# *“beReal”* – DEVELOPMENT OF A NEW TEST METHOD FOR FIREWOOD ROOMHEATERS REFLECTING REAL LIFE OPERATION

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ABSTRACT: Standard type testing methods for biomass room heating appliances have driven technological development tremendously in the last decades towards low emissions and high efficiency. However, they are not suitable to reflect real life performance as operating conditions and user habits are not sufficiently considered in the test procedure. Several studies revealed a major contribution of batch fired room heating appliances to harmful gaseous and particulate emissions. Consequently, there is the need to optimize the combustion performance of these technologies in future significantly, especially in real life operation. Advanced test procedures implemented in normative standards or labels are effective instruments to assess product quality and to trigger technological development. Therefore, a new test method for firewood roomheaters (EN 13240) was developed focusing on real life operation performance. The test procedure is based on a European survey on user behavior, long term field monitoring as well as comparative combustion tests under laboratory conditions. Validation tests confirmed a high repeatability of the testing procedure of the suggested test method “*beReal-Firewood*”.
Keywords: roomheater, test method, real life, firewood combustion, emissions, efficiency

## 1 “*beReal*” – MISSION & VISION

In the European project “*beReal*” a new test method for firewood roomheaters (tested acc. to EN 13240 [1]) was developed. The new “*beReal*” test method aimed at the provision of following characteristics:

- Good reproducibility: The reproducibility will be evaluated and demonstrated by a Round Robin Test.
- High real life relevance: Comparative tests under lab and field conditions shall confirm high real life relevance.
- Quality assurance (QA) concept: A web based tool for standardized data evaluation was elaborated.
- Quality criteria: The beReal test results reveal suitable quality criteria for the tested product. A better product diversification regarding emission and efficiency performance is possible.

The “*beReal*” project aims to implement the advanced test procedure in a “*beReal*”-labelling scheme.

## 2 APPROACH

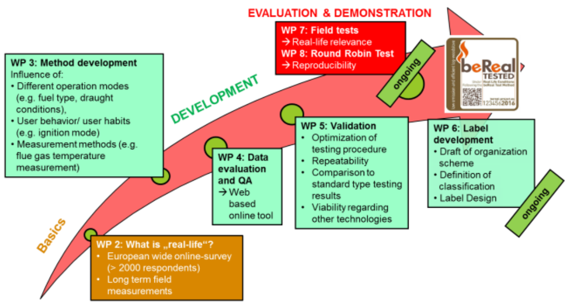


**Figure 1**: General approach – The way of developing “*beReal-Firewood*”

The “*beReal*” project was structured in nine work packages (WP). WP1 included the project management and in WP9 dissemination activities were performed. The R&D work regarding method and label development as well as evaluation and demonstration tests were carried out in WP2 – WP8 (Figure 1).

## 3 WHAT IS REAL LIFE?

### 3.1 Survey on user behavior

A European online survey was carried out in order to get an impression about typical user behavior and operational characteristics in real life. Therefore, a questionnaire based on multiple-choice questions was elaborated.

More than 2,200 questionnaires were completed and used for data evaluation. The findings showed that predominantly hardwood is used for heating operation (88% of users of firewood stoves). The most common effective chimney height in real life was specified in the range of 5-10 meters. Figure 2 illustrates the findings for users of firewood stoves regarding the procedure of ignition of the first fuel batch.

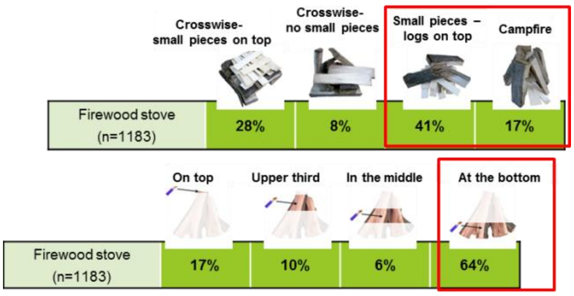


**Figure 2:** Results of online survey regarding the ignition procedure

More detailed results about the user survey are published in Wöhler et al. 2016 [2].

3.1 Long term field measurements

For several appliances in Austria, Germany, Sweden and Denmark firewood roomheaters (EN 13240) were monitored over a three to four months period under real life operating conditions. The frequency of use, the number of batches per heating cycle and typical draught conditions in real life were investigated **(**Figure 3).

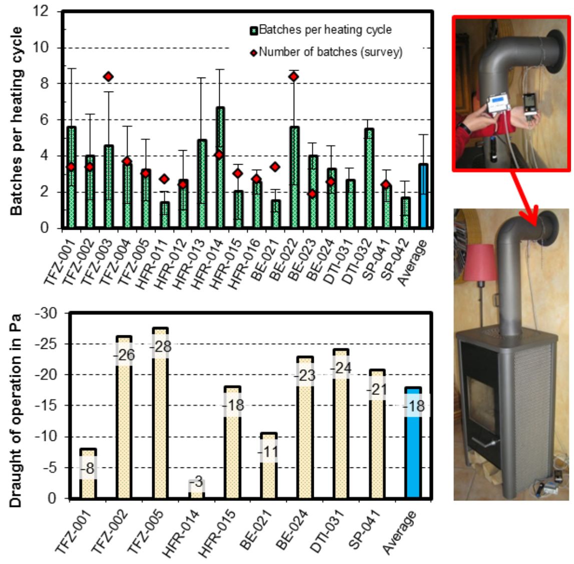


**Figure 3:** Results of long term field measurements regarding batches per heating cycle (top) and draught conditions (bottom); Example of stove used for temperature and draught measurements (right)

Additionally, the questionnaires of the survey were also answered by persons participating in the field measurements. The evaluation of their survey answers was possible for some aspects by comparing field measurements and survey answers (e.g. Figure 3 top). In most cases estimations of the users in the survey fitted quite well to the findings of the field measurements.

## 4 HIGHLIGHTS OF DEVELOPMENT PROCESS

### 4.1 Effect of draught conditions

The long term field measurements revealed that the average draught conditions are often higher compared to the average draught conditions applied for testing according to EN 13240 standard (12 ± 2 Pa).

Therefore, a test series was carried out, where draught conditions were varied under constantly controlled conditions at 12 Pa, 24 Pa and 48 Pa.

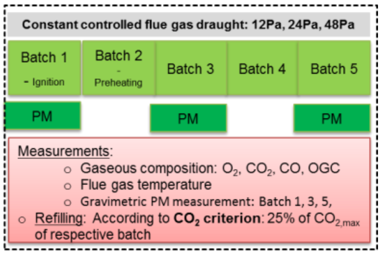


**Figure 4:** Test cycle used for investigation of the effect of different draught conditions on combustion performance

Three different roomheaters (A, C, D: acc. to EN 13240) were used for this test series. For each draught level and each roomheater one combustion test was performed using a heating cycle of five consecutive batches (Figure 4). All batches were performed with a batch mass representing the nominal heat load of the respective combustion appliance.

The results of the test series showed that the effect of draught conditions on gaseous emissions (CO-Carbon monoxide/ OGC – organic gaseous compounds) is different for each stove (Figure 5).

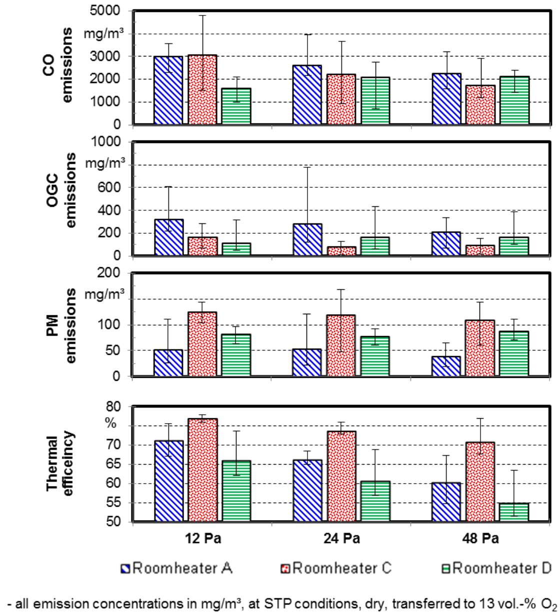


**Figure 5:** Results of test series on the effect of different draught conditions on combustion performance of firewood roomheaters

For roomheater A and C the gaseous emissions decreased, for roomheater D the gaseous emissions increased at higher draught conditions. No effect of higher draught conditions on particle emissions (PM) was observed in this test series. Regarding thermal efficiency a negative correlation was found: Increased draught conditions decreased the thermal efficiency.

### 4.2 Investigation on different ignition modes

According to the user survey the most common ignition procedure is the bottom-up ignition mode (Figure 2). In a test series the differences of bottom-up and top-down ignition mode as well as the use of different kindling material were investigated (Figure 6).


**Figure 6:** Scheme of top-down and bottom-up ignition mode and types of used kindling material

For this test series two different roomheaters (A, B: acc. to EN 13240) were used. In total four different variations were tested for each roomheater (Table I). Each variation was tested three times (n = 3). Each test run started from cold conditions. For each test run the same mass of firewood and kindling material was used.

**Table I:** Overview of tested variations of ignition test series

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

The average results of each tested variation are illustrated in Figure 7.

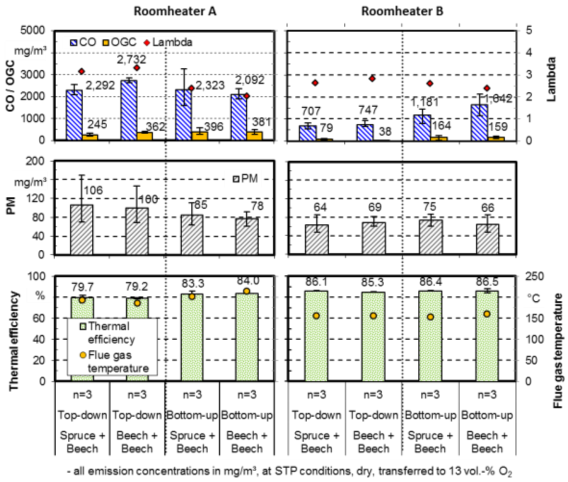


**Figure 7:** Results of ignition tests for roomheater A (left) and roomheater B (right)

The results showed that the use of different kindling material (beech or spruce) has only low effect on emissions and efficiency results. When comparing the results of emissions and thermal efficiency it was evident that both ignition modes can lead to different absolute levels for different combustion appliances.

For roomheater A the bottom-up ignition mode resulted in lower CO and PM emissions, but in higher OGC emissions compared to top-down ignition results. For roomheater B the results were different. Top-down ignition mode showed lower results for gaseous (CO, OGC) emissions. However, only marginal differences for PM emissions were observed between both ignition modes for roomheater B.

Further, it has to be mentioned that for both roomheaters best thermal efficiency values were reached by application of bottom-up ignition mode.

Consequently, the comparison of results of different ignition modes indicated that there is no general advantage of top-down ignition mode for each appliance. Therefore, it is important to identify the optimal ignition mode specifically for each appliance in future.

4.3 Thermal efficiency – the effect of cooling down

The calculation of thermal efficiency according to EN 13240 standard is done by determination of thermal and chemical flue gas losses as well as by including the losses due to unburnt residues by a constant factor of 0.005 (Equation 1).

**Equation 1:** Determination of thermal efficiency according to EN 13240 standard

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

The thermal efficiency calculation according to EN 13240 standard is done for each batch separately. Additionally, EN 13240 standard evaluates only parts of the total heating operation. Consequently, potential thermal and chemical flue gas losses in the cooling down phase are not considered in the EN 13240 approach.

In the context of the beReal method development process comparative tests were carried out in a calorimeter room (Figure 8) in order to compare direct and indirect efficiency determination [3].

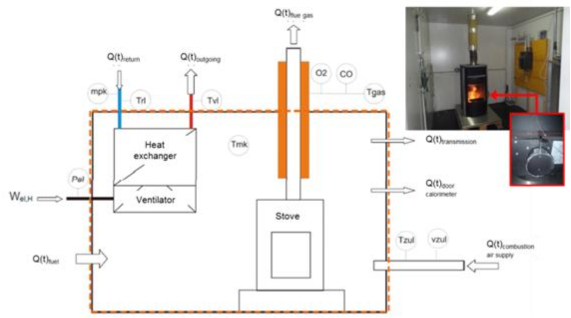


**Figure 8:** Scheme of calorimeter room for direct efficiency determination and used roomheater as well as air valve for combustion air supply

Using the calorimeter room the balancing of energy flows was possible. The useful heat was measured by a heat exchanger. Transmission losses of the cabin were determined by pretests and were included for each test run. The calculation of thermal efficiency according to the direct determination approach was done as follows (Equation 2).

**Equation 2:** Determination of thermal efficiency using the calorimeter room

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

For investigation of thermal flue gas losses during the cooling down phase two test runs were performed using a roomsealed roomheater according to EN 13240 standard.

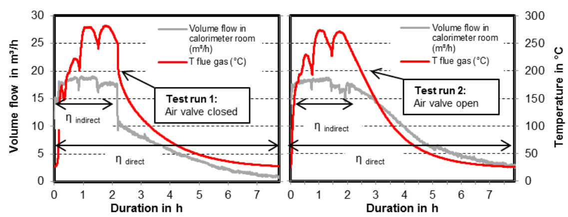


**Figure 9:** Test runs performed for investigating the effect of air valve settings on thermal flue gas losses during cooling down phase

For each test run three consecutive batches at nominal load were performed starting from cold conditions. After the test run the air valve was closed (Test run 1) or remained open (Test run 2) (Figure 8,

Figure 9). The flue gas temperature and the volume flow entering the calorimeter room were monitored over the whole heating duration and also during the cooling down phase. During heating operation (batch 1 – 3) a constant flue gas draught of 12 ± 2Pa was applied. After finishing heating operation the flue gas fan was set on constant settings in order to simulate natural draught conditions.

Thermal heat losses were calculated for the heating operation phase and also for the cooling down phase (Figure 10).

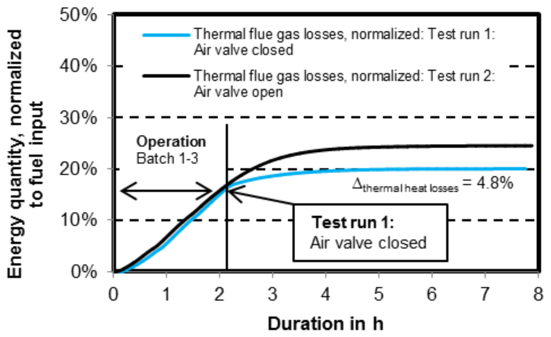


**Figure 10:** Curve of thermal flue gas losses during test run 1 and 2 (normalized to fuel input)

The results of test run 1 and 2 showed that thermal flue gas losses occurred during cooling down phase. If the air valve remained open the thermal flue gas losses during cooling down phase were 4.8% higher. This difference is also illustrated by the step of decreasing flue gas temperature as well as volume flow (Figure 9 – left) of test run 1. More detailed information about these combustion tests is available in Sturmlechner et al. 2016 [3].

Based on these results it was evident that overall thermal efficiency is influenced by the conditions during cooling down phase. Consequently, it was decided to implement the cooling down phase in the test procedure of "*beReal-Firewood*".

## 5 SUGGESTED METHOD "*beReal-Firewood*"

### 5.1 Test procedure and measurements

The suggested method "*beReal-Firewood*" is represented by a heating cycle including eight consecutive batches and a certain time of the cooling down phase (Figure 11).

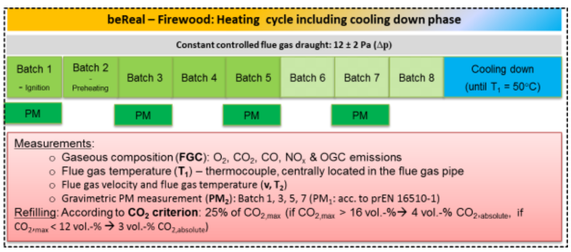


**Figure 11:** "*beReal –Firewood*" – test procedure and measurements

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 was defined until the measured flue gas temperature ($T_1$) reaches 50°C.

As fuel the use of hardwood (beech or birch) is required. Each firewood piece has to be covered with bark at least at one side ("covered" is defined as >80% of surface area). 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 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.

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.-% $CO_2$. 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".

According to the results of the user survey this is the instant of time where users commonly refill a new fuel batch [2]. 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).

If the test appliance offers an automatically controlled combustion air supply the adaption of air settings is done by the automatic control system.

Figure 12 illustrates the scheme of the suggested test set-up for "*beReal*" testing.

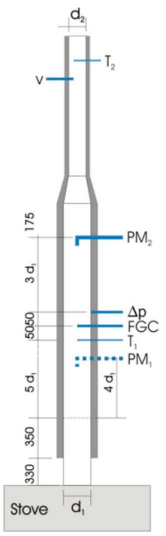


**Figure 12:** Suggested test set-up for "*beReal-Firewood*"

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 ($T_1$) 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. It is suggested to use the approved EN-PME test method [4].

The flue gas velocity (v) and a second flue gas temperature ($T_2$) measurement is necessary for calculation of thermal and chemical flue gas losses and for volume weighed data evaluation.

5.2 Quality assurance: Quick-User-Guide & Online tool

A concept for a Quick-User-Guide (QUG) was elaborated. The QUG defines all relevant operating parameters specifically for each appliance on one or two pages. The information about –

- Preparations before heating operation
- Ignition mode
- Refilling
- Fuel properties
- Air settings

- shall be given by text and pictures (Figure 13).

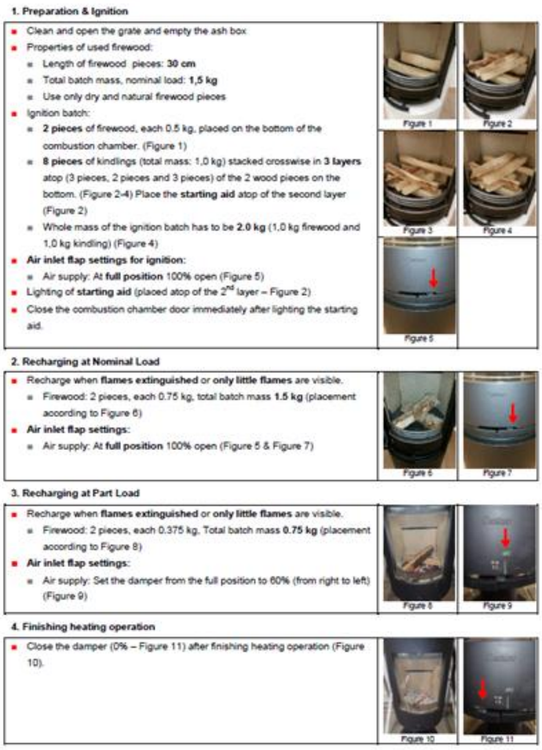


**Figure 13:** Example of a Quick-User-Guide

The QUG which is elaborated by the manufacturer is obligatory for "*beReal*" testing. The QUG shall be handed unchanged to the end-costumer. Therefore, the QUG can be used as an effective instrument to enhance a correct and appliance specific best-practice heating operation in real life.

A web-based calculation tool for standardized data evaluation of "*beReal"* tests was developed (http://bereal.bioenergy2020.eu/). Via a log-in the user of the online tool (notified testing institute for "*beReal"*) is able to insert general test data as well as data of the tested appliance, used fuel etc. (Figure 14). Subsequently, raw data of the "*beReal"* test as well as the used QUG for testing has to be up-loaded. Finally, the "*beReal"* test results are calculated according to "*beReal"* definitions and a standardized test report is produced automatically.

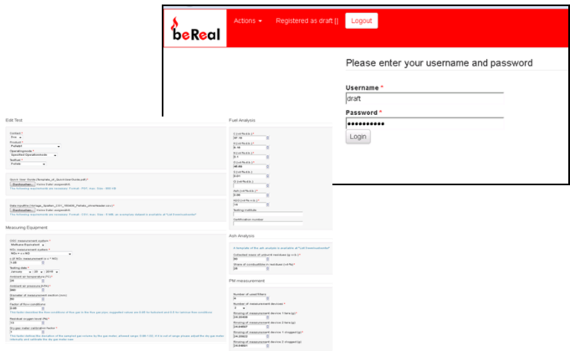


**Figure 14:** Online tool for standardized data evaluation

5.3 Results of validation process: Repeatability

The "*beReal*" test procedure was validated by different RTD partners using 9 different firewood roomheaters (EN 13240). The used roomheaters had a broad range of nominal heat output (4kW-10kW). With each roomheater three "*beReal*" tests (n=3) were carried out. For each tested parameter the coefficient of variation (r) was calculated. Thereby the standard deviation (s) was divided by the arithmetic mean (x) of the respective parameter (Equation 3).

**Equation 3:** Calculation of the coefficient of variation

$$r = \frac{s}{\bar{x}} \times 100\%$$

The coefficient of variation expresses the relative standard deviation. Using this factor it is possible to compare the variation of parameters with different absolute levels.

The coefficient of variation was used as an indicator for the repeatability of beReal test results. Figure 15 shows the coefficient of variation results of relevant parameters of performed "*beReal"* validation tests.

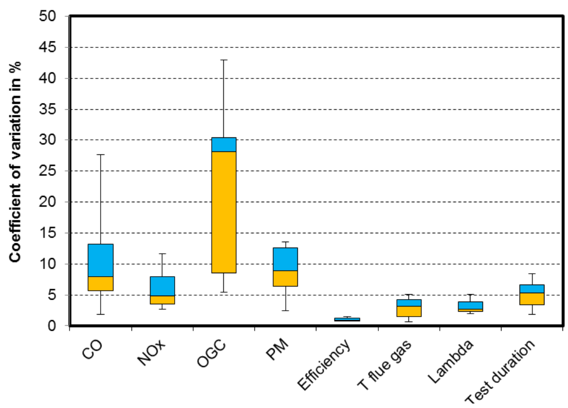


**Figure 15:** Boxplots including coefficient of variation results of the validation process

The median of coefficient of variation results were below 10% for all parameters except OGC emissions (median at 28%). Consequently, the validation test results confirmed in general a good repeatability of "*beReal*" testing. However, it was shown that OGC emissions are the most critical measurement parameter revealed by the highest deviations between single "*beReal"* tests. This indicates that OGC measurements (as THC using FID) is the most sensitive measurement parameter regarding different combustion conditions.

## 6 SUMMARY

A new test method for firewood roomheaters called „*beReal-Firewood*" was developed focusing on real life operation. The findings of a European user survey, long term field measurements and extensive lab testing on the effect of relevant operating parameters were the basis for the "*beReal"* test procedure. An obligatory Quick-User-Guide is not only the basis for testing, but should also enhance correct and appliance specific heating operation in real life. Validation tests showed in general a good repeatability of beReal testing. The main differences in the procedure of "*beReal-Firewood*" compared to existing EN standard type test method are:

- Ignition and preheating included
- No failed batches and "batch picking" ("*beReal*" result represents the whole test cycle)
- Thermal efficiency includes cooling down losses
- PM sampling during the entire batch

First preliminary results of demonstration and evaluation tests (field tests and Round Robin tests) showed a good real life relevance and sufficient reproducibility.

## 7 REFERENCES

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## 8 ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union Seventh Framework Program (FP7-SME-2013) under Grant Agreement no. 606605.

More information about the project is available on the beReal web page (http://www.bereal-project.eu/).

## 9 LOGO SPACE