report

beReal

Morten Gottlieb Jespersen, Jan Hinnerskov Jensen (DTI)

Marie Rönnbäck, Henrik Persson (SP)

Marius Wöhler (HFR)

Deliverable D 8.1

Report on Round Robin tests

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Danish Technological Institute

Headquarters
Gregersensvej 1
2630 Taastrup
Telephone +45 72 20 20 00
info@teknologisk.dk
www.dti.dk

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1 Introduction

This deliverable (D8.1) sums up preparation, organization, execution and analysis of the results of the Round Robin test performed in the frame of the project.

The objective of WP8 is to verify the reproducibility and the repeatability of the proposed test method through a Round Robin test involving all project partners and external accredited test laboratories. The tasks which are presented in the report are in detail:

- Task 8.1 Planning of the Round Robin test
  - Responsible - SP Technical Research Institute of Sweden
- Task 8.2 Execution
  - Responsible - SP Technical Research Institute of Sweden
- Task 8.3 Evaluation
  - Responsible – Danish Technological Institute

The Round Robin was performed to provide performance data of the new method in form of reproducibility and the report will focus on the analysis of these data. The Round Robin was also used to assess the effect of fuel quality and differences between the labs from use of different fuels. In addition, the Round Robin also gathered data to compare the beReal method with type testing. To assess the repeatability of the method values from WP5 were used and analysed.

This deliverable was elaborated by Danish Technological Institute, the planning and execution were done by SP Technical Research Institute of Sweden, and evaluation and analysis of the results was done by Danish Technological Institute.

The Round Robin was performed among 7 different laboratories, where 3 were accredited laboratories.

Feedback concerning this deliverable is welcomed and can be given to:

- Morten Gottlieb Jespersen - mgjn@teknologisk.dk
- Marie Rönnbäck - Marie.Ronnback@sp.se

2 Planning

2.1 Participants

During the Round Robin 7 laboratories participated, 3 of these laboratories where accredited for measurements of wood stoves according to EN 13240 [1]/ prEN 16510 [2] and pellet stoves according to EN 14785 [3]. The remaining laboratories were experienced in measurements according to the above mentioned standards on wood stoves and pellet stoves for experimental purposes. A list of the participants is given in Table 1.

Table 1 – List of participants.

Name of participant	Country	Accreditation		Testing on	
		EN 13240	EN 14785	Wood stove	Pellet stove
BIOENERGY 2020+ GmbH	Austria	No	No	Yes	Yes
Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe	Germany	No	No	Yes	Yes
Danish Technological Institute	Denmark	Yes	Yes	Yes	Yes
Hochschule für Forstwirtschaft Rottenburg	Germany	No	No	Yes	Yes
SP Technical Research Institute of Sweden	Sweden	Yes	Yes	Yes	Yes
Rhein-Ruhr Feuerstätten Prüfstelle GmbH	Germany	Yes	Yes	Yes	Yes
Deutsches Biomasseforschungszentrum gemeinnützige GmbH	Germany	No	No	Yes	No

2.2 Schedule

The Round Robin test was performed in the period from 16th of November 2015 until 16th of September 2016. The 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). Afterwards the appliance was packed and shipped to the next laboratory within 7 days.

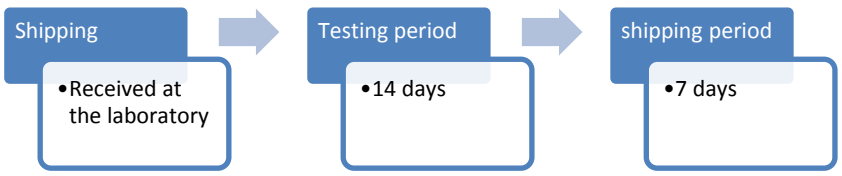

Figure 1 – Graphical representation of schedule for each participant for handling and measurement of one appliance

2.3 Outline for the Round Robin

In the DOW of WP8, the evaluation of the results is intended to be made according to Annex B of EN ISO/ IEC 17043 “General requirements for proficiency testing” [4]. The purpose of a proficiency test is to evaluate the performance of the individual participant, and participation in this kind of Round Robin is typically a demand from an accreditation body to an accredited laboratory. The statistical methods in Annex B of EN ISO/ IEC 17043 [4] reflect this, in that a z-score is calculated for each laboratory, based on the closeness of the result from the laboratory to the average of results from all laboratories in the Round Robin. Formulas for calculating repeatability and reproducibility are however not presented in Annex B.

The aim of the Round Robin performed in WP8 is 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. This type of Round Robin is named an inter-laboratory test. Consequently, the statistical treatment of the results is made in accordance with the principles in ISO 5725 “Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests” [5].

2.3.1 Stoves

To ensure that the different laboratories have 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 has to use its own equipment. The values of the pellet and wood stoves recorded during their initial type testing is showed blow in Table 2.

Table 2 – Values of the different applicances recorded during their initial type testing

	Wood stove	**Pellet stove**	**Unit**
Power Output	5 kW	2.5-8	[kW]
Efficiency	80 %	91.5	[%]
CO at 13 % oxygen	1125	30	[mg/m_n^3]
Dust emission	12	15	[mg/m_n^3]
Exhaust temperature	299	155.2	[^oC]

2.3.2 Fuel

The quality and the resulting combustion behaviour of firewood is influenced by various parameters. These include the obvious parameters such as wood species, bark content and water content and also the chemical composition of the firewood. The chemical composition of

wood is influenced by the age of the tree and factors which are given by the growing area such as soil composition and environmental influences.

The firewood for the beReal Round Robin test was produced by the project partner HFR in cooperation with a local forest company. Therefore, three similar shaped beech trees which stood next to each other were chosen in the research forest of the HFR. The trees were harvested, converted to firewood, technically dried and delivered to HFR. There the firewood was mixed and stored under roof outside for several weeks to equalize the water content. Afterwards the firewood was prepared to the so called “beReal fuel box”. One fuel box contained the firewood for one participant of the round robin test. For preparation of a fuel box only uniform wood pieces were selected (i.e. without branched) and the size and mass per piece were adjusted close to the requirements of the combustion method. The box also included fire starter and a description about the proper use of the fuel. The firewood was packed in sealed plastic bags and send to the Round Robin test participants a few days before the stove.

Figure 2 – The content of the “beReal fuel box” for wood stoves. The wood logs were prepared by the beReal project partner HFR.

For the wood stoves each laboratory received fuel for three days of testing. Fuel for one day of testing for beReal fuel with bark, fuel for a day without bark and fuel for a day which was for type testing also without bark. In order to investigate how the use of local fuel (the fuel that the test lab normally uses) influences the combustion, identical measurements were performed where the only change was the used fuel which in that case was the fuel that the individual laboratory normally used.

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.

The pellets were produced by the EC Heidelberg GmbH at the production site in Dotternhausen, Germany. In cooperation with the producer HFR collected one ton of pellets directly from the production line to ensure a uniform pellet quality and raw material composition. Then pellets were transported to the laboratory of HFR and mixed. Pellets were packed in sealed plastic bags and send to all participants.

For the pellet stoves each laboratory received fuel for two days of testing and as for wood stoves the influence of local fuel was investigated.

2.3.3 Schedule of individual test days

The measurements at each laboratory consisted of 4 testing days for wood stoves and 3 testing days for pellet stoves, with only one change from the previous day. For beReal testing the settings are the same at each day only the fuel is changed.

Type testing has its own settings, to perform a type testing according to the preliminary standard prEN 16510 [2], which was chosen for the Round Robin. At the firewood stove minimum 5 batches were conducted of which the first two batches served for heating up while the following batches were considered for the evaluation. For the pellet stove, three repetitions of 30 min duration both at nominal and at partial load, were performed. The evaluation is based on the mean value of the two best batches respectively repetitions (according to the respective CO value) which don't have to be consecutive. The specific tests performed at each of the individual test days are given in Table 3 for firewood stoves and in Table 4 for pellet stoves.

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 – prEN 16510	HFR test fuel without bark (wob)

Table 4 – Schedule of test days for pellet stoves

Day	Method	Fuel
1	beReal	Local fuel
2	beReal	HFR test fuel
4	Type test – prEN 16510	HFR test fuel

2.4 Protocols

As preparation for the measurement, protocols for the complete round robin were developed. In Table 5 a list of protocols for the Round Robin is presented. Each protocol is attached to the report as appendix. The protocols were sent to each laboratory in advance.

Table 5 – List of protocols for the Round Robin test performed under WP8 in the beReal project. The protocols where prepared by SP.

no.	Protocol name	Description of protocol
1	Oven dry method	Method on how to measure the moisture content of the fuel
2	Leakage check prEN 16510	Method description on how to perform leakage rate test of the appliances
3	Test Scheme	Schedule of the individual testing days for both pellet and wood stove
4	EU-BeReal_WP8_Measurement procedure_beReal_method	Description of how to perform the beReal method including description of measurement arrangement.
5	EU-BeReal_WP8_Measurement procedure_type_tests	Description of how to perform the type testing in this project including description of measurement arrangement.
6	Checklist for Round Robin test	Procedure for handling, preparation, results and shipping
7	Example of QUG	Description on how to operate the pellet stove.

2.5 Measurement sections

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 Figure 3 and Figure 4.

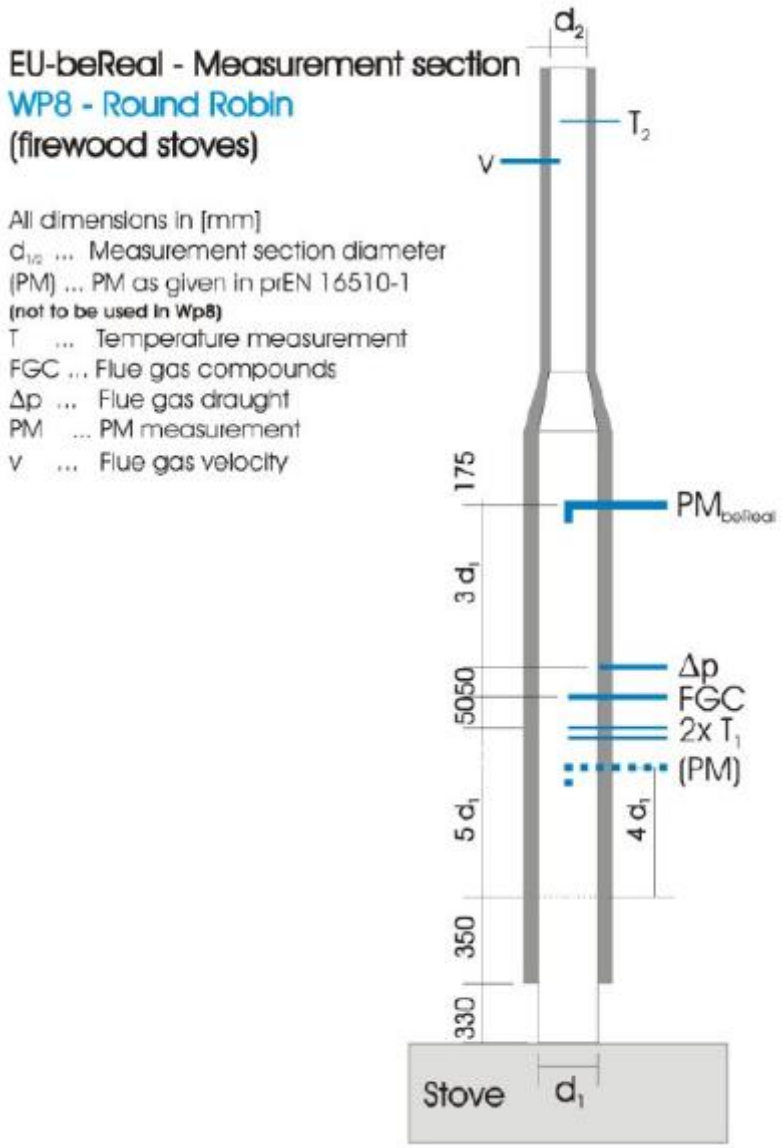

Figure 3 – EU beReal – Measurement section for firewood stove in WP 8 Round Robin test. The figure is prepared by TFZ.

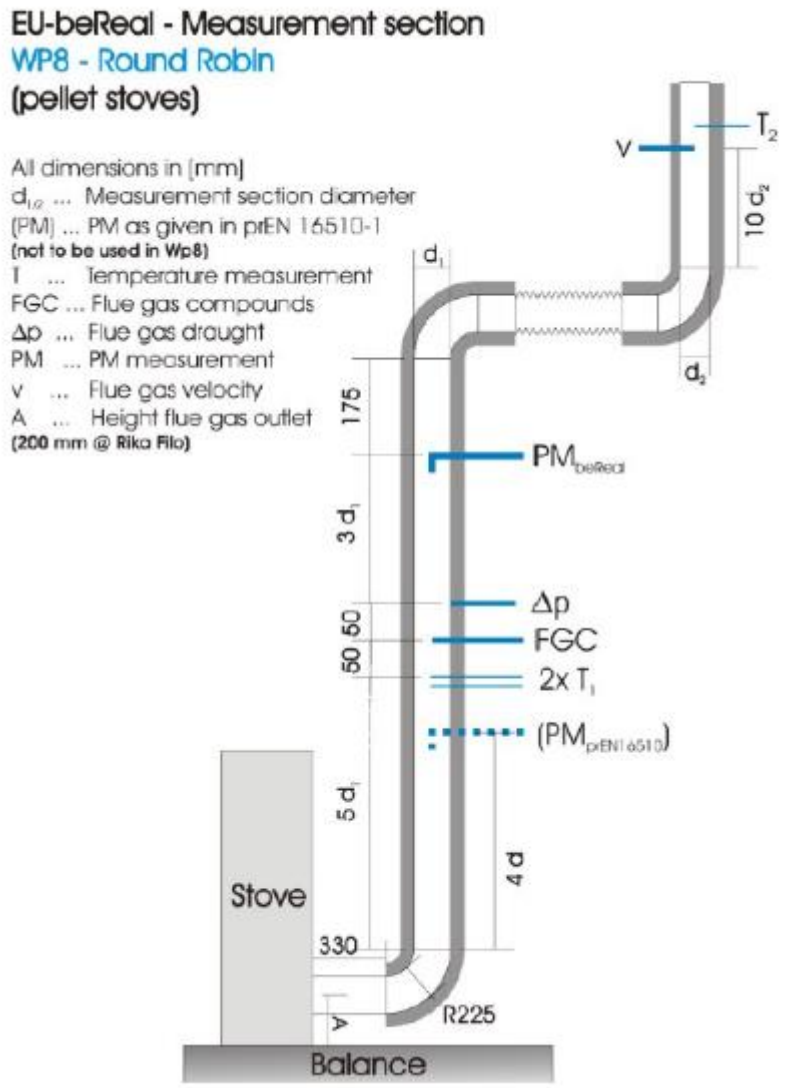

Figure 4 – EU be Real – Measurement section for pellet stove in WP 8 Round Robin test. The figure is prepared by TFZ.

2.6 Calculation

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, 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.

The following parameters presented in Table 6 were calculated in the above mentioned calculation sheet and are the results of the Round Robin test. In addition, each partner performed ash analysis as described in the beReal method.

Table 6 – Parameters analysed 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	[%]

3 Results

3.1 Repeatability for the beReal method

3.1.1 Definitions

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 %”. The repeatability is defined as r = f * $\sqrt{2}$ * s_r. The coefficient $\sqrt{2}$ is used because r refer to the difference between two single test results. The value of the factor f depends on the number of test results, but for practical reasons this factor is set to the value 2 in the standard. The repeatability limit is then calculated as r = 2.8 * s_r. The repeatability limit is an absolute measure given in the same unit as the measured component.

In the WP8 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 work within WP 5, in which at four laboratories three successive measurements were performed at each. A pooled estimate of s_r is then calculated for each component.

3.1.2 Repeatability estimates

Table 7 and Table 8 compile the calculated values for the overall averages, the repeatability standard deviation s_r and the repeatability limit r for 6 different pellet stoves and 7 different firewood stoves using the beReal test method in WP 5. First, the average and the standard deviation is calculated for each test consisting of three repeated measurements. Secondly, the overall average and s_r is then calculated based on these numbers. The tables also show the concentration ranges during testing.

Table 7 – Repeatability estimates for testing of pellet stoves with the beReal method within WP5.

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

Table 8 – Repeatability estimates for testing firewood stoves with the beReal method within WP5.

Firewood stoves		Range	Average	s_r	r
CO	[mg/m³$_{STP, dry, 13\% O2}$]	1300 – 3700	2300	373	1045
OGC	[mg/m³$_{STP, dry, 13\% O2}$]	50 – 350	140	58	163
NO_x	[mg/m³$_{STP, dry, 13\% O2}$]	70 – 140	114	9	26
PM	[mg/m³$_{STP, dry, 13\% O2}$]	40 – 120	69	9	26
Efficiency	[%]	50 - 75	66.4	0.7	2.0

3.2 Reproducibility for the beReal method

3.2.1 Definitions

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 $CV_R = 100 * \frac{s_R}{X}$, 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 %". It is defined as $R = f * \sqrt{2} * s_R$ and calculated as $R = 2.8 * s_R$. The reproducibility limit is an absolute measure given in the same unit as the measured component.

The reproducibility standard deviation is calculated as $s_R^2 = s_L^2 + s_r^2$, in which s_L is the "between laboratory standard deviation". If repeated measurements are made in each laboratory, s_L is calculated on the laboratory averages. In the present Round Robin, s_L is calculated on the single measurements in each laboratory.

3.2.2 Validation of 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 okay to proceed with the measurements. After the measurement a new leakage test was performed and evaluated.

After a full circulation of the stoves between the participating laboratories, they were sent back to the laboratory who 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 for of the test showed no significant trend for neither the pellet stove nor the wood stove. The differences are therefore expected to be an expression for the method variability between the laboratories.

Before calculation of s_L and subsequently s_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.

3.2.3 Compilation of results

Table 9 compiles 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), between-laboratory standard deviation (s_L) and the between-laboratory coefficient of variation (CV_L).

Table 9 – Results for the pellet stove using the beReal method with test pellets.

Pellet stove	**CO**	**OGC**	**NO_x**	**PM**	**Efficiency**
		[$mg/m^3_{STP, dry, 13\% O2}$]			[%]
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

The results from the laboratories given in Table 9 are visualised in Figure 5 to Figure 9 together with X, s_L and CV_L. The excluded results are indicated in dashed bars.

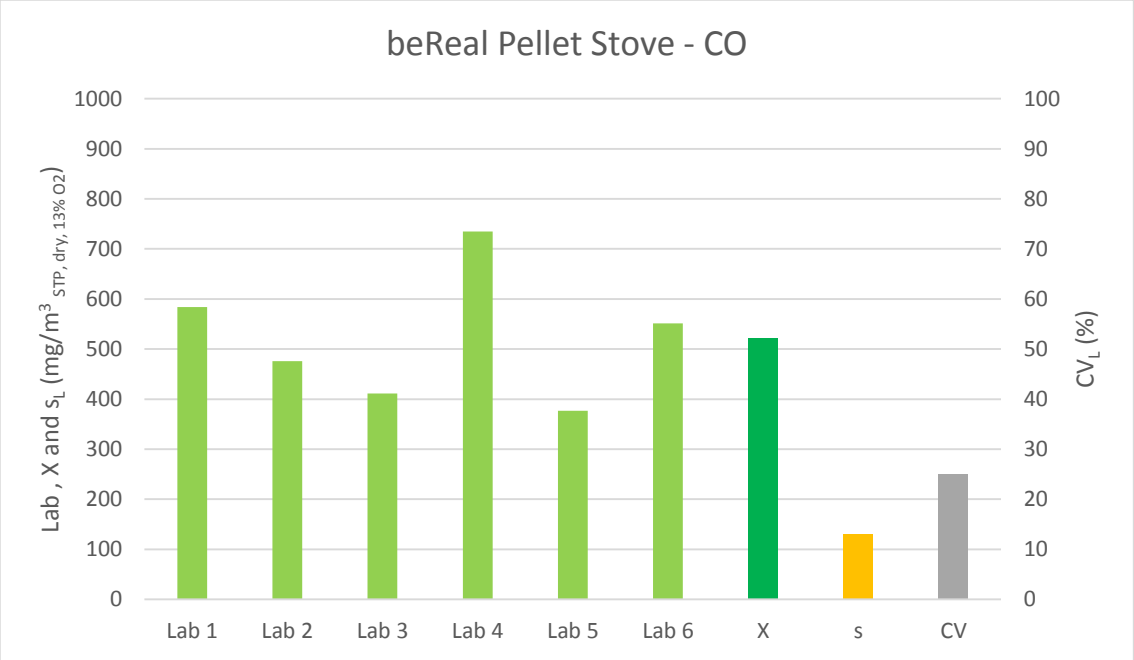

Figure 5 – Results for CO from the pellet stove using the beReal method with test pellets.

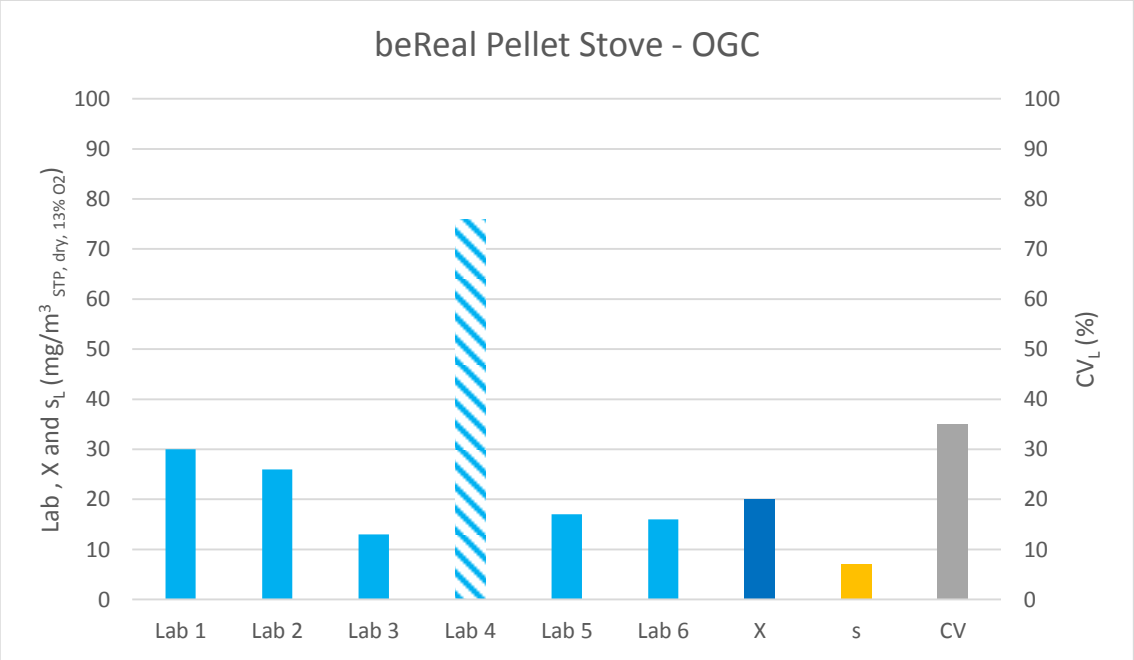

Figure 6 – Results for OGC from the pellet stove using the beReal method with test pellets.

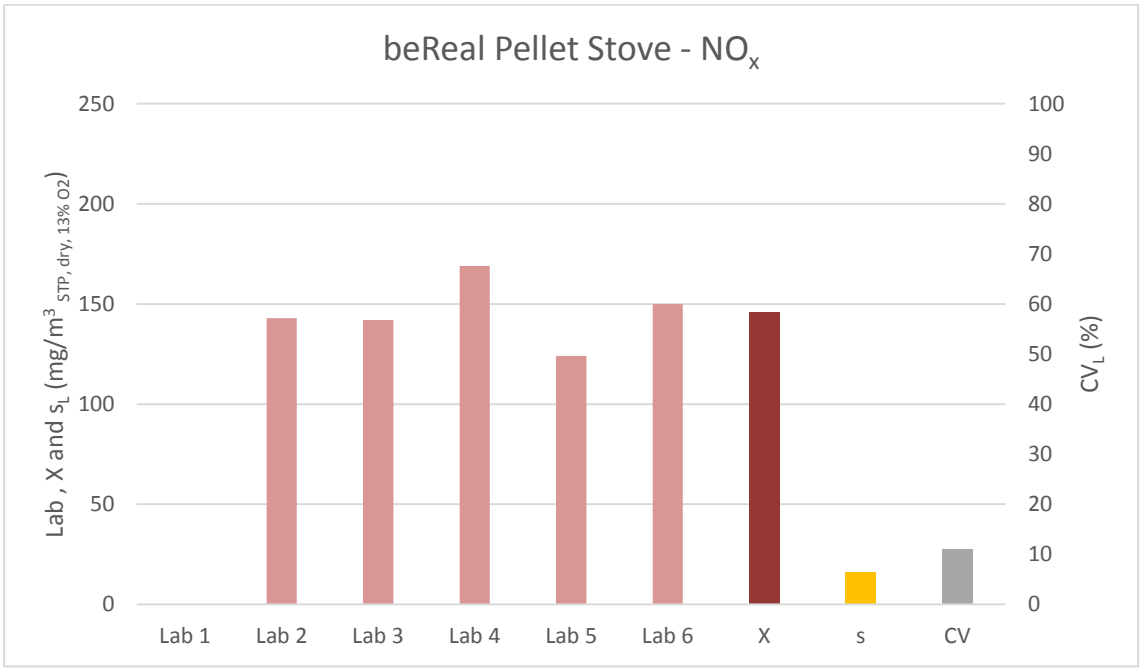

Figure 7 – Results for NO_x from the pellet stove using the beReal method with test pellets.

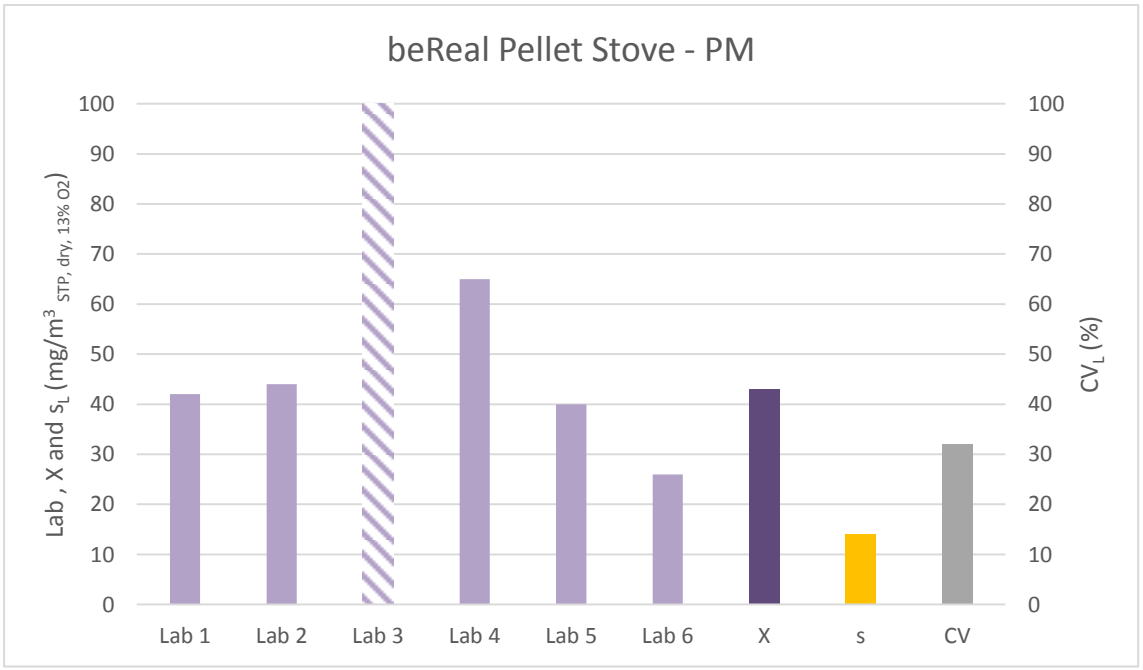

Figure 8 – Results for PM from the pellet stove using the beReal method with test pellets.

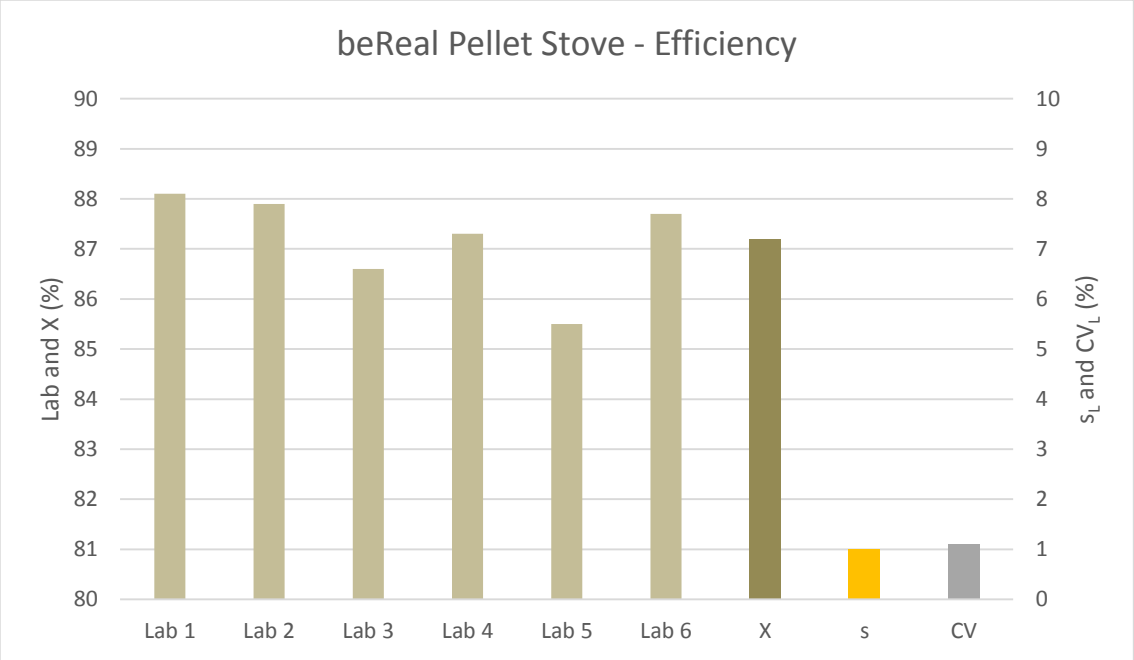

Figure 9 – Results for efficiency from the pellet stove using the beReal method with test pellets.

Table 10 compiles all reported results for the firewood stove using the beReal method and test fuel with bark. The results are listed in the same order as in which the stove was circulated between the participants. One laboratory hasn't calculated the efficiency as no ash analysis was made. All other results are used in the calculation of X, s_L and CV_L.

Table 10 – Results for the firewood stove using the beReal method and test fuel with bark.

Firewood stove	**CO**	**OGC**	**NO_x**	**PM**	**Efficiency**
	[mg/m³$_{STP, dry, 13\% O2}$]				[%]
Lab 1	2613	105	104	28	72.6
Lab 2	2487	175	101	63	66.1
Lab 3	2729	97	83	59	77.4
Lab 4	2078	28	101	29	n.a.
Lab 5	3208	168	94	57	73.2
Lab 6	3025	277	103	30	69.6
Lab 7	3566	117	101	21	72.7
X	2815	138	98	41	71.9
S_L	494	78	7	18	3.8
CV_L [%]	18	57	8	43	5.3

The results from the laboratories given in Table 10 are visualised in Figure 10 to Figure 14 together with X, s_L and CV_L.

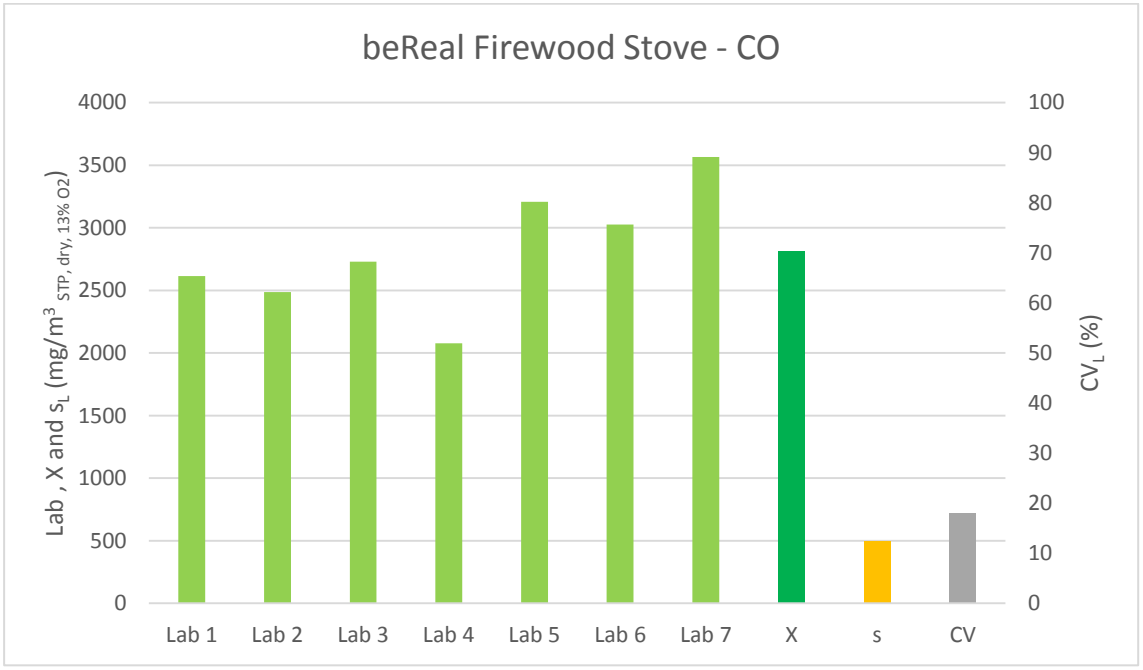

Figure 10 – Results for CO from the firewood stove using the beReal method and test fuel with bark.

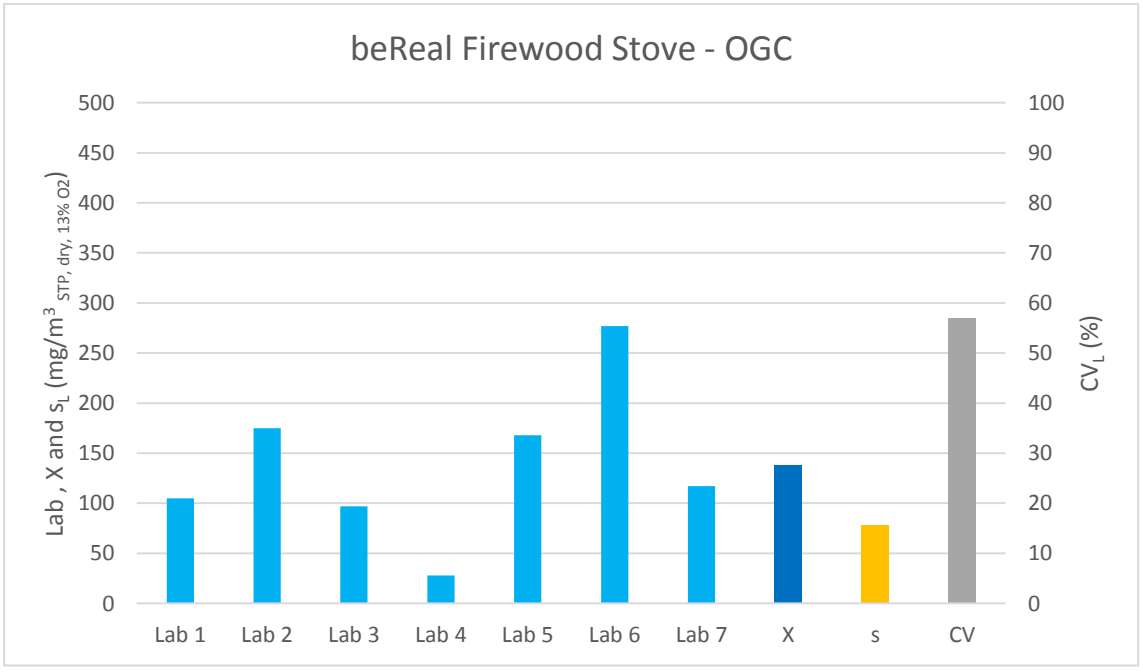

Figure 11 – Results for OGC from the firewood stove using the beReal method and test fuel with bark.

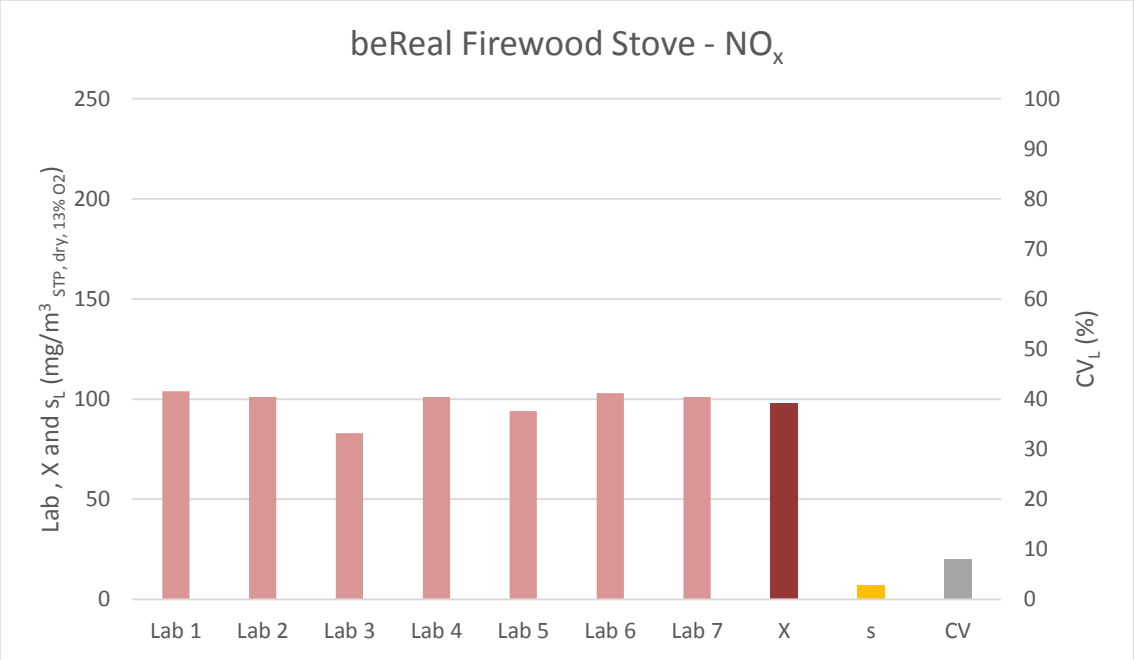

Figure 12 – Results for NO_x from the firewood stove using the beReal method and test fuel with bark.

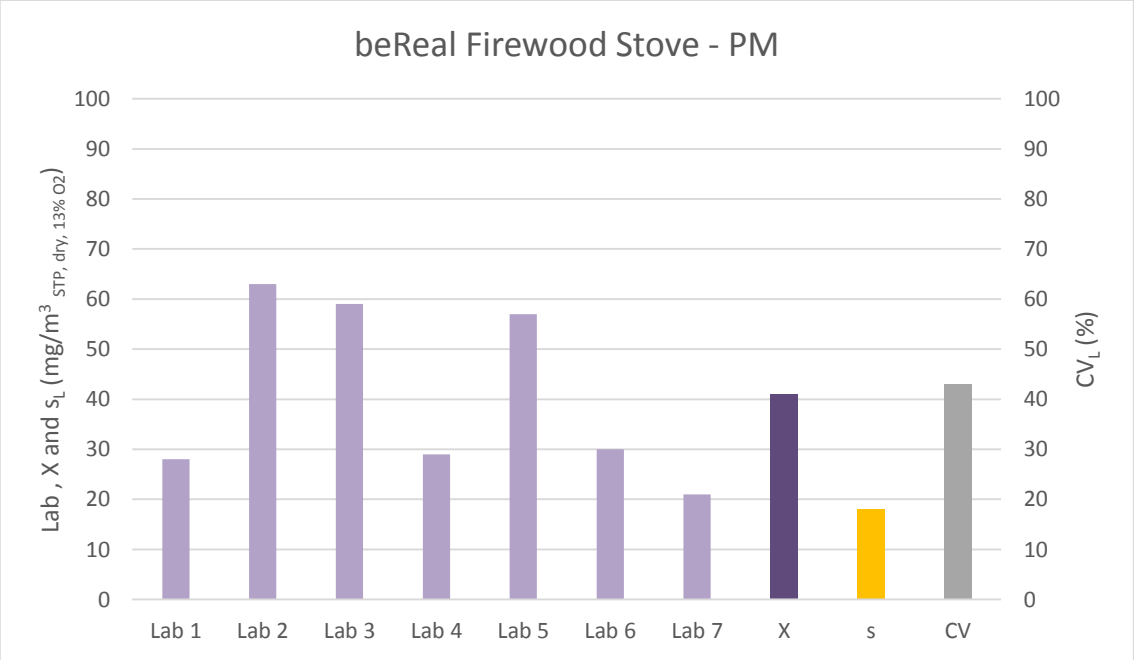

Figure 13 – Results for PM from the firewood stove using the beReal method and test fuel with bark.

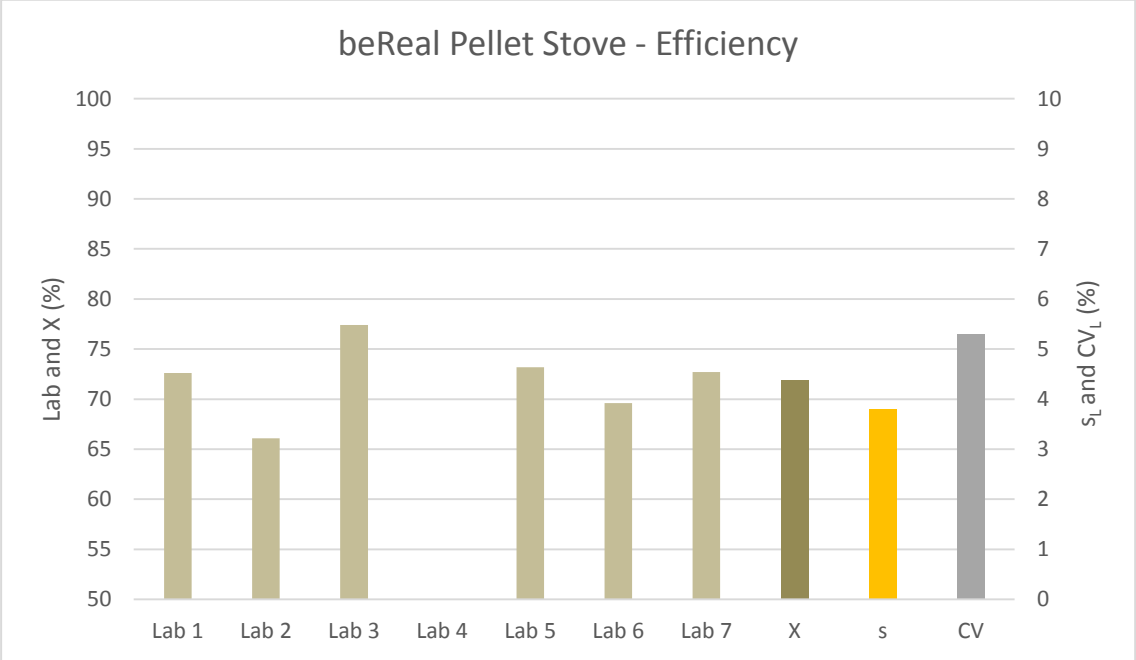

Figure 14 – Results for efficiency from the firewood stove using the beReal method and test fuel with bark.

3.2.4 Reproducibility values

An overview of reproducibility values obtained for the beReal method on the pellet stove is given in Table 11. The overview includes the absolute values of s_L, s_R and R, together with the relative values of CV_L and CV_R.

Table 11 – Reproducibility values for the beReal method on pellet stove.

Pellet stove	**CO**	**OGC**	**NO_x**	**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
R	411	20	46	41	3.0

A similar overview of reproducibility values obtained for the beReal method on the firewood stove is shown in Table 12.

Table 12 – Reproducibility values for the beReal method on firewood stove.

Firewood stove	CO	OGC	NO_x	PM	Efficiency
	[$mg/m^3_{STP,\ dry,\ 13\%\ O2}$]				[%]
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
R	1733	273	33	56	10.8

The calculated values for the reproducibility limits (R) might seem quite high when compared to the respective average values of the results, for example CO for the firewood stove with R = 1733 $mg/m^3_{STP,\ dry,\ 13\%\ O2}$ and X = 2815 $mg/m^3_{STP,\ dry,\ 13\%\ O2}$. However, compared to the difference between the highest and the lowest results within a measurement series (for CO from the firewood stove this difference is 1.488 $mg/m^3_{STP,\ dry,\ 13\%\ O2}$), the reproducibility limits are just up to a factor of 1.3 higher. This ratio is for a smaller part caused by the addition of the repeatability when calculating reproducibility, and mainly by the fact that the reproducibility limit is calculated as a confidence interval.

3.3 Effect of fuel quality

3.3.1 Pellet stove

For the pellet stove each laboratory performed the beReal test both with pellets from HFR (Test) and with pellets from a badge of their own local supply reflecting a typical quality of fuel (Local). Table 13 shows the results together with calculated values of X, s_L, and CV_L.

Table 13 – Comparison of the beReal method using test pellets and local pellets.

Pellet stove	CO		OGC		NO_x		PM		Efficiency	
	$mg/m^3_{STP,\ dry,\ 13\%\ O2}$								%	
	Test	Local	Test	Local	Test	Local	Test	Local	Test	Local
Lab 1	584	896	30	50	n. a.	n. a.	42	51	88.1	86.9
Lab 2	476	842	26	52	143	119	44	48	87.9	85.8
Lab 3	411	1371	13	40	142	144	**159**	73	86.6	81.3
Lab 4	735	1098	**76**	42	169	264	65	70	87.3	87.4
Lab 5	377	456	17	22	124	n. a.	40	29	85.5	84.7
Lab 6	551	550	16	15	150	150	26	31	87.7	87.6
X	522	869	20	37	146	169	43	50	87.2	85.6
S_L	131	340	7	15	16	65	14	19	1.0	2.4
CV_L (%)	25	39	35	41	11	38	32	37	1.1	2.8

The use of local pellets leads in general to higher emissions and higher variations in the results compared to test pellets. The efficiency is reduced using local pellets compared to test pellets, and the variation is higher based on all reported results. Excluding the value of 81.3 % for efficiency from laboratory 3 on local pellets will however lead to comparable values.

The results from the laboratories given in Table 13 are visualised in Figure 15 to Figure 19 together with X and s_L.

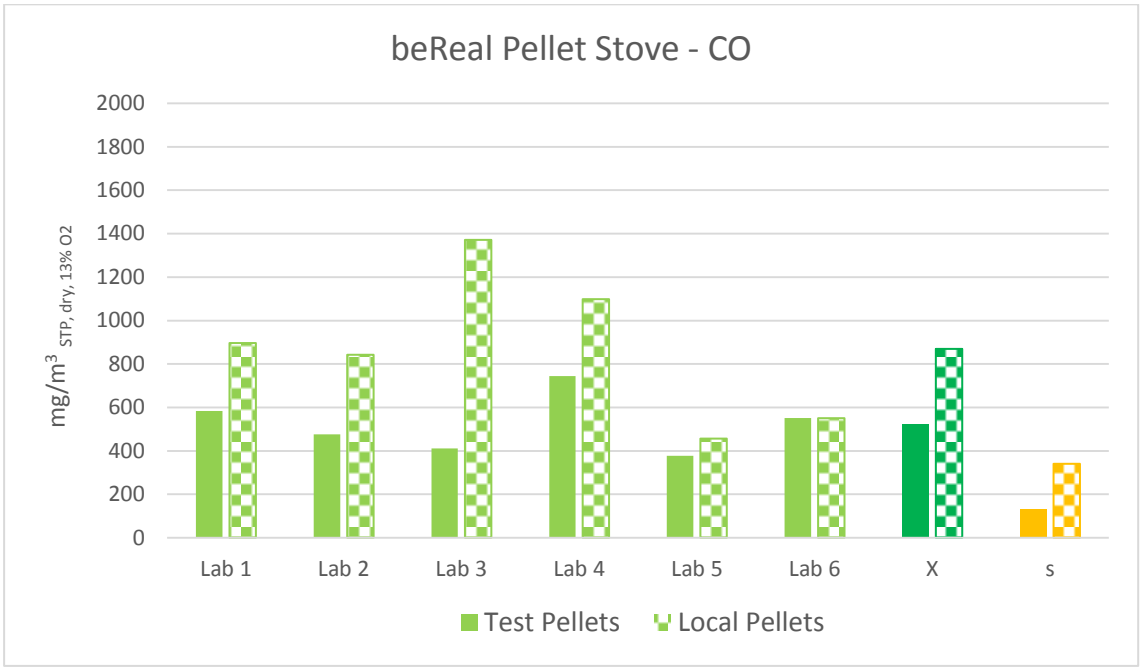

Figure 15 – Comparison of the beReal method for CO using test pellets and local pellets.

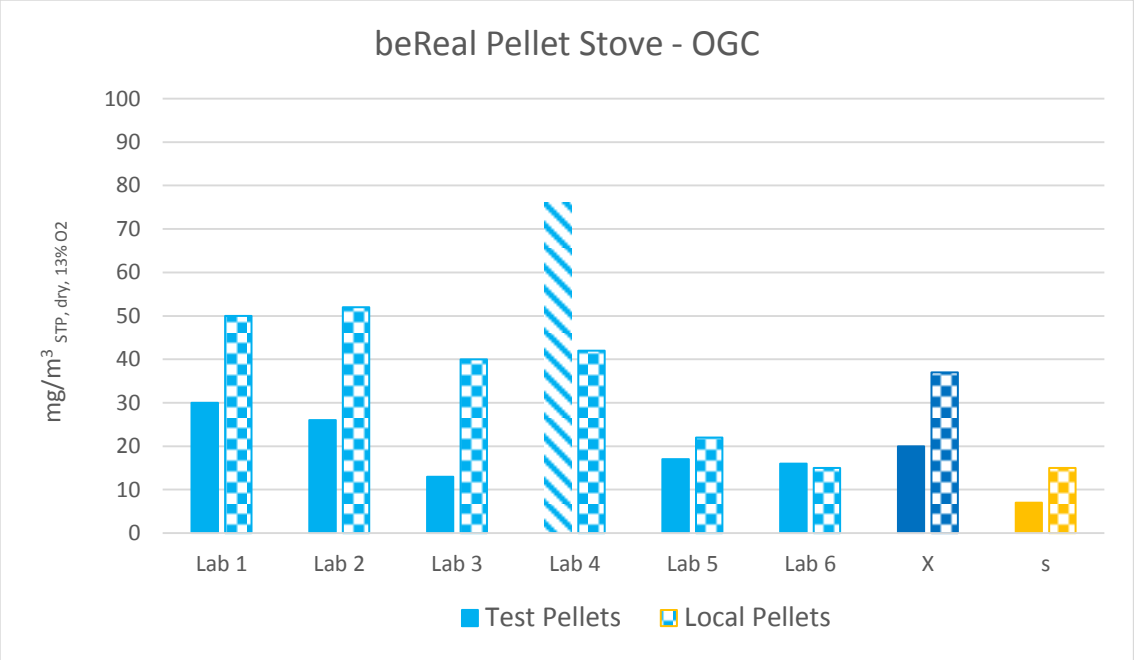

Figure 16 – Comparison of the beReal method for OGC using test pellets and local pellets.

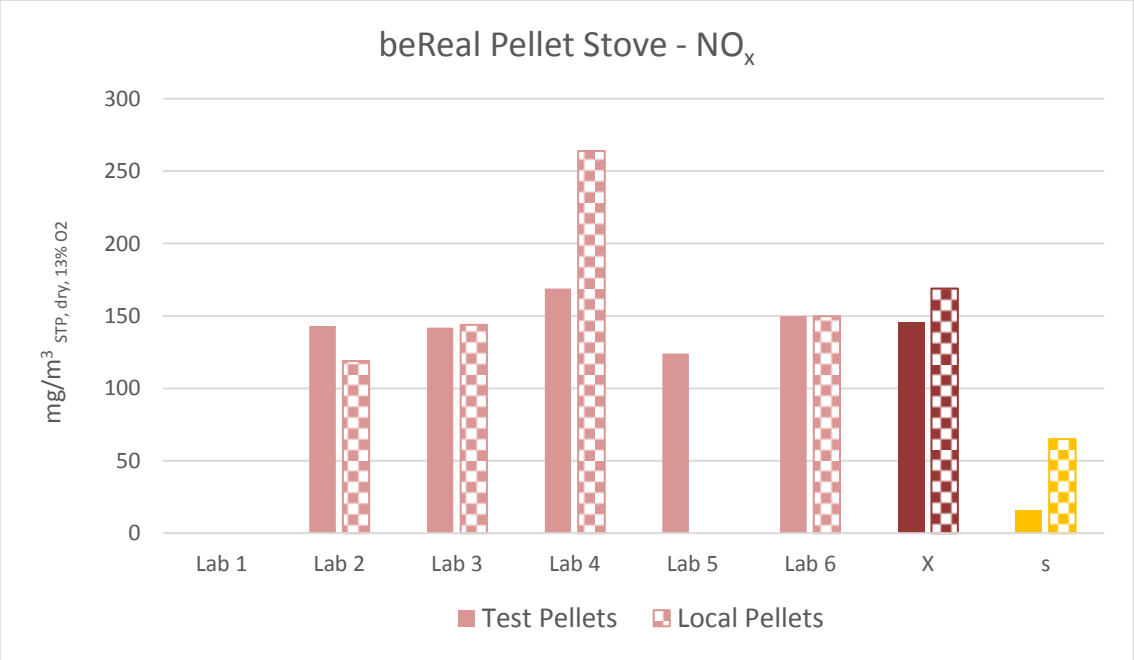

Figure 17 – Comparison of the beReal method for NO_x using test pellets and local pellets.

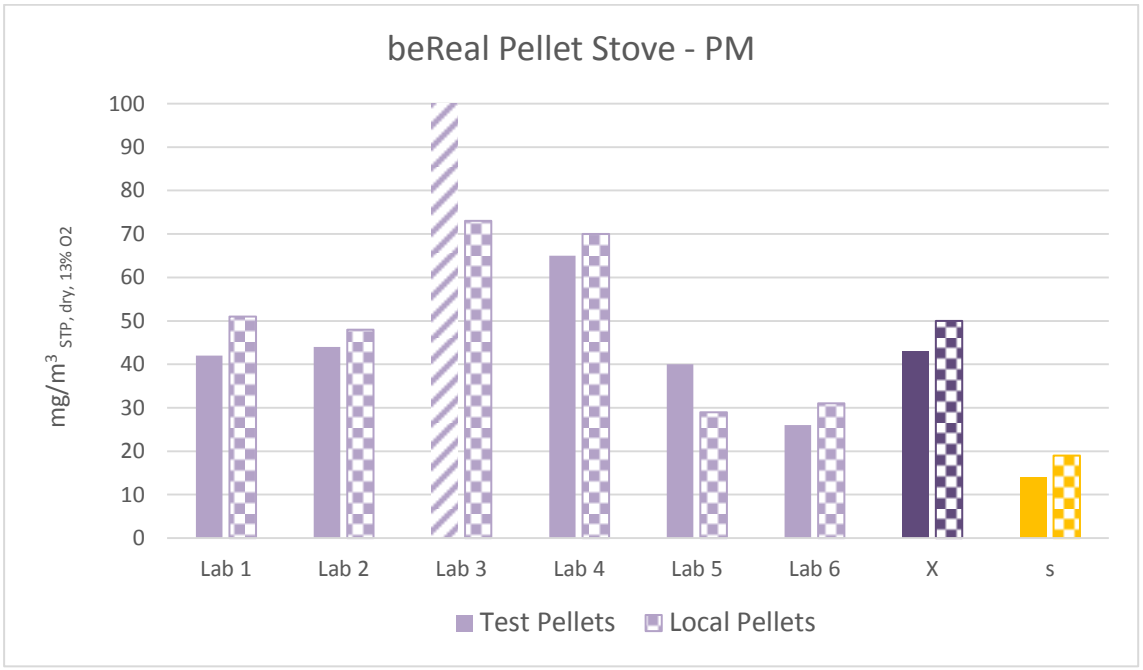

Figure 18 – Comparison of the beReal method for PM using test pellets and local pellets.

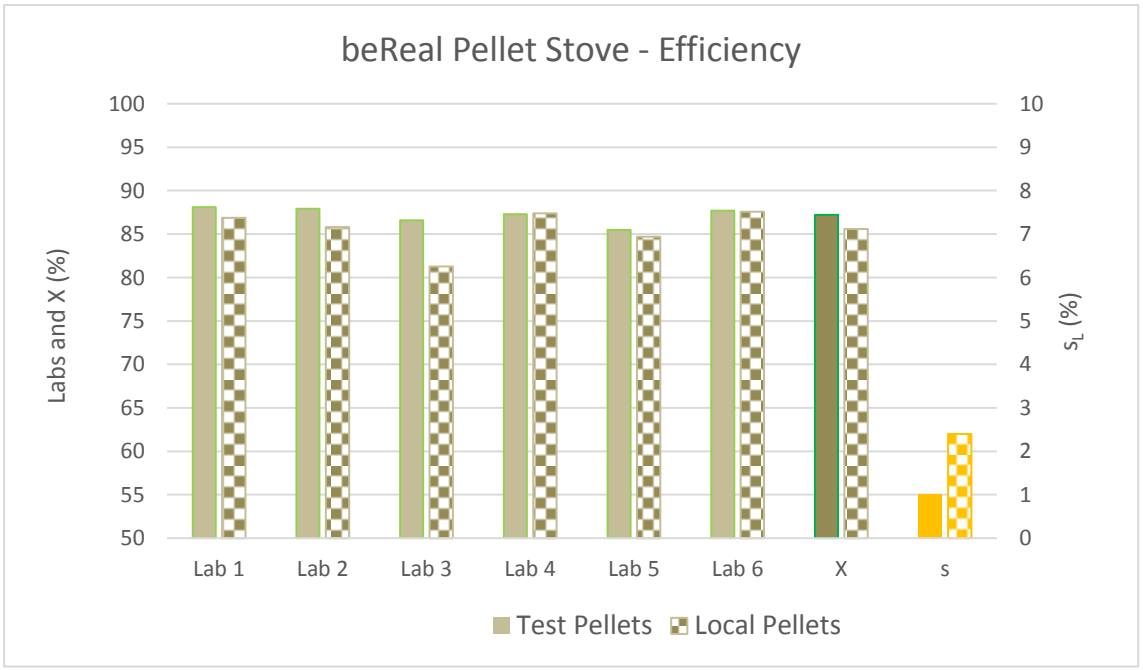

Figure 19 – Comparison of the beReal method for efficiency using test pellets and local pellets.

3.3.2 Firewood stove

3.3.2.1 Bark

For the firewood stove each laboratory performed the beReal method both on test fuel from HFR with bark (wb) and with test fuel from HFR without bark (wob). Table 14 shows the results together with calculated values of X, s_L and CV_L. Three results for efficiency are not included as no ash analysis was made.

Table 14 – Comparison of the beReal method using firewood with and without bark.

Firewood stove	**CO**		**OGC**		**NO_x**		**PM**		**Efficiency**	
	$mg/m^3_{STP, dry, 13\% O2}$								%	
	wb	wob	wb	wob	wb	wob	wb	wob	wb	wob
Lab 1	2613	2911	105	127	104	93	28	40	72.6	73.0
Lab 2	2487	2642	175	131	101	92	63	48	66.1	72.3
Lab 3	2729	2584	97	135	83	81	59	59	77.4	n.a.
Lab 4	2078	2634	28	43	101	87	29	34	n.a.	n.a.
Lab 5	3208	2836	168	130	94	101	57	68	73.2	73.2
Lab 6	3025	3158	277	**314**	103	**56**	30	56	69.6	67.5
Lab 7	3566	3332	117	90	101	86	21	31	72.7	73.3
X	2815	2871	138	109	98	90	41	48	71.9	71.9
S_L	494	285	78	36	7	7	18	14	3.8	2.5
CV_L (%)	18	10	57	33	8	8	43	29	5.3	3.4

Overall, there is no significant improvement on emission levels going from test fuel with bark to test fuel without bark. For CO, OGC, PM and efficiency, the between-laboratory variation decreases using test fuel without bark. Notice that excluding the value of 67.5 % for efficiency from laboratory 6 on fuel without bark will lead to s_L = 0.5 % and CV_L = 0.6 %. From these measurements, no precise conclusion could be drawn concerning an advantage respectively a disadvantage of using fuel without bark.

The results from the laboratories given in Table 14 are visualised in Figure 20 to Figure 24 together with X and s_L.

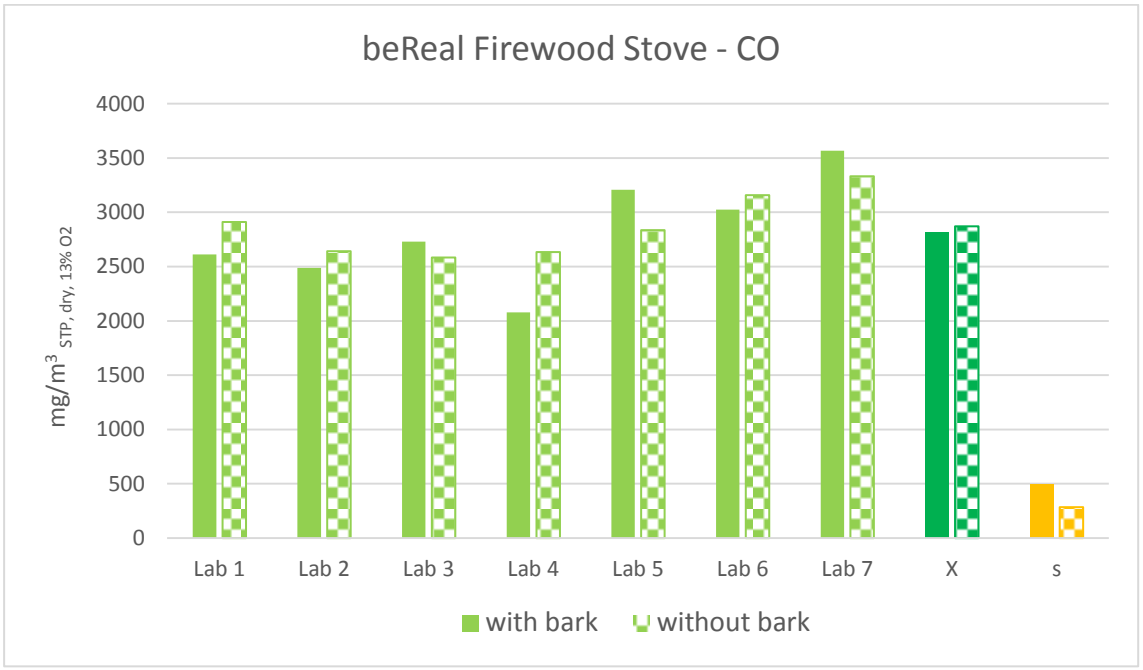

Figure 20 – Comparison of the beReal method for CO using firewood with and without bark.

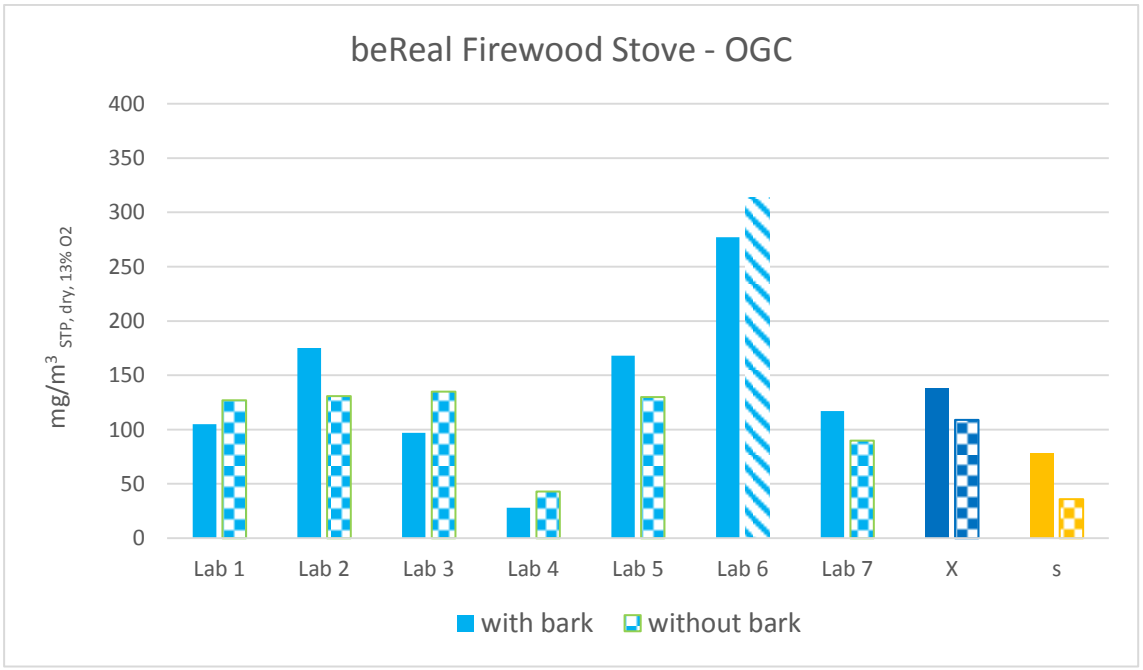

Figure 21 – Comparison of the beReal method for OGC using firewood with and without bark.

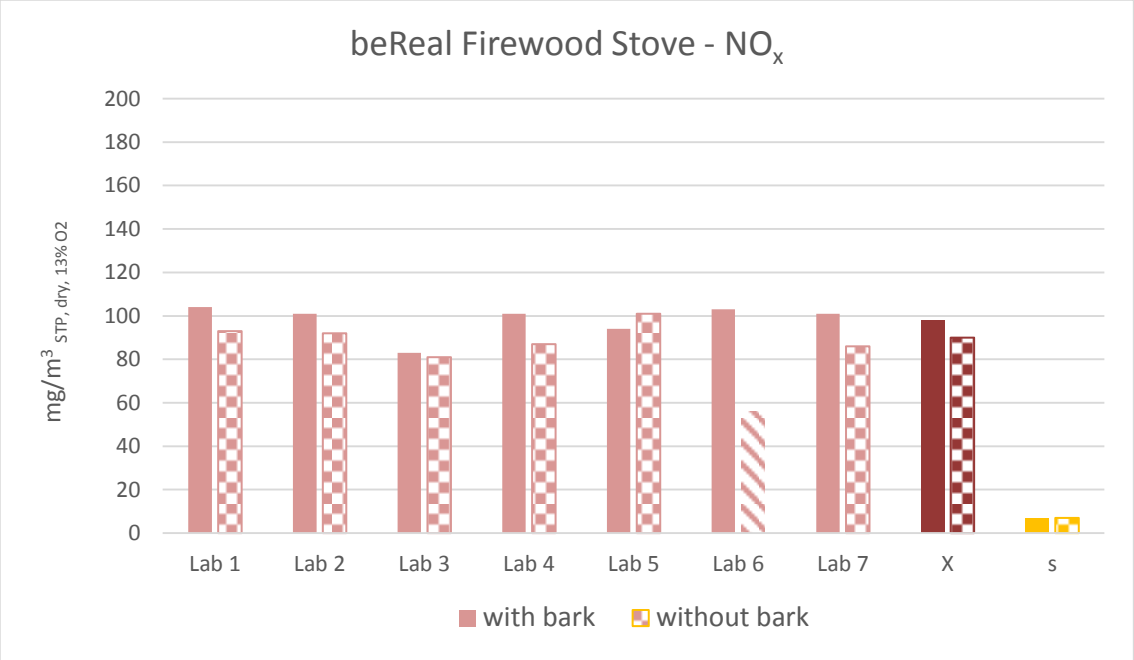

Figure 22 – Comparison of the beReal method for NO_x using firewood with and without bark.

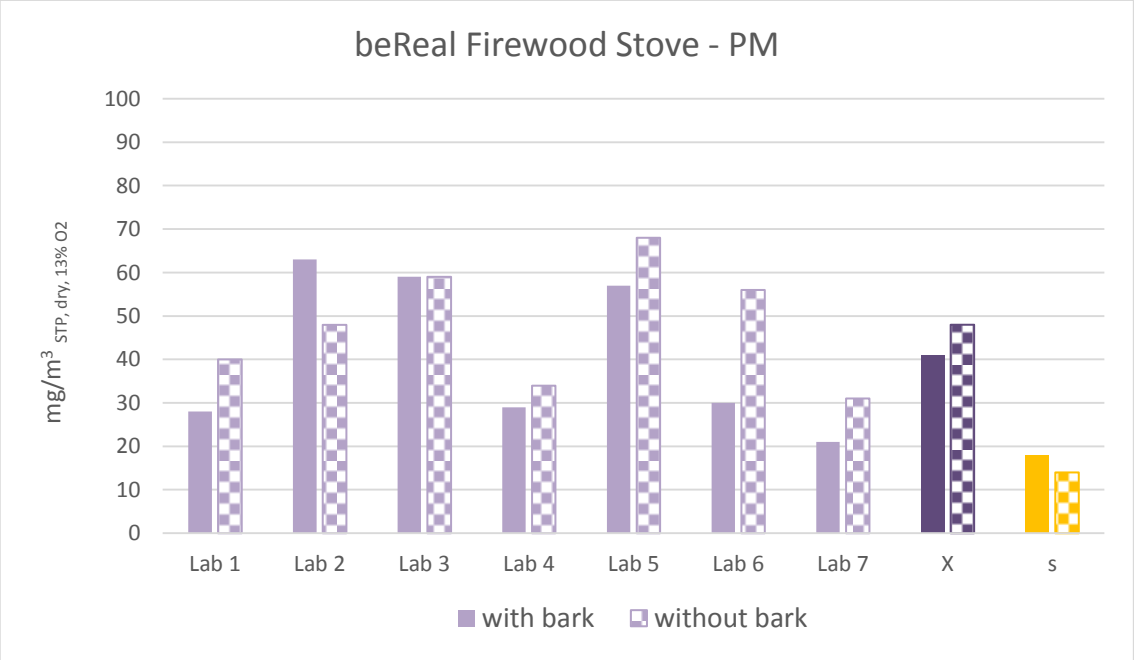

Figure 23 – Comparison of the beReal method for PM using firewood with and without bark.

Figure 24 – Comparison of the beReal method for efficiency using firewood with and without bark.

3.3.2.2 Local fuel

For the firewood stove each laboratory also performed the beReal test both with test fuel with bark from HFR (Test) and with fuel from a badge of their own local supply reflecting a typical quality of fuel (Local). Table 15 summarizes the results together with calculated values of X, s_L and CV_L. Three results for efficiency are not included as no ash analysis was made.

Table 15 – Comparison of the beReal method using test firewood and local firewood.

Firewood stove	**CO**		**OGC**		**NO_x**		**PM**		**Efficiency**	
	$mg/m^3_{STP, dry, 13\% O2}$								%	
	Test	Local	Test	Local	Test	Local	Test	Local	Test	Local
Lab 1	2613	2279	105	101	104	118	28	41	72.6	71.6
Lab 2	2487	3248	175	219	101	122	63	44	66.1	70.1
Lab 3	2729	2486	97	178	83	58	59	47	77.4	n.a.
Lab 4	2078	1758	28	27	101	107	29	25	n.a.	n.a.
Lab 5	3208	2376	168	124	94	140	57	58	73.2	73.3
Lab 6	3025	2506	277	224	103	100	30	48	69.6	70.5
Lab 7	3566	3012	117	88	101	95	21	26	72.7	73.4
X	2815	2524	138	137	98	106	41	41	71.9	71.8
S_L	494	489	78	73	7	26	18	12	3.8	1.5
CV_L (%)	18	19	57	53	8	24	43	29	5.3	2.1

Overall, there is no significant difference on emission levels and variation going from test fuel with bark to local fuel.

The results from the laboratories given in Table 15 are visualised in Figure 25 to Figure 29 together with X and s_L.

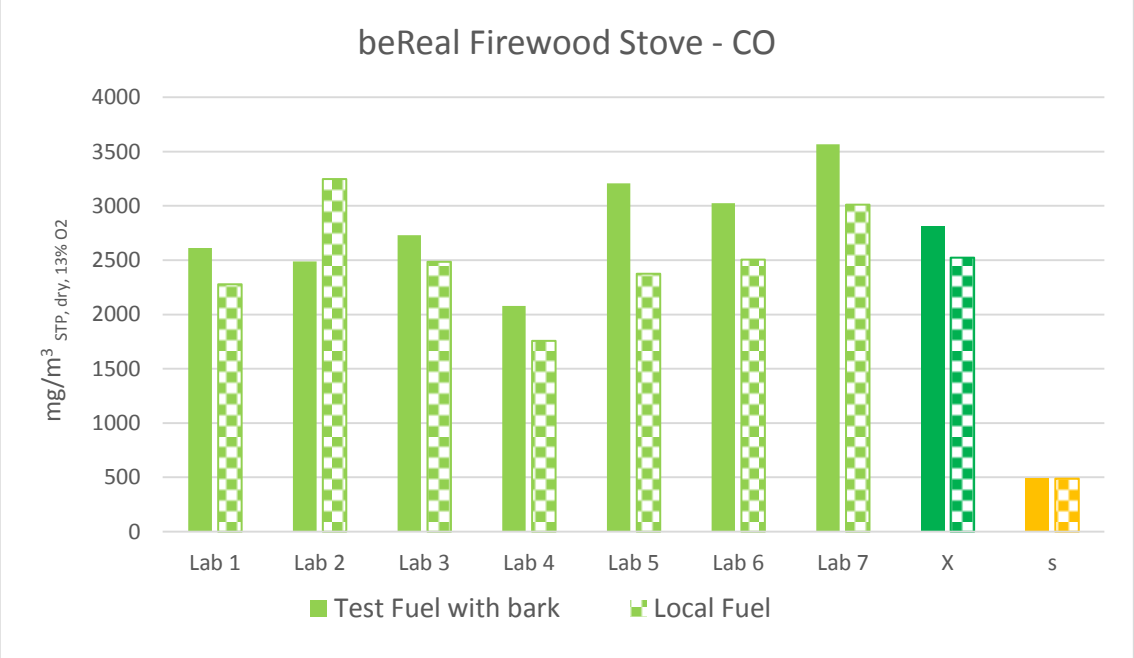

Figure 25 – Comparison of the beReal method for CO using test fuel and local fuel.

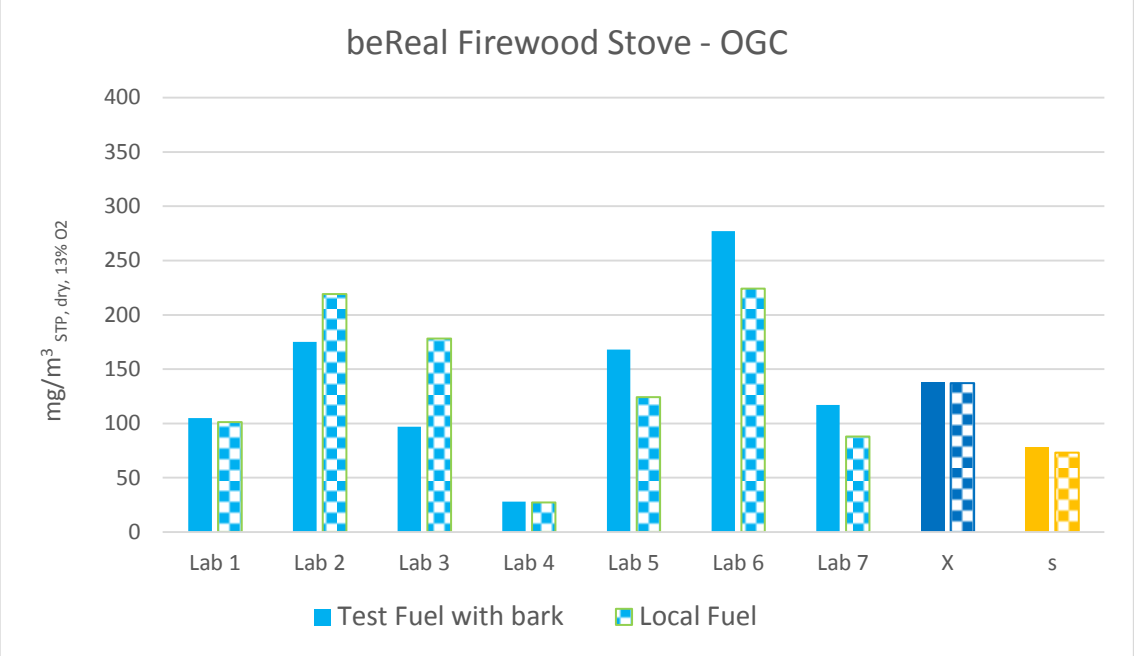

Figure 26 – Comparison of the beReal method for OGC using test fuel and local fuel.

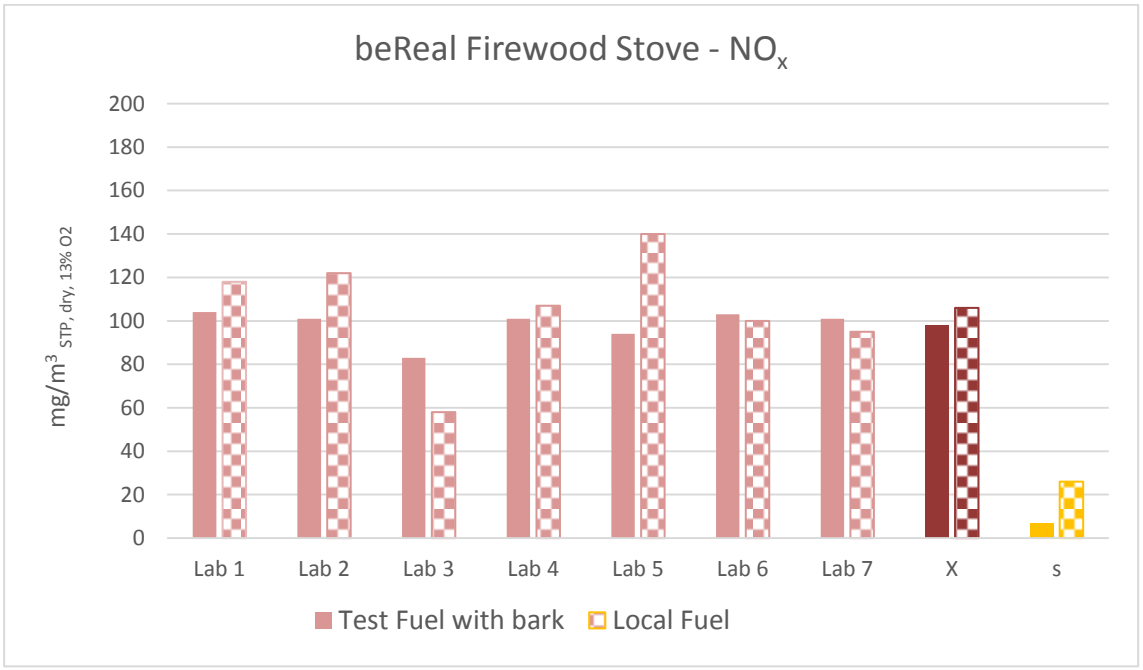

Figure 27 – Comparison of the beReal method for NO_x using test fuel and local fuel.

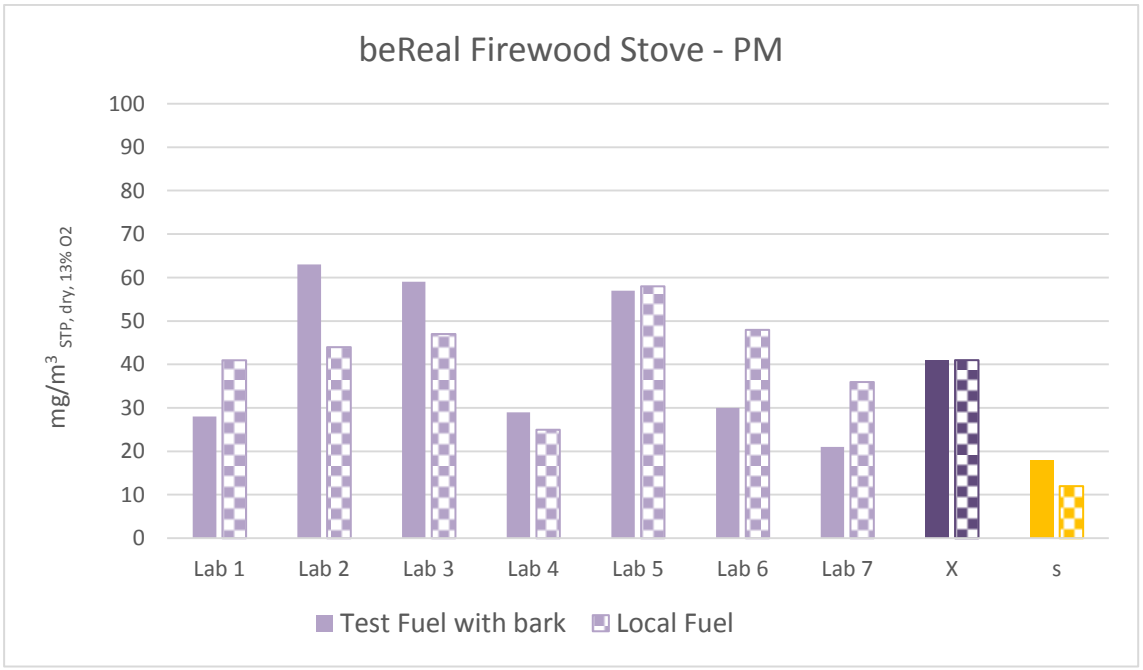

Figure 28 – Comparison of the beReal method for PM using test fuel and local fuel.

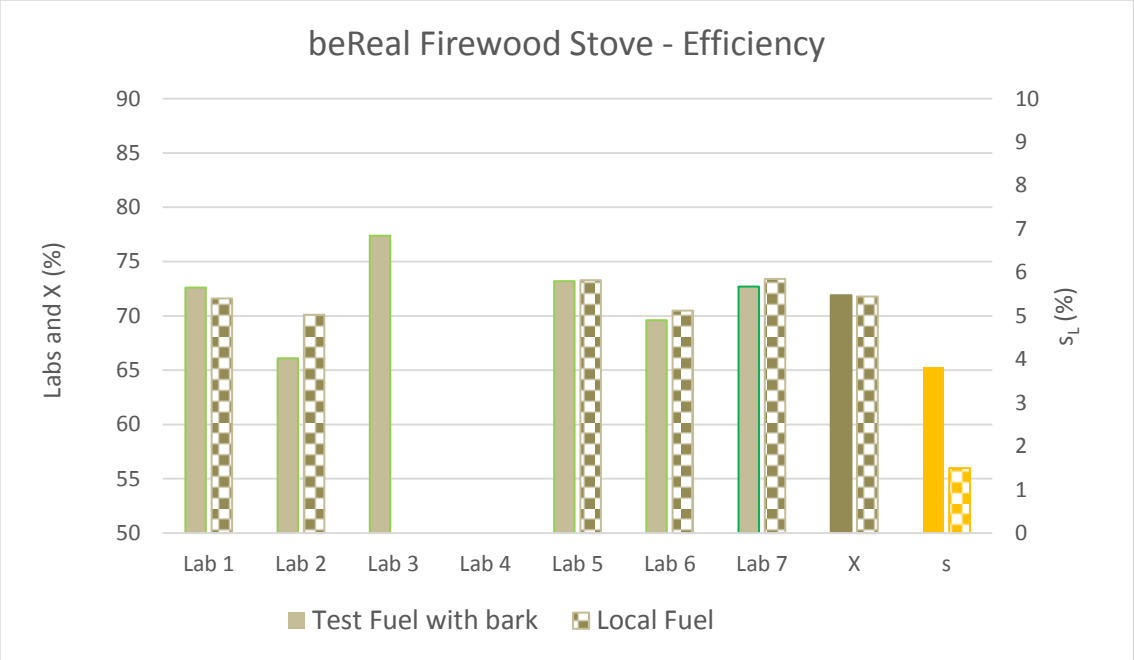

Figure 29 – Comparison of the beReal method for efficiency using test fuel and local fuel.

3.4 The beReal method compared to Type Testing

3.4.1 Pellet stove

For the pellet stove each laboratory performed both the beReal (bR) method and a type test with pellets from HFR. Table 16 shows the results together with calculated values of X, s_L and CV_L. The results for the type test are reported for both nominal load (NL) and partial load (PL).

Table 16 – Comparison of the beReal method and type testing using test pellets-

	CO			**OGC**			**NO_x**			**PM**			**Efficiency**		
	mg/m³$_{STP, dry, 13\% O2}$												%		
	bR	NL	PL	bR	NL	PL	bR	NL	PL	bR	NL	PL	bR	NL	PL
L1	584	55	1796	30	**5**	**82**	n.a.	n.a.	n.a.	42	47	56	88.1	87.9	82.6
L2	476	57	714	26	2	18	143	132	147	44	48	45	87.9	88.4	86.3
L3	411	169	n.a.	13	1	n.a.	142	119	n.a.	**159**	47	n.a.	86.6	85.6	n.a.
L4	735	103	101	**76**	2	1	169	117	149	65	51	43	87.3	86.9	87.4
L5	377	198	250	17	2	3	124	112	123	40	**102**	**110**	85.5	86.7	84.8
L6	551	133	1107	16	2	22	150	131	145	26	58	65	87.7	89.0	86.0
X	522	119	794	20	2	11	146	122	141	43	48	52	87.2	87.4	85.4
S_L	131	59	686	7	0.4	11	16	9	12	14	5	10	1.0	1.2	1.8
CV_L	25	49	86	35	25	96	11	7	9	32	9	20	1.1	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 NO_x the values are comparable. No consistent result was achieved on the ratio between the beReal result, the NL figure and the PL result as the mean beReal value is either between NL and PL (at CO and efficiency), above NL and PL (at OGC and NO_x) or below NL and PL (at PM).

The results from the laboratories given in Table 16 are visualised in Figure 30 to Figure 34 together with X and s_L.

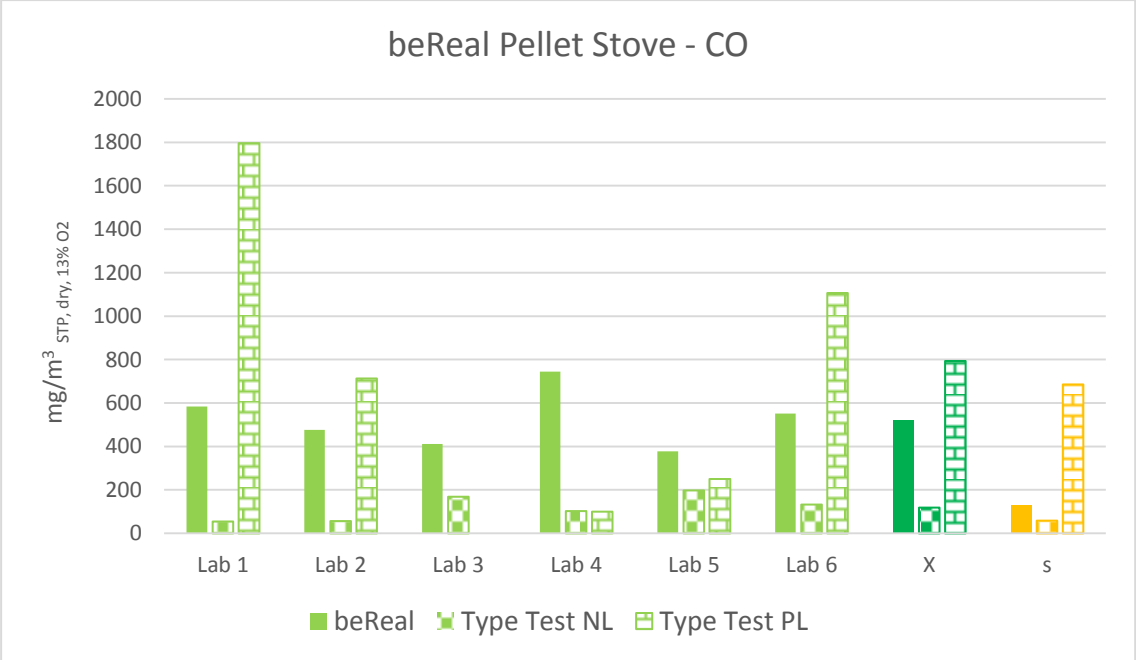

Figure 30 – Comparison of the beReal method and type testing for CO using test pellets.

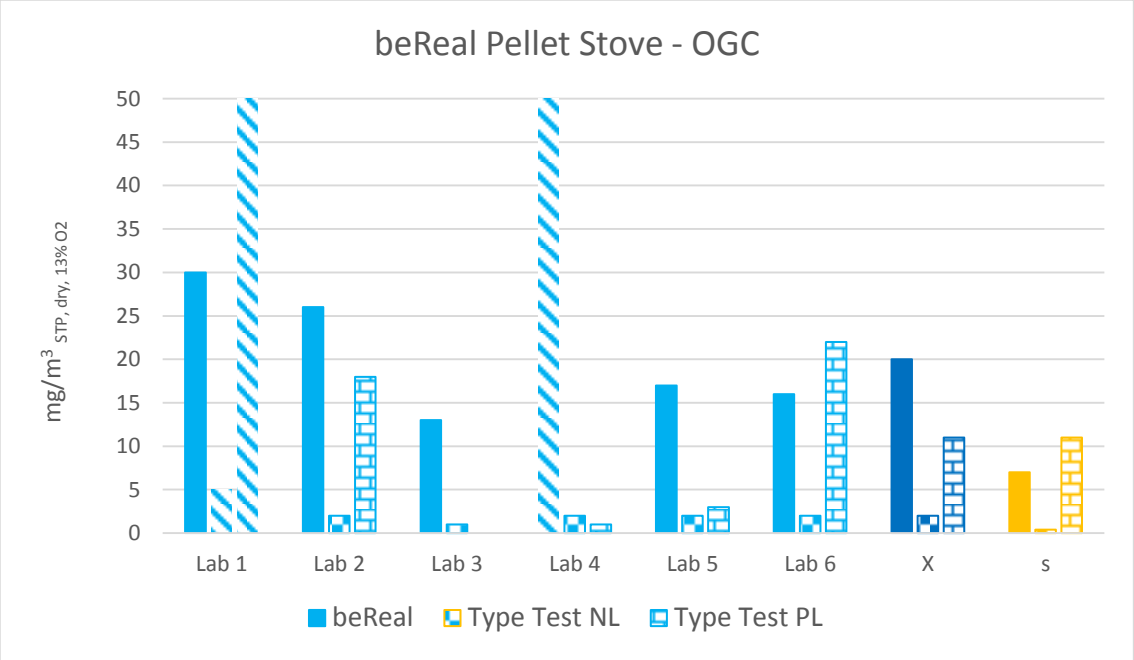

Figure 31 – Comparison of the beReal method and type testing for OGC using test pellets.

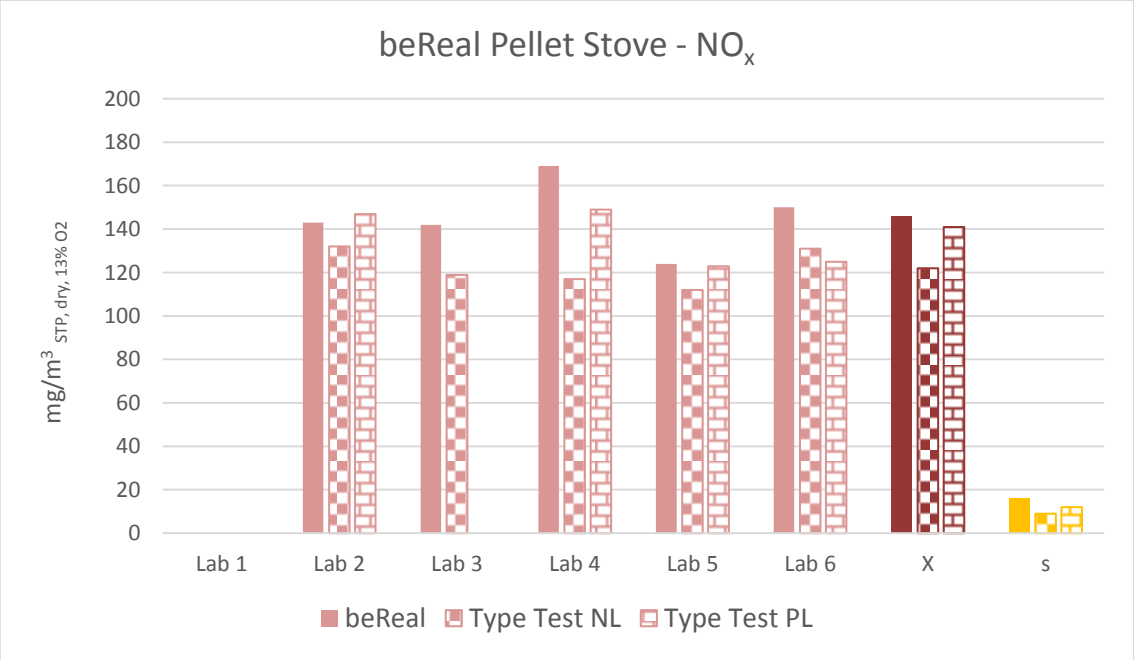

Figure 32 – Comparison of the beReal method and type testing for NO_x using test pellets.

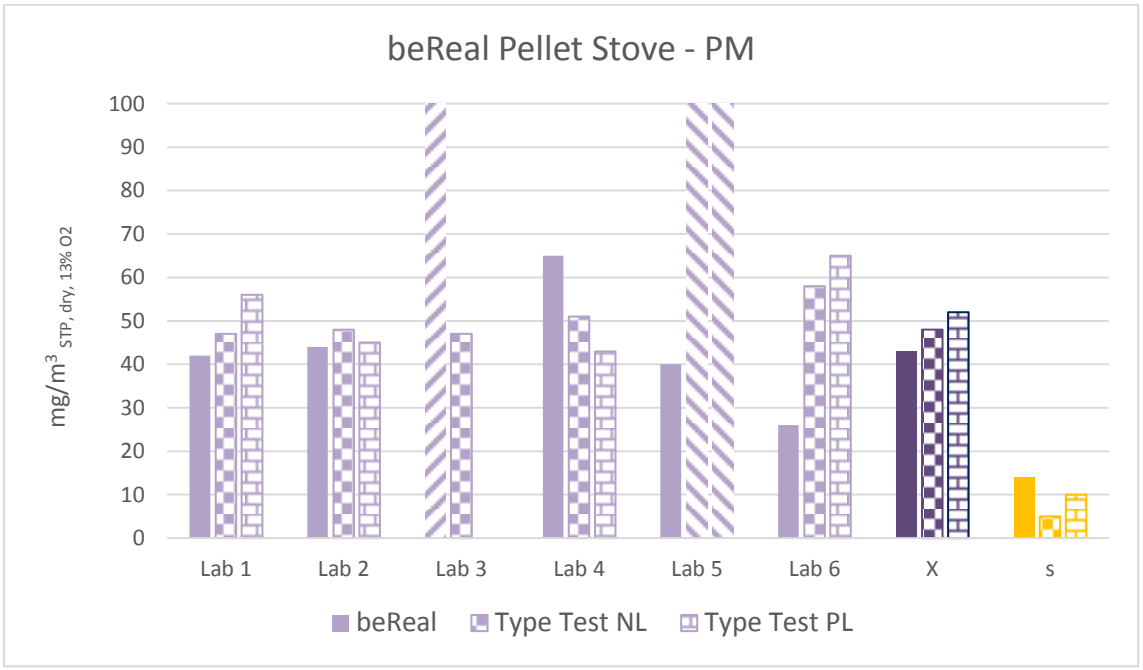

Figure 33 – Comparison of the beReal method and type testing for PM using test pellets.

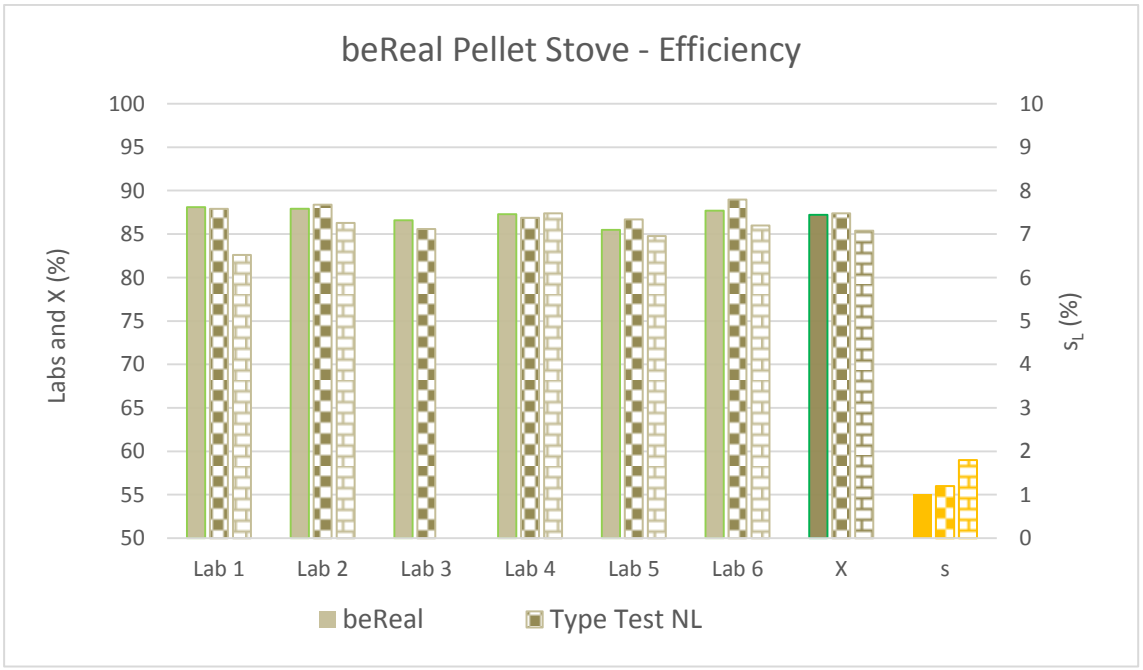

Figure 34 – Comparison of the beReal mehod and type testing for efficiency using test pellets.

3.4.2 Firewood stove

For the firewood stove each laboratory performed both the beReal (bR) method and a type test (TT) with fuel without bark from HFR. Table 17 shows the results together with calculated values of X, s_L and CV_L.

Table 17 – Comparison of the beReal method and type testing using test firewood without bark.

	CO		**OGC**		**NO_x**		**PM**		**Efficiency**	
	mg/m³$_{STP, dry, 13\% O2}$								%	
	bR	TT	bR	TT	bR	TT	bR	TT	bR	TT
Lab 1	2911	2320	127	73	93	88	40	71	73.0	73.2
Lab 2	2642	3307	131	181	92	103	48	51	72.3	72.2
Lab 3	2584	2637	135	76	81	73	59	46	n.a.	81.0
Lab 4	2634	n.a.	43	na	87	na	34	n.a.	n.a.	n.a.
Lab 5	2836	2159	130	197	101	101	68	31	73.2	79.9
Lab 6	3158	2238	**314**	103	**56**	75	56	47	67.5	74.7
Lab 7	3332	2732	90	33	86	92	31	15	73.3	75.2
X	2871	2566	109	111	90	89	48	44	71.9	76.0
S_L	285	428	36	65	7	13	14	19	2.5	3.6
CV_L	10	17	33	59	8	14	29	44	3.4	4.7

The results show that the beReal method can be reproduced with the same variability or even better than the type testing method. This is even though that the type testing results only consists of two charges which are picked out, while beReal results are based on the complete burn cycle.

The results from the laboratories given in Table 17 are visualised in Figure 35 to Figure 39 together with X and s_L.

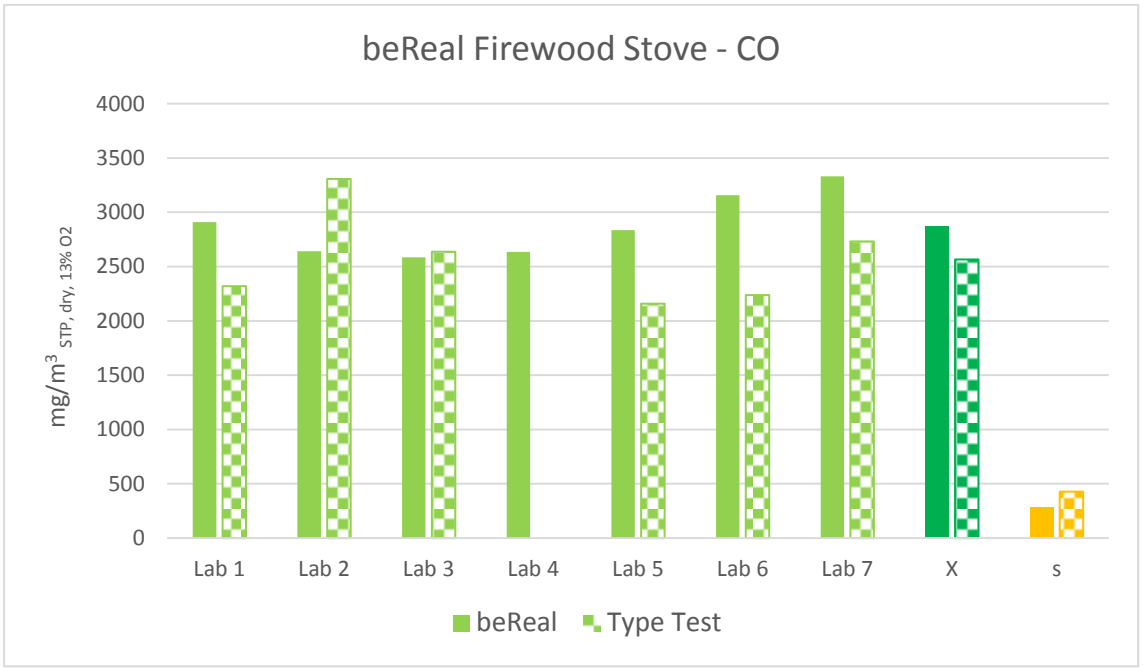

Figure 35 – Comparison of the beReal method and type testing for CO using test fuel.

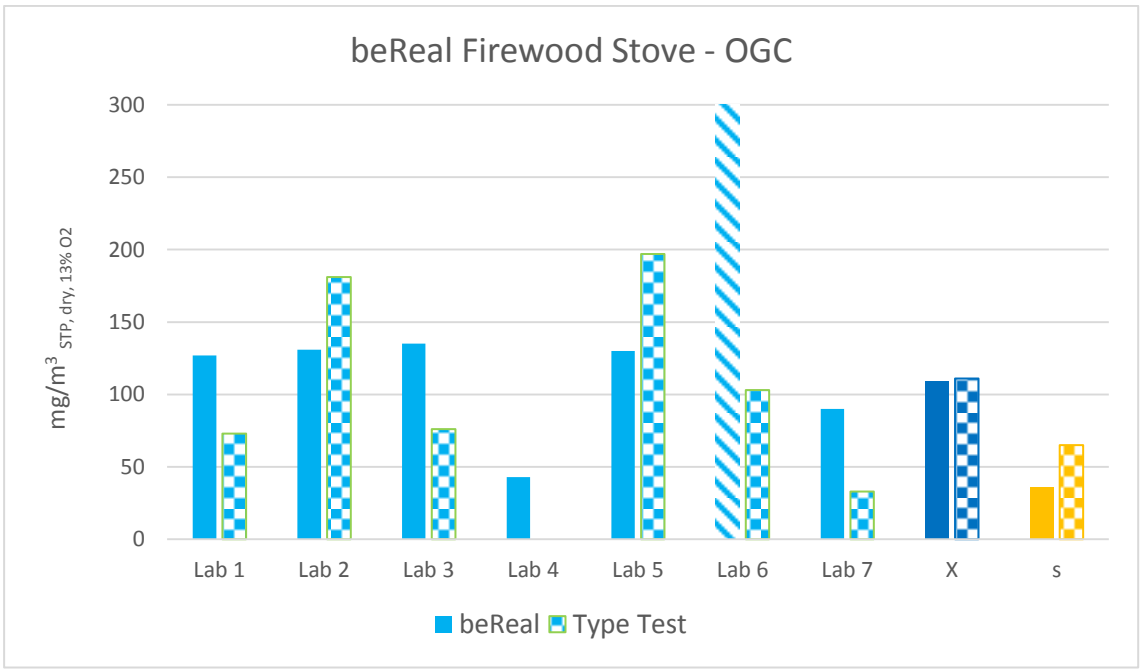

Figure 36 – Comparison of the beReal method and type testing for OGC using test fuel.

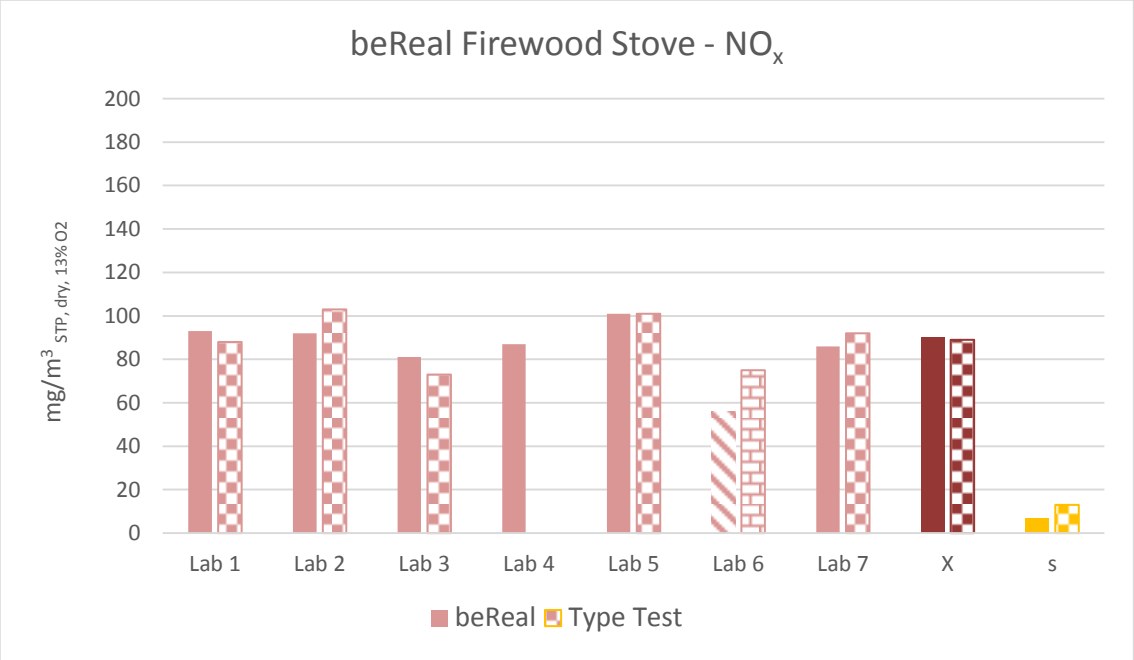

Figure 37 – Comparison of the beReal method and type testing for NO_x using test fuel.

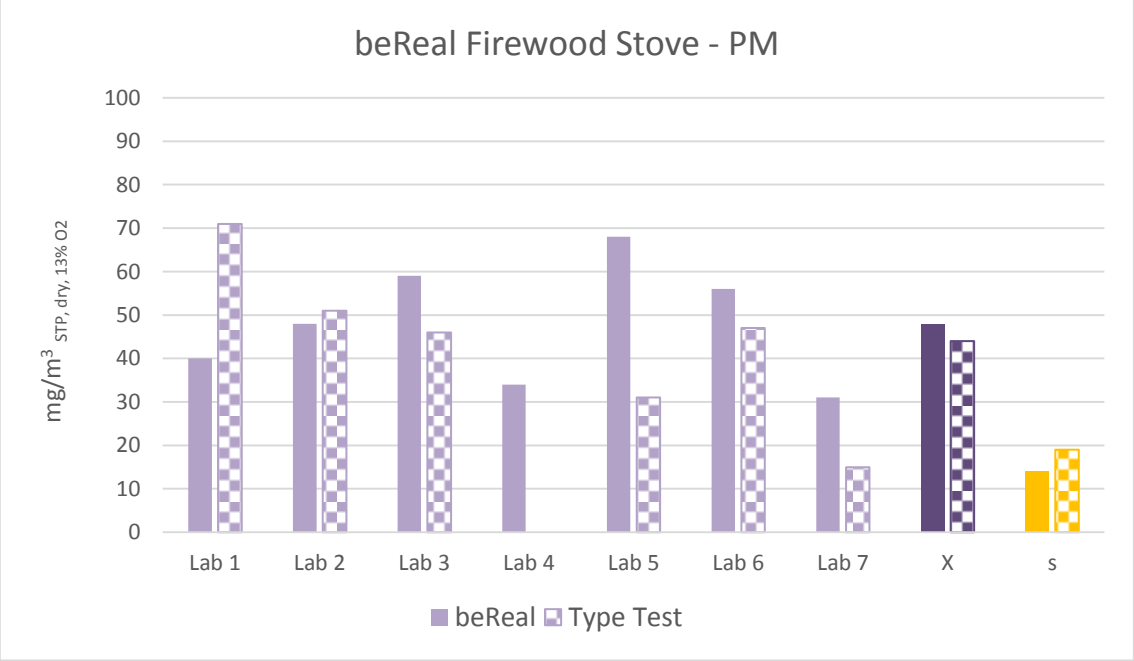

Figure 38 – Comparison of the beReal method and type testing for PM using test fuel.

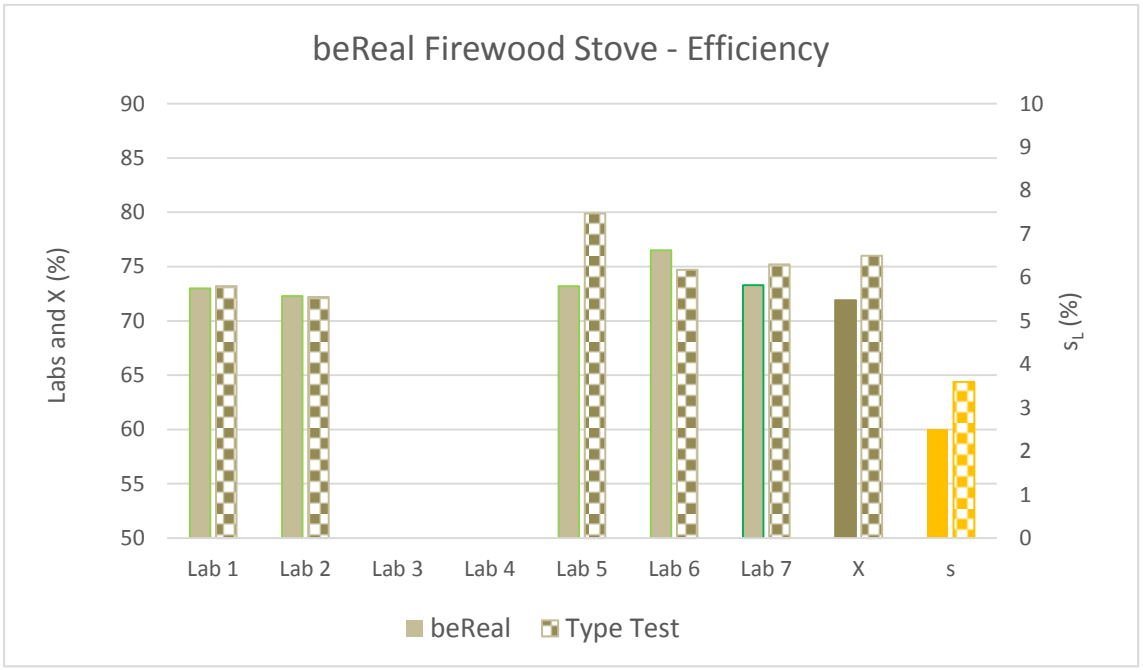

Figure 39 – Comparison of the beReal method and type testing for efficiency using test fuel.

4 Summary and discussion

4.1 Reproducibility of the beReal method

In the development of a new measurement method, it is essential that the final procedure can be reproduced in different laboratories. The Round Robin executed within WP8 has successfully provided data for estimating the reproducibility of the beReal method using both a pellet stove and a firewood stove. Table 18 gives an overview of reproducibility values from the Round Robin using test fuel, expressed as the reproducibility coefficient of variation CV_R.

Table 18 – Reproducibility values for the beReal method.

	CV_R (%)	
Parameter	**Pellet Stove**	**Firewood Stove**
CO	28	22
OGC	36	71
NO_x	11	12
PM	34	49
Efficiency	1.2	5.4

The best reproducibility for the emissions is achieved for NO_x followed by CO, PM and OGC for both the pellet stove and the firewood stove.

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-standardisation project BioNorm for obtaining reproducibility values for the laboratory analysis of solid biofuels. In the European standards EN 15104 [6] and EN 15289 [7] the reproducibility is given as CV_R for nitrogen and sulphur in wood chips and olive residues, see Table 19.

Table 19 – Examples of reproducibility values for analysis of solid biofuels.

		CV_R (%)	
Standard	**Parameter**	**Wood chips**	**Olive residue**
EN 15104	Nitrogen	30	8
EN 15289	Sulphur	34	17

Compared to the numbers in Table 19, the reproducibility values obtained in the beReal Round Robin is quite good, 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.

4.2 Reproducibility for different fuel qualities and for type testing

4.2.1 Pellet Stove

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. The reproducibility coefficient of variation is not used because repeatability data is not available from WP5 for all set-ups. An overview of reproducibility values expressed as the between-laboratory coefficient of variation CV_L is given in Table 20, which summarises the values when using the beReal method on different fuel qualities, and for type test using test fuel.

Table 20 – 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
NO_x	11	38	7	9
PM	32	37	9	20
Efficiency	1.1	2.8	1.4	2.1

A graphical presentation of the values in Table 20 is given in Figure 40.

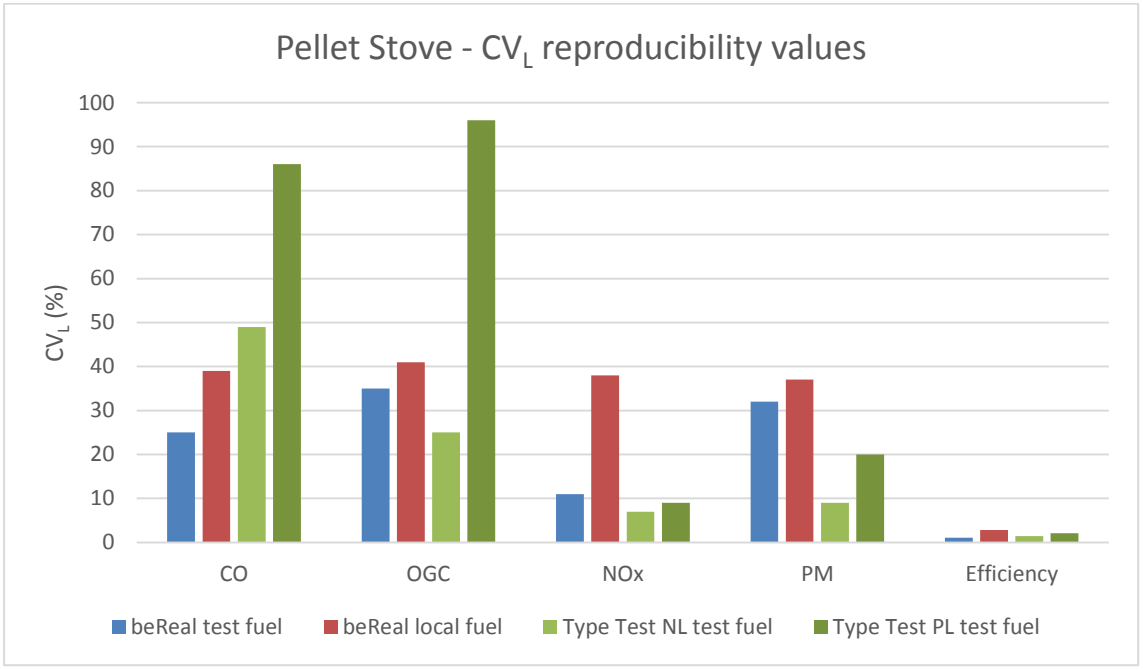

Figure 40 – Reproducibility values for the pellet stove.

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.

4.2.2 Firewood stove

An overview of reproducibility values expressed as the between-laboratory coefficient of variation CV_L is given in Table 21, which summarises the values when using the beReal method on different fuel qualities, and for type test using test fuel without bark.

Table 21 – 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
NO_x	8	8	24	14
PM	43	29	29	44
Efficiency	5.3	3.4	2.1	4.7

A graphical presentation of the values in Table 21 is given in Figure 41.

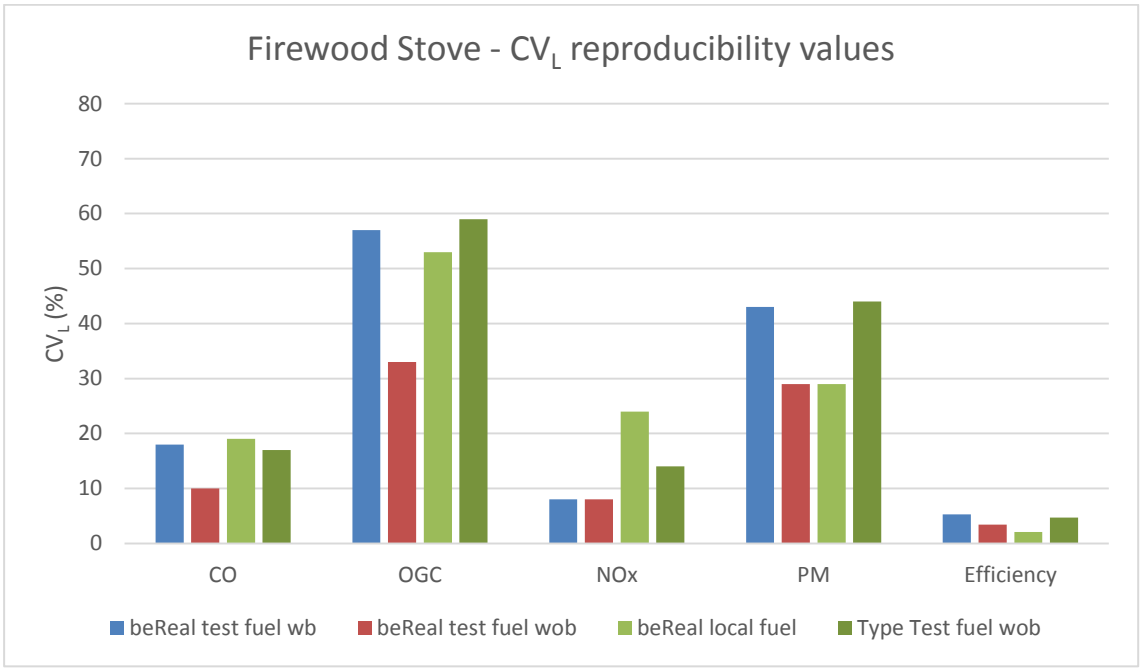

Figure 41 – Reproducibility values for the firewood stove.

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. This is even though that the type testing results only consists of two charges which are picked out, while beReal results are based on the complete burn cycle.

5 Literature

[1] EN 13240:2004 – Roomheaters fire by solid fuel – Requirements and test methods

[2] prEN 16510:2016 – Residential solid fuel burning appliances

[3] EN 14785:2006 – Residential space heating appliances fired by wood pellets – Requirements and test methods

[4] EN ISO/ IEC 17043:2010 – Conformity assessment – General requirements for proficiency testing.

[5] ISO 5725:1986 – Precision of test methods – Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.

[6] EN 15104:2011 – Solid biofuels - Determination of total content of carbon, hydrogen and nitrogen. Instrumental methods.

[7] EN 15289:2011 – Solid biofuels – Determination of total content of sulfur and chlorine.

6 List of figures

7 List of tables