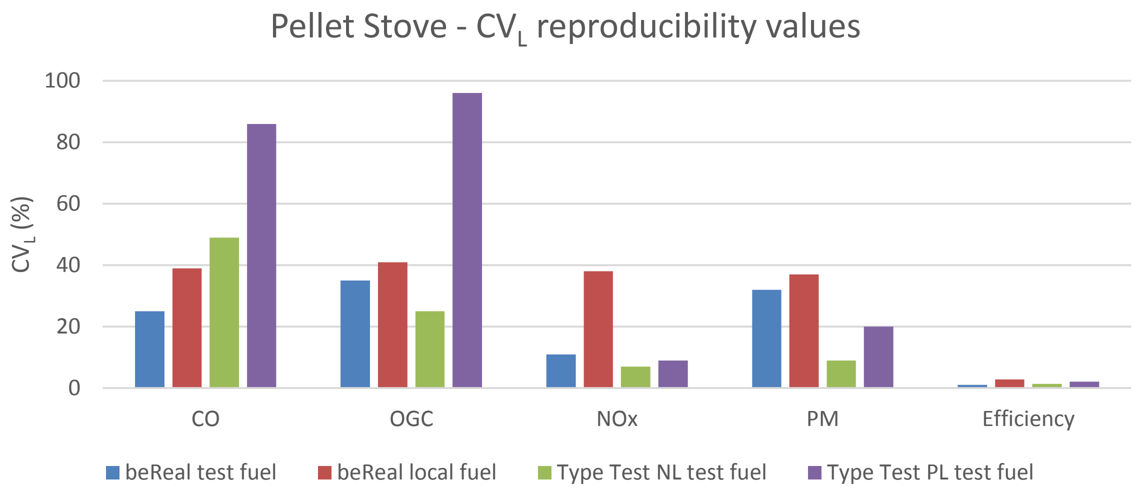
Firewood	CO	OGC	NOx	PM	Efficiency
stove		$[mg/m^3_{STP, dry, 13\% O2}]$			[%]
X	2815	138	98	41	71.9
S_L	494	78	7	18	3.8
CV_L [%]	18	57	8	43	5.3
S_R	619	97	12	20	3.9
CV_R [%]	22	71	12	49	5.4

The reproducibility obtained in the beReal Round Robin is quite high, taking into account that a procedure involving manual charging and operation of a stove during combustion potentially will have more sources to variation than a laboratory analysis step alone. The effect on reproducibility of fuel and the comparison with the type testing procedure was also evaluated. The between-laboratory coefficient of variation CV_L is used to evaluate the effect of different fuel qualities and to compare the beReal method with type testing. See Table 7 and Figure 22 for reproducibility values of the pellet stove.

Table 7 – Summary of reproducibility values for the pellet stove.

Pellet Stove	CV_L (%)			
	beReal		**Type Test**	
Parameter	**Test Fuel**	**Local Fuel**	**Test Fuel NL**	**Test Fuel PL**
CO	25	39	49	86
OGC	35	41	25	96
NOx	11	38	7	9
PM	32	37	9	20
Efficiency	1.1	2.8	1.4	2.1

Figure 22 - Reproducibility values for the pellet stove.



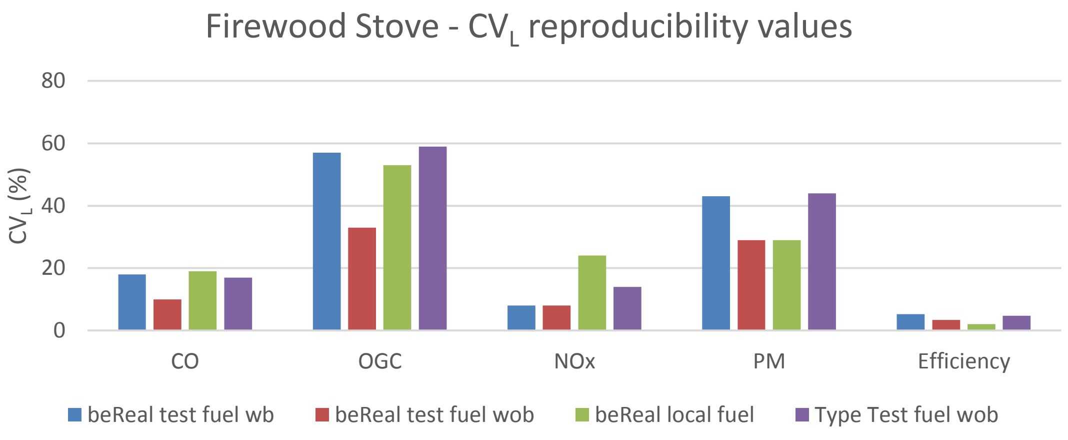
The use of local pellets leads generally to higher variations compared to test pellets for the beReal method. From a statistical point of view this is logical, as the use of local pellets introduces a new source of variation compared to the use of a more homogenous test fuel. As the results provide evidence that a common test fuel with clearly defined properties leads to an increased reproducibility, an implementation of clear fuel definitions into the method description could be considered. The values for CV_L show that the beReal method can be reproduced with the same variability or even better than the type testing method with exception of PM.

See Table 8 and Figure 23 for the reproducibility values of the firewood stove

Table 8 – Summary of reproducibility values for the firewood stove.

Firewood	CV_L (%)			
		beReal		**Type Test**
Parameter	**Test Fuel wb**	**Test Fuel wob**	**Local Fuel**	**Test Fuel wob**
CO	18	10	19	17
OGC	57	33	53	59
NOx	8	8	24	14
PM	43	29	29	44
Efficiency	5.3	3.4	2.1	4.7

Figure 23 - Reproducibility values for the firewood stove.



The between-laboratory variation generally decreases for the beReal method when using test fuel without bark compared to test fuel with bark, especially for CO, OGC and PM. In contrary to the pellet stove, there is no significant overall difference on the variation when going from test fuel with bark to local fuel for the beReal method. As mentioned above the use of local fuel instead of test fuel will potentially introduce a new source of variation. In the case of the firewood stove it must be concluded that this variation source is not significant compared to the variation introduced by using firewood with bark. Finally, the results show that the beReal method can be reproduced with the same variability or even better than the type testing method both using test fuel without bark.

9 Work package 9 – Dissemination and exploitation

To communicate the project idea, results and progress, different target groups were identified and addressed using appropriate communication means and tools. These groups include the project partners, public stakeholders, expert audience or standardization bodies and the general public.

Dissemination of project results took place on different levels. Internal project results were circulated on regular project meetings and via the online platform. During the project, a multitude of consortium and WP meetings have been held in which the progress, interim results and next steps of the project were discussed. An advisory board provided information exchange and discussion with an expert audience (e.g. standardization bodies, testing houses for stove testing, other research institutes, environmental agencies or public authorities). Presentations at technical conferences or seminars, technical publications, special events, newsletters and web publications completed the dissemination activities.

The beReal project generated basically the following foreground:

- Advanced test methods better reflecting real life performance of biomass room heating appliances
- Common web-based measurement data analysis and evaluation tool
- Labelling schemes allowing to differentiate biomass room heating appliances according to their real life performance

Business negotiations with certification institutes were made in order to decide for the appropriate economic strategy for the deployment of the label. The most likely case will be the cooperation with existing label suppliers or Europe-wide associations with relevant experience. Beyond a label several other exploitation possibilities have been identified. The consortium agreed on the fact, that the beReal testing procedure could have a positive influence on the type testing method- once it is integrated. Within the project consortium several industry partners expressed their intention to internally use the beReal method to further optimize their stoves in a more holistic way than it is possible with the type testing methods. It was suggested by members of the consortium to use the method to revise the (rather theoretic) factors for the calculation of national emission inventories. All members of the consortium agreed on the positive influence of the QuickUserGuide (QUG) on the end user behaviour.

The beReal test results show a much higher differentiation between poor and excellent products than current type testing does. This will stimulate the further development of existing products to the benefit of customers and the environment.