BEREAL – METHOD FOR PELLET STOVES: FIELD TEST AND ROUND ROBIN

Bachmaier, H.[1], Oehler, H.[1], Hartmann, H.[1], Rönnbäck, M.[2], Persson, H.[2], Jespersen, M. G.[3], Jensen J. H.[3]; Schmidl, Ch.[4], Reichert, G.[4], Pelz, S.[5], Wöhler, M.[5]
[1]Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ), Schulgasse 18, D-94315 Straubing, Germany, Tel.: (+49) 9421-300-160, Email: johannes.bachmaier@tfz.bayern.de
[2]SP Technical Research Institute of Sweden – Energy and Bioeconomy Box 857, SE-501 15 Borås, Sweden
[3]Danish Technological Institute, Center for Biomass and Biorefinery, Division for Energy and Climate, DK-8000 Aarhus, Denmark
[4] Bioenergy 2020+ GmbH, Small scale combustion systems, Gewerbepark Haag 3, A-3250 Wieselburg-Land, Austria
[5] University of Applied Forest Sciences, Schadenweilerhof, D-72108 Rottenburg am Neckar, Germany

ABSTRACT: Recent pellet stoves perform excellently under type test conditions. In contrast, typical real life emissions show significantly higher values under usual operational conditions. Consequently, type testing procedures may not account for real life stove operation and, thus, do not allow to distinguish between low- and high-tech appliances. The EU-project beReal aimed at the development of a testing method for pellet stoves that reflects real life operations better and to support innovative pellet stoves that perform well under typical operational conditions.
Based on an online survey and field observations, an advanced real life testing procedure for pellet stoves was established reflecting real life user behavior, e.g. regarding different load levels and the ignition phase. A field test was designed at the end of the project to demonstrate the applicability and practical relevance. The field test proved that emission values for beReal at the test stand and in the field stay within the same range. A Round Robin test proved the repeatability and reproducibility of the beReal testing procedure. The beReal method can be reproduced with the same statistical variability or performed even better than the type testing method with exception of PM between different laboratories.
Keywords: Small scale application, solid biofuel, pellet stove, wood pellet, emissions, quality standards.

1 INTRODUCTION AND OBJECTIVES

During the last decades, emission and energy efficiency thresholds of certification standard testing procedures for biomass room heating appliances tightened considerably. This triggered an enormous technological improvement of current stoves. As a consequence, recent pellet stoves perform excellently under type testing conditions and achieve the respective emission levels without difficulty. In contrast, typical real life emissions show significantly higher values under usual operation conditions [1]. To a certain extent, this has to be attributed to the end-user's operational misbehavior but is also caused by deviations between real life stove usage and the operational procedure during type testing. Consequently, type testing procedures may not account for real life stove operation and, thus, do not allow for the distinction between low- and high-tech appliances, i. e. between appliances that operate poorly or optimal under real life conditions.

The EU-project beReal aimed at the development of a testing method for pellet stoves that reflects real life operations better. Based on an online survey and field observations, a testing procedure for pellet stoves was established reflecting real life user behavior. The testing procedure shall be repeatable (within the same lab), reproducible (among different labs) and should allow for a substantial differentiation between products of the same product category regarding their real life emissions.

Objective of this study was to test the applicability of the beReal method. Therefore, a field test was performed at the end of the project to demonstrate both the applicability and the practical relevance of the advanced testing method reflecting real life conditions. Four pellet stoves were installed in the field at a natural draught system.

Furthermore, a Round Robin test with seven laboratories was performed to provide performance data of the new method in terms of reproducibility and to assess the effect of different fuel qualities. In addition, the Round Robin also provided data to compare the beReal method with type testing.

2 MATERIAL AND METHODS

2.1 beReal method for pellet stoves

Intending to represent typical user behavior, the real live test consists of four combustion phases: 1a, 1b, 2, 3 (figure 1). Three defined load levels are applied: 100 % (1a, 2), 65 % (3) and 30 % (1b). Two intermediate standby phases are included: S1 between phases 1b and 2 and S2 between phases 2 and 3. Load change operation occurs from phase 1a to 1b. The cycle therefore exhibits one cold start (at phase 1a), two warm starts (at phases 2 and 3) and three burn-out phases (after phases 1b, 2, and 3). The test cycle is depicted in figure 1; the duration of each phase is given in table I. For details of the method see [2] and [3].

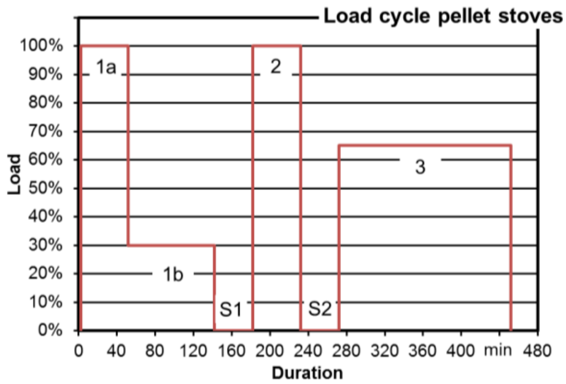

Figure 1: Scheme of load cycle of the beReal method for pellet stoves

Table I: Operational mode, load level and duration of the beReal load cycle

Phase	Operation al 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

2.2 Field test

Preparations before the field measurements comprised the development of a time schedule for the measurements, the preparation of test fuels to ensure the comparability of all measurements and the installation of the appliances. In total, four pellet stoves were tested at different field sites. All stoves were tested previously at the research partner's test stands before installing them in the field in private homes of different end users. The appliances were also tested for leakage at the field sites before the field measurements to compare the result at the field site with the leakage rate reached at the test stand in order to exclude that any damages occurred at the stoves during transportation and setup.

The appliances were installed at least one month before the field tests to ensure that the users had become familiar with the appliances and had developed their own operational habits before the field tests were conducted.

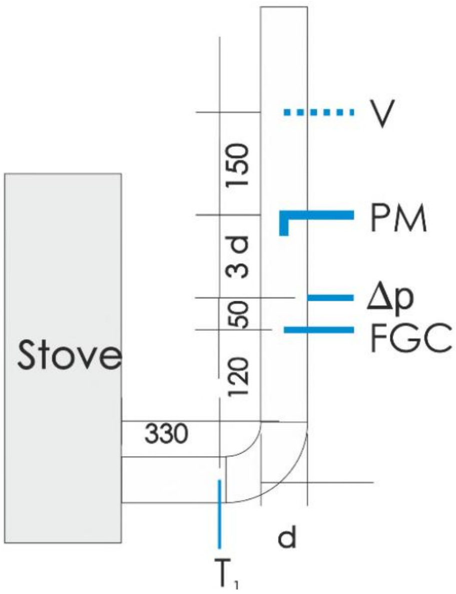

Figure 2: beReal-measurement section for field testing of pellet stoves (d: diameter, T: flue gas temperature, FGC: flue gas compounds, Δp: flue draught measurement, PM: particle measurement, v: flue gas velocity (all dimensions in mm))

The end users provided access to their homes for three days including the allowance to setup the measurement equipment and allowing for the presence of the measurement staff.

Of the four tested stoves, two were tested at private homes and two stoves were tested in laboratories that could provide conditions comparable to field conditions. Requirements for performing the tests in a laboratory required that a natural draft chimney existed in the laboratory and that the stove could be operated by untrained / various operators. This was considered necessary to provide data equivalent to field data.

The field test was carried out during three days. On day 1, the end user was told to use their normal procedure and fuel quality. The measurement staff was observing the operation but did not interfere or instruct the operator. On day 2, the end user was told to use their normal procedure but to use the supplied test fuel, i.e. the same fuel quality that is normally used at the test stand. Again, the measurement staff observed the operation but did not interfere nor instruct. On day 3, the end user was told to use the supplied test fuel again (same as day 2) and was coached by the experienced measurement staff to fire according to beReal.

During day 1 to 3, measurements were done according to figure 2, including measurements of the emissions of carbon monoxide (CO), volatile organic compounds (OGC), and particulate matter (PM). Furthermore, the efficiency of the stoves was determined.

All test days were performed during the heating season and all measurements were made in-door. The parameters to be analyzed were the same as in the beReal method [2] [3].

2.3 Round Robin test

Seven laboratories participated within the Round Robin test. Three of these laboratories where accredited for measurements of pellet stoves according to EN 14785 [4]. The remaining laboratories were experienced in measurements according to the above mentioned standards on pellet stoves for experimental purposes.

The aim of the Round Robin was to estimate and evaluate the performance of the new method developed within the beReal project in terms of repeatability and reproducibility. In other words - how well can the method be repeated within a laboratory respectively a testing institute, and how well can it be reproduced by different laboratories/testing institutes. Thus, this type of Round Robin is named an inter-laboratory test.

According to ISO 5725 [5] *repeatability* is defined as precision under "repeatability conditions", that is "conditions where test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time". The precision is measured as "repeatability standard deviation" s_r. The "repeatability limit" r is "the value less than or equal to which the absolute difference between two test results obtained under repeatability conditions may be expected to be with a probability of 95 %". In the Round Robin only single measurement were performed in each laboratory, which do not allow for calculation of s_r. However, suitable data was available from the method validation work package, in which at four laboratories three successive measurements were performed at each. A pooled estimate of s_r is then calculated for each component.

According to ISO 5725 [5] *reproducibility* is defined as precision under "reproducibility conditions", that is "conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment". In the present Round Robin "test item" includes both the stove and the fuel. The precision is measured as "reproducibility standard deviation" s_R.

The "reproducibility coefficient of variation" CV_R is calculated as $CV_R = 100 * s_R/X$, in which X is the average value. CV_R is a relative measure given in %.

The "reproducibility limit" R is "the value less than or equal to which the absolute difference between two test results obtained under reproducibility conditions may be expected to be with a probability of 95 %".

To ensure that the different laboratories have as similar testing conditions as possible, one pellet stove was sent between the participating laboratories. Since the main focus of the Round Robin was to test the reproducibility for the method, each lab had to use its own measuring equipment. The characteristics of the pellet stove recorded during the initial type testing at the labs prior to applying the beReal method are shown in Table II.

Table II: – Performance characteristics of the pellet stove recorded during initial type testing

	Pellet stove	Unit
Power Output	2.5-8	kW
Efficiency	91.5	%
CO at 13 % oxygen	30	mg/m_n^3
Dust emission	15	mg/m_n^3
Exhaust temperature	155.2	^oC

To ensure similar fuel quality, one ton of pellets was directly collected from the production line at a German pellet producer and distributed to the participating labs.

The measurements at each laboratory consisted of 3 testing days. For beReal testing the settings are the same at each day only the fuel is changed (Table III).

Table III: – Schedule of Round Robin test days for pellet stoves

Day	Method	Fuel
1	beReal	Local fuel
2	beReal	test fuel
4	Type test – prEN 16510 [6]	test fuel

The parameters presented in table IV were calculated according to a common procedure.

Table IV: Parameters analyzed and calculated during the Round Robin measurement.

Result parameter	Unit after calculation
CO	$mg/m^3_{STP,\ dry,\ 13\%\ O2}$
OGC	$mg/m^3_{STP,\ dry,\ 13\%\ O2}$
NO_X	$mg/m^3_{STP,\ dry,\ 13\%\ O2}$
PM	$mg/m^3_{STP,\ dry,\ 13\%\ O2}$
Efficiency	%

Figure 3 shows the measurement section for the Round Robin. This setup was identical at all seven labs.

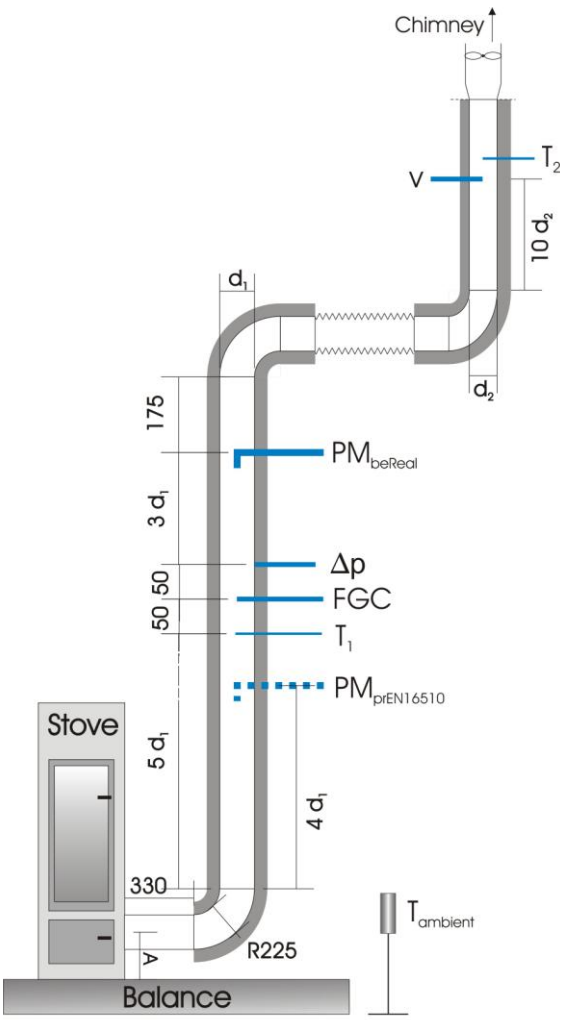

Figure 3: beReal-measurement section for Round Robin testing of pellet stoves (abbreviations see fig. 2)

3 RESULTS AND DISCUSSION

3.1 Field test

Four pellet stoves were tested at the test stand and in the field resp. comparable to the field. Figure 4 summarizes the gained results. All values are referred to beReal at the test stand which is set to a value of 1.

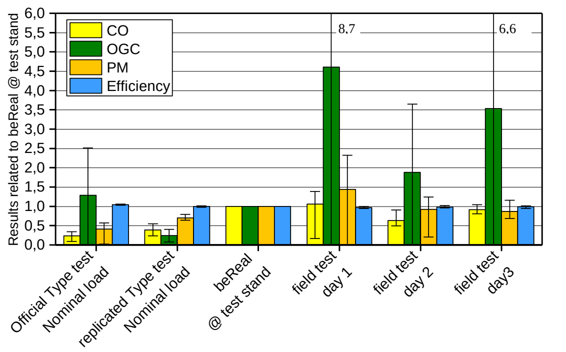

Figure 4: Field test results of four pellet stoves at the test stand and in the field together with official and replicated type testing. All values are relative to beReal at test stand. The error bars show the Min and Max values.

The field test showed that the values from beReal at the test stand and the field tests results stay within the same scope. The beReal method truly reflects typical user behavior and enables laboratories to test stoves under such conditions. Emission values are clearly higher than for type testing, because unfavorable operating conditions like load change, standby and burnout phases are included.

For the pellet stoves, the highest variation in emission results was observed for day 1 in the field, when the end users were using their usual fuel and operated the stove according to their usual procedure. The variation was already lower on day 2 when the fuel was changed to test fuel and could further be improved on day 3 when measurements were done according to the beReal load cycle (with exception of OGC). Overall, emissions of the beReal method and real life operations were higher compared to the official and replicated type tests.

Obviously, the choice of fuels influences the combustion result. Pellets used at day 2 and 3 show improved results both in terms of emissions and in efficiency. For the pellet stoves, there are few possibilities to influence the combustion and therefore the difference between day 2 and day 3, when the end user is coached by the experienced measurement staff, is small.

3.2 Round Robin test

The *repeatability* is calculated using data from the validation work package of the beReal project. During the Round Robin test only one repetition at each lab was performed which is not sufficient to calculate repeatability. Table V summarizes the calculated values for the overall averages, the repeatability standard deviation s_r and the repeatability limit r for six different pellet stoves measured with the beReal method. First, the average and the standard deviation are calculated for each test consisting of three repeated measurements. Secondly, the overall average and s_r is then calculated based on these numbers. The table also shows the concentration ranges during testing.

Table V: Repeatability estimates for testing of pellet stoves with the beReal method

Pellet stoves		Range	Average	s_r	r
CO	(mg/m³$_{STP, dry, 13\% O2}$)	300 - 1000	516	66	185
OGC	(mg/m³$_{STP, dry, 13\% O2}$)	10 – 25	16	1.8	5
NO_x	(mg/m³$_{STP, dry, 13\% O2}$)	100 - 150	118	3.2	9
PM	(mg/m³$_{STP, dry, 13\% O2}$)	25 – 75	51	4.0	11
Efficiency	(%)	50 - 90	79.3	0.4	1.1

Several measures were taken to validate the Round Robin test results. During the test leakage rate of the appliance was used actively to ensure that the stove didn't change during the test for example due to transportation. After a full circulation of the stove between the participating laboratories, it was sent back to the laboratory that did the first measurement. A new measurement was performed and results were evaluated and the differences are for all analysis parameters close to or within the repeatability.

Furthermore, the "von Neumann ratio test" was performed to check if there was a significant trend of increasing or decreasing values when listed in the order of circulation. The result of the test showed no significant trend for the pellet stove. The differences are therefore expected to be an expression for the method variability between the laboratories.

Before calculation of the relative between-laboratory standard deviation CV_L and subsequently the relative *reproducibility* standard deviation CV_R, the compiled results for the beReal method were tested for statistical outliers using Grubbs' test and Dixon's test. Both tests are based on the assumption of a normal distribution of the results. A limited number of results were pointed out as outliers. A review of the calculation sheets for the respective results didn't reveal any obvious technical explanation for the deviation. Normally it is "good praxis" not to exclude a statistical outlier unless a technical explanation can be found, but in this case the outliers are however excluded in the calculation of reproducibility to show the potential of the method.

Table VI summarizes all reported results for the pellet stove using the beReal method with test pellets. The results are listed in the same order as in which the stove was circulated between the participants. Two results, indicated in red, are pointed out as outliers and are excluded in the calculation of average (X), s_L and the between-laboratory coefficient of variation (CV_L). Figure 5 illustrates the CO emission results

Table VI: Results for the Round Robin with the pellet stove using the beReal method with test pellets.

	CO	OGC	NO_x	PM	Efficiency
	mg/m³$_{STP, dry, 13\% O2}$				%
Lab 1	584	30	n. a.	42	88.1
Lab 2	476	26	143	44	87.9
Lab 3	411	13	142	**159**	86.6
Lab 4	735	**76**	169	65	87.3
Lab 5	377	17	124	40	85.5
Lab 6	551	16	150	26	87.7
X	**522**	**20**	**146**	**43**	**87,2**
S_L	**131**	**7**	**16**	**14**	**1.0**
CV_L %	**25**	**35**	**11**	**32**	**1.1**

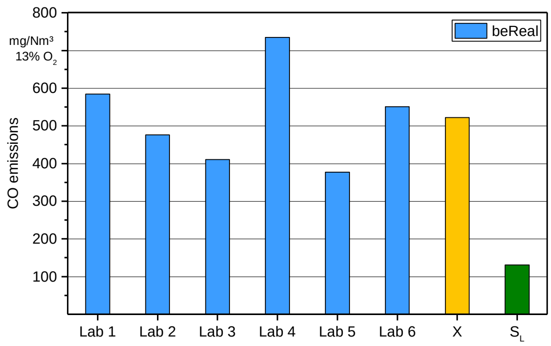

Figure 5: Round Robin results for CO from the pellet stove using the beReal method with test pellets.

The use of local pellets leads in general to higher emissions and higher variations in the results compared to test pellets (figure 6 / table IX). The efficiency is reduced using local pellets compared to test pellets, and the variation is higher based on all reported results.

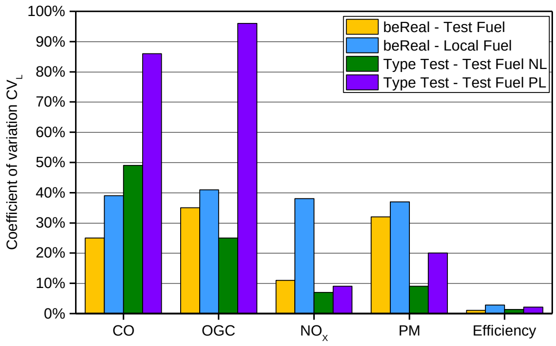

Figure 6: Coefficient of variation CV_L for beReal method and type testing method (test fuel and local fuel, NL: nominal load, PL: part load)

Table IX: Coefficient of variation CV_L for beReal method and type testing method (TF: test fuel, LF: local fuel, NL: nominal load, PL: part load)

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

The calculated values for CV_L show that the beReal method can be reproduced with the same variability or even better than the type testing method for CO, OGC and efficiency. For NOx the values are comparable.
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.

In the development of a new measurement method, it is essential that the final procedure can be reproduced in different laboratories. The Round Robin has successfully provided data for estimating the reproducibility of the beReal method for a pellet stove. Table VII gives an overview of reproducibility values from the Round Robin using the test fuel, expressed as the reproducibility coefficient of variation CV_R.

Table VII: Reproducibility values for the beReal method (test fuel).

Parameter	CV_R (%)
CO	28
OGC	36
NO_x	11
PM	34
Efficiency	1.2

The best reproducibility for the emissions is achieved for NO_x followed by CO, PM and OGC. There are no official or general acceptance criteria for reproducibility values. A number of Round Robins, similar to the beReal Round Robin, were performed in the European pre-standardization project BioNorm for obtaining reproducibility values for the laboratory analysis of solid biofuels. In the European standards EN 15104 [7] and EN 15289 [8] the reproducibility is given as CV_R for nitrogen and sulphur in wood chips (table VIII).

Table VIII: Examples of reproducibility values for the analysis of solid biofuels.

		CV_R (%)
Standard	**Parameter**	**Wood chips**
EN 15104	Nitrogen	30
EN 15289	Sulphur	34

Compared to the numbers in table VIII the reproducibility values obtained in the beReal Round Robin are quite good, taking into account that operation of a stove during combustion potentially will have more sources to variation than a laboratory analysis step alone.

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. An overview of reproducibility values expressed as the between-laboratory coefficient of variation CV_L is given in Table IX, which summarizes the values when using the beReal method on different fuel qualities, and for type test using test fuel.

3.3 Conclusion

Good testing procedures should test stoves in all practically relevant operation modes. However, current type testing for pellet stoves excludes environmentally problematic phases of stove operation. For pellet stoves, these include the start and stop phases, load changes or cleaning phases. The integration of those phases into the test cycle as well as ongoing uninterrupted emission measurement and evaluation would lead to emission values much closer to real life than current type testing results. Provided with such a test method, stove developer would have an interest in improving those stove operating phases that cause much of the environmental effect. This would also have a positive effect on the public perception of pellet stoves leading to overall higher acceptance of this sustainable heating method.

4 REFERENCES

[1] M. Wöhler, D. Jaeger, G. Reichert, C. Schmidl und S. K. Pelz, Influence of pellet length on performance of pellet room heaters under real life operation conditions, Renewable Energy 105, doi: 10.1016/j.renene.2016.12.047, (2017), p. 66–75
[2] H. Oehler, R. Mack, H. Hartmann, S. Pelz, M. Wöhler, C. Schmidl, G. Reichert, Development of a Test Procedure to Reflect the Real Life Operation of Pellet Stoves, Proceedings of the 24th European Biomass Conference and Exhibition, (2016), p. 738-747

[3] G. Reichert, R. Sturmlechner, H. Stressler, M. Schwabl, Ch. Schmidl H. Oehler, R. Mack, H. Hartmann, Definition of Suitable Measurement Methods and Advanced Type Testing Procedure for Real Life Conditions Deliverable D3.3 of the EU-beReal project, Grant Agreement No. 606605, online available under www.bereal-project.eu, (2016)
[4] EN 14785, Residential space heating appliances fired by wood pellets – Requirements and test methods, (2006)
[5] ISO 5725, Precision of test methods – Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests, (1986)
[6] prEN 16510, Residential solid fuel burning appliances, (2016)
[7] EN 15104, Solid biofuels - Determination of total content of carbon, hydrogen and nitrogen. Instrumental methods, (2011)
[8] EN 15289, Solid biofuels – Determination of total content of sulfur and chlorine, (2011)

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6 LOGO SPACE

SEVENTH FRAMEWORK PROGRAMME

beReal

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