reReport

beReal

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Deliverable D7.1

Documentation and evaluation of field data demonstration

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BeReal - Deliverable 7.1

Table of Content

1 Introduction

The beReal project includes the development of methods and testing procedures for firewood and pellet stoves. The aim of the measuring methods and procedures is to reflect real life operation in the best possible way (but without maloperation). It is also a fundamental goal that the advanced testing procedures are repeatable, reproducible and provide a substantial differentiation between products of the same product category.

The purpose of WP7, reported in this deliverable, was to demonstrate the applicability and practical relevance of the advanced testing method reflecting real life conditions. To this aim thirteen firewood stoves and four pellet stoves were installed in the field at a natural draught system. The methods developed in WP3 *("Measuring methods and testing procedures")* were used and data was documented and analyzed with the tools developed in WP4 *("Data evaluation and documentation")*. The results were compared with results from the lab tests performed in WP5 *("Validation")*.

The measurements provided data for:

- Real life emissions by field testing at end users.
- Comparison between end user procedure and the beReal test method.
- Evaluation of the effect of implementing Quick User Guides.

This report sums up preparation, measurements and evaluation of the field demonstration.

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

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2 Planning, participants and methods

The work package 7 was planned by DTI and executed by each RTD partner (DTI, SP, TFZ, HFR and BE2020) at the respective field testing site. The preparatory activities prior to the field measurements comprised:

- The selection of appliances.
- Setting up and securing the time schedule for and the number of measurements.
- The preparation of test fuels to ensure the comparability of measurements.
- The preparation of the method for field testing according to the Quick User Guide (QUG).
- The selection of measurement methods and data evaluation routines according to WP3 and WP4.
- The installation of appliances and the performance of pre-tests at the field sites (e.g. tightness test, operating test, etc.).

Altogether thirteen firewood stoves and four pellet stoves were tested, see Table 1 for data on the firewood stoves and Table 2 for data on the pellet stoves. The participating manufacturers provided the stoves and the end users payed for the installation of the stove and other costs. Each RTD partner was responsible for the planning and execution of their field tests, including the task of finding the private end users willing to participate. All stoves were tested previously at the RTD's test stands before installing them in the field in private homes at different end users. The appliances were also tested for leakage at the field sites before the field measurement to compare the result with the leakage rate reached previously at the test stand to exclude that any damages occurred at the stoves during transportation.

Table 1. Firewood stoves tested in field. The numbering is not in accordance with any presentation.

Stove nr	Year of pro-duction	Nominal heat output [kW]	Weight [kg]	Dimenstions (HxLxD) [mm x mm x mm]	Room air inde-pendent	Automatic air control
1	2014	6.0	111	904x557x427	no	no
2	2013	8.0	280	1109x584x499	yes	yes
3	2015	9.0	245	1098x817x424	yes	yes
4	2015	5.0	135	1150x460x435	yes	no
5	2015	9.0	145	975x470x400	no	no
6	2015	4.5	75	1000x430x370	yes	yes (mechanical)
7	2015	8.0	204	1464x520(diameter)	yes	no
8	2015	8.0	204	1464x520(diameter)	yes	no
9	2014	8.0	224	1140x574x446	yes	no
10	2015	6.0	114	1040x447x465	yes	no
11	2015	4.5	75	100x43x37	yes	yes
12	2014	5.0	105	1080*495*440	yes	no
13	2015	10.0	260		yes	no

Table 2. Pellet stoves tested in field. The numbering is not in accordance with any presentation.

Stove nr	Year of pro-duction	Nominal/minimal heat output [kW]	Weight [kg]	Dimenstions (HxLxD) [mm x mm x mm]	Room air inde-pendent	Automatic air control
1	2015	10.0/2.5	255	1115x793x433	yes	yes
2	2014	8.0/2.5	178	1200x560x545	-	-
3	2013	8.1/2.4	150	1100x526x498	yes	yes
4	2015	9.2/2.7	90	1022x498x504	yes	yes

The appliances were installed at least a month before the field tests to ensure that the users had become familiar with the appliances and had developed their own habits before the field tests were conducted. The end user also had to be at home during the three measurement days to fire the stove. Each RTD partner provided the necessary measurement section and replaced the existing connecting pipe during the time of measurement. If the installation was altered when installing the measurement section, e.g. due to a different length of the flue gas pipe, the flue draught might have changed as well. The end users were given a few days to adapt to any changes in operation by the installation, prior to the measurements. Measurement sections are shown in Figure 1. The end users provided their home during three measurement days including the allowance to set up the measurement equipment and of the presence of staff from the RTD partners, see example in Figure 2.

Quick User Guides, QUG, were prepared for the firewood stoves. The QUG consisted of short guidelines on how to prepare and ignite the stove, recharge and fire it on nominal and on partial load and how to finish the heating operation. The QUGs were prepared in collaboration with the manufacturers. Detailed information about the QUG can be found in Deliverable 4.2.

Of the tested stoves, twelve were tested at private homes and five stoves (three firewood stoves and two pellet stoves) were tested in laboratories that could provide conditions comparable to field conditions. Requirements for performing the tests in laboratory comprised that a natural draft chimney existed in the laboratory and that the stove could be operated by untrained/ various operators. This was considered to give data equivalent to field data.

2.1 Measurement sections

The optimal scenario was that the measurement section used for measurement was the same as the beReal measurement section. However, this was not possible in all private households. Instead measurement sections that could be adapted at all different real life test houses were developed, see Figure 1. After the measurement section only uninsulated piping was used and a thermocouple was placed before the chimney inlet (5 cm to 10 cm) to calculate the “real life efficiency for the selected room”.

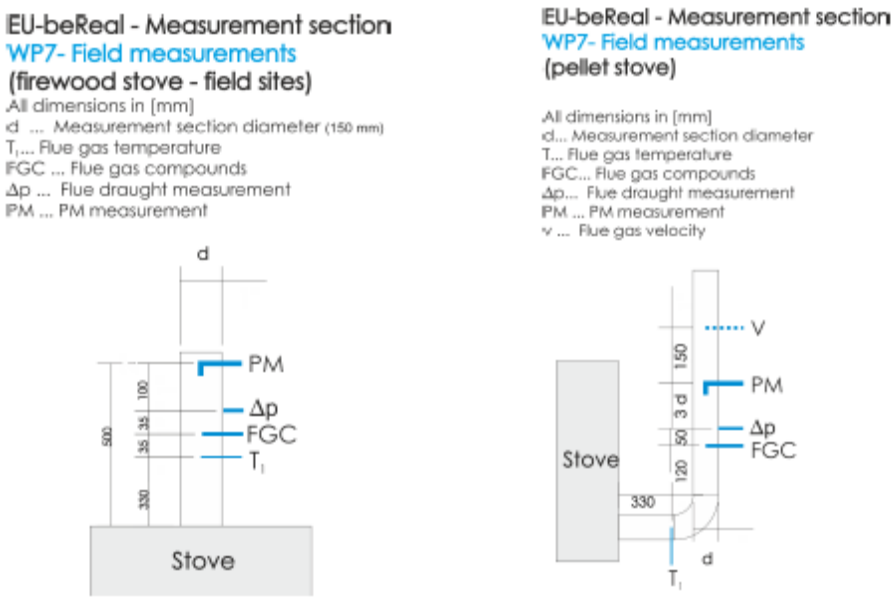

Figure 1. Measurement sections for the field tests.

2.2 Measurement procedures

During the measurements, the emissions of carbon monoxide (CO), volatile organic compounds (OGC), and particulate matter (PM), were measured and the efficiency was determined.

Figure 2. Measurement equipment at end user site.

Some conditions were fixed for all measurements in the field. All test days were performed during the heating season and all measurements were made in-door. The parameters to be analysed were the same as in the beReal method. The end users needed time to develop good habits with the new stove before testing. Therefore, the measurements were performed several weeks after installation. The stoves were operated by the end users on all three test days. The operation of the stoves on the three days of measurements was done according to

- the usual procedure of the end user (Day 1),
- the Quick User Guide at the firewood stoves respectively the usual procedure but with RTD fuel at the pellet stoves (Day 2),
- the instructions by the RTD partner according to beReal method (Day 3).

The fuel was either the usual end user quality for log wood and pellets, or the quality the RTD partners usually uses for testing.

2.2.1 Procedure for firewood stoves

The firewood stoves installed in the field were fired during three days. The first day, the end users fired the stove as they normally did, using the fuel they normally used. The RTD partners were present and performed the measurements but did not give any advice nor interfered they. The second day the QUG was handed to the end users and they were told to fire according to the guide, using the fuel they normally used. Again, the RTD partners did not give any advices nor did they interfere. The third day, the RTD partners coached the end users to fire according to the beReal method and provided test fuel, i.e. the same quality they normally used at the test stand. During all field days, the total test time was approximately 7 hours, including ignition, nominal load during more than 3 hours and partial load during more than 2 hours. On testing day 1 and 2, emission measurements were conducted during every batch. On day 3, gaseous emission measurements were performed in every batch while PM measurements were conducted in every second batch (batch 1, 3, 5, 7).

2.2.2 Procedure for pellet stoves

The pellet stoves installed in the field were fired during three days. On day 1, the end user was told to use their normal procedure and fuel quality. RTD partners were observing but did not interfere or instruct. On day 2, the end user was told to use their normal procedure but to use RTD supplied fuel, i.e. the same quality they normally used at the test stand. RTD partners were observing but did not interfere nor instruct. On day 3, the end user was told to use the fuel delivered by RTD (same as day 2) and was coached by the RTD partners to fire according to beReal. Testing days 1 and 2 consisted of four different periods, ignition, steady state nominal load, regulated partial load (load change from nominal load to 50% partial load) and steady state partial load (50% of nominal load). The time duration for ignition was not specified. Steady state nominal load was considered reached when deviations in the flue gas temperature were below 5 K over a period of 10 min ($\Delta T \leq 5$ K/ 10 min). The total duration of this period was > 1 hour. The duration for regulated load was not specified. Steady state partial load was considered reached when $\Delta T \leq 5$ K/ 10 minutes. The total duration of steady state partial load again was > 1 hour.

For the pellet stoves, the emission measurements were performed in each of the four periods on day 1 and day 2. On day 3, the beReal procedure was followed.

2.3 Measurement evaluation

The results were evaluated by SP and six different methods were compared:

For firewood stoves they comprised:

1. Type test according to EN 13240, official results.

2. Type test according to EN 13240, results from RTD project partners, gained in test stand measurements.

3. beReal method, laboratory tests done by RTD partners.

4. beReal methon in field, day 1: End user normal procedure and normally used fuel.

5. beReal method in field, day 2: End user using QUG and normally used fuel.

6. beReal method in field, day 3: End user coached by RTD partner according to beReal. Fuel is of the same quality as the RTD partners use at the lab test stand.

For pellet stoves:

1. Type test according to EN 14785, official results.

2. Type test according to EN 14785, results from RTD project partners, gained in test stand measurements.

3. beReal method, laboratory tests done by RTD partners.

4. beReal method in field, day 1: End user normal procedure and normally used fuel.

7. beReal method in field, day 2: End user normal procedure. Fuel is of the same quality as the RTD partners use at the lab test stand.

8. beReal method in field, day 3: End user is coached by RTD partners according to beReal. Fuel is of the same quality as the RTD partners use at the lab test stand.

The measured emissions and calculated efficiency values are given as time weighted values in diagrams and in tables in the appendix. The results from the thirteen firewood stoves are given also in box-and-whisker diagrams. Box-and-whisker diagrams are one way to visualize results. Therefore, they are used here to compare the methods. The median value, the spread of the values, any skewness of the results, the maximum and the minimum value and any outliers are easily distinguishable, see Figure 3 for an example. In the middle of the box, there is the median value. The lower side of the box indicates the 25% range of the resulting values. The upper side of the box indicates the 75% range of the resulting values. The maximum and minimum values are indicated by the whiskers. In this report, outliers are defined as extreme values that are distant from the box more than 1.5 times the side of the box. Outliers do not affect the median value or the size of the box, only the length of the whiskers. All results in the box-and-whisker-diagrams are relative to the result gained from the beReal method measurement at the test stand. Therefore the value for beReal at the test stand is always 1.

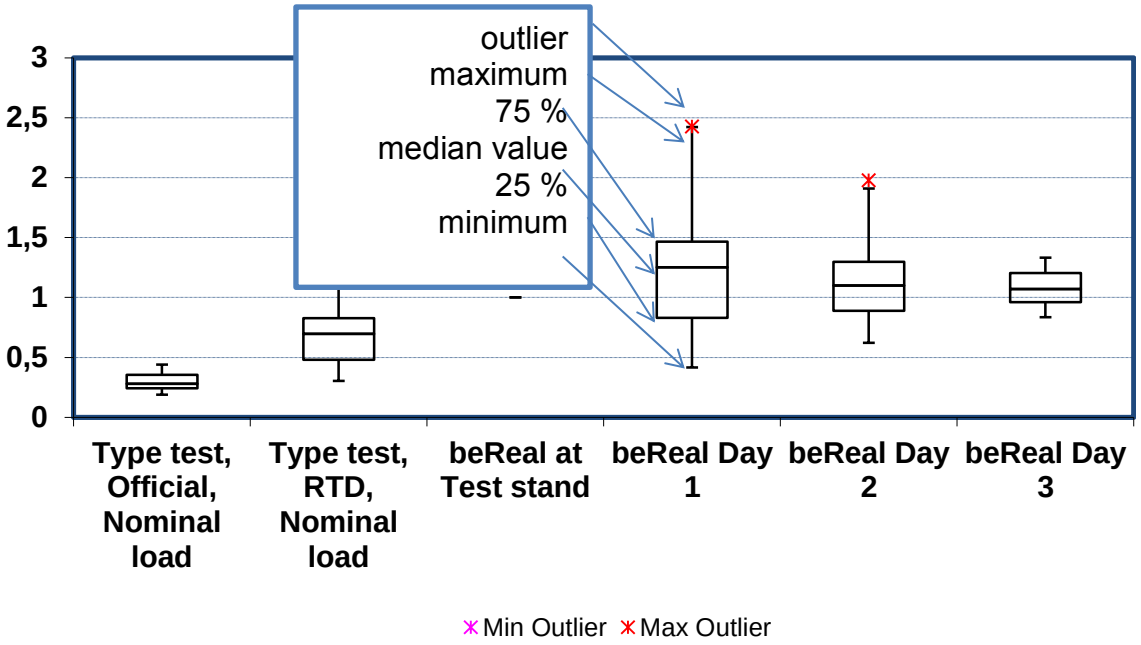

Figure 3. Example of a Box-and-whisker diagram where outliers, maximum, box size lengths and minimum were indicated. All values are relative to the result gained from the beReal method measurement at the test stand. Therefore the value for beReal at test stand is 1.

3 Results

Time averaged emission data and efficiency values are shown in bar graphs and in box-and-whisker diagrams and as average emission values in a table. All data can be found in Appendix 1.

3.1 Firewood stoves

Thirteen firewood stoves were tested in lab stand and in the field. The number of values is thirteen for all measurements, except for OGC, where one measurement failed during day 2 and as the official type test results were gathered from the manufacturers and OGC is not compulsory, those values are available for only 10 stoves.

Looking at the CO emissions in Figure 4 it is seen that official type test measurements display lowest emissions for all stoves, while type test measurements performed by the RTD partners in the lab test stand lead to the next lowest values for 12 stoves. This can also be seen in Table 3 where the average values for the different procedures are found. The largest emissions are found during the field testing days, for eight of the stoves during day 1 or day 2 and for three stoves during day 3. Three stoves (number 9, 11 and 13) have low emissions with less than 3000 mg/ Nm^3 during all test procedures.

Type tests by RTD partners and the days 1 and 2 in the field show the largest spread in numbers. For six stoves at day 1 and 2 the values are almost equivalent. Day 3 in the field and beReal at the test stand show comparable numbers for twelve stoves.

The box-and-whisker diagram in Figure 5 shows the same tendencies as explained above; lowest values for type tests, largest spread for day 1 and day 2, and a similarity between beReal at the test stand and day 3 in field. It can be concluded that all results for one respective stove comply quite well with the result gained from the beReal test at the test stand.

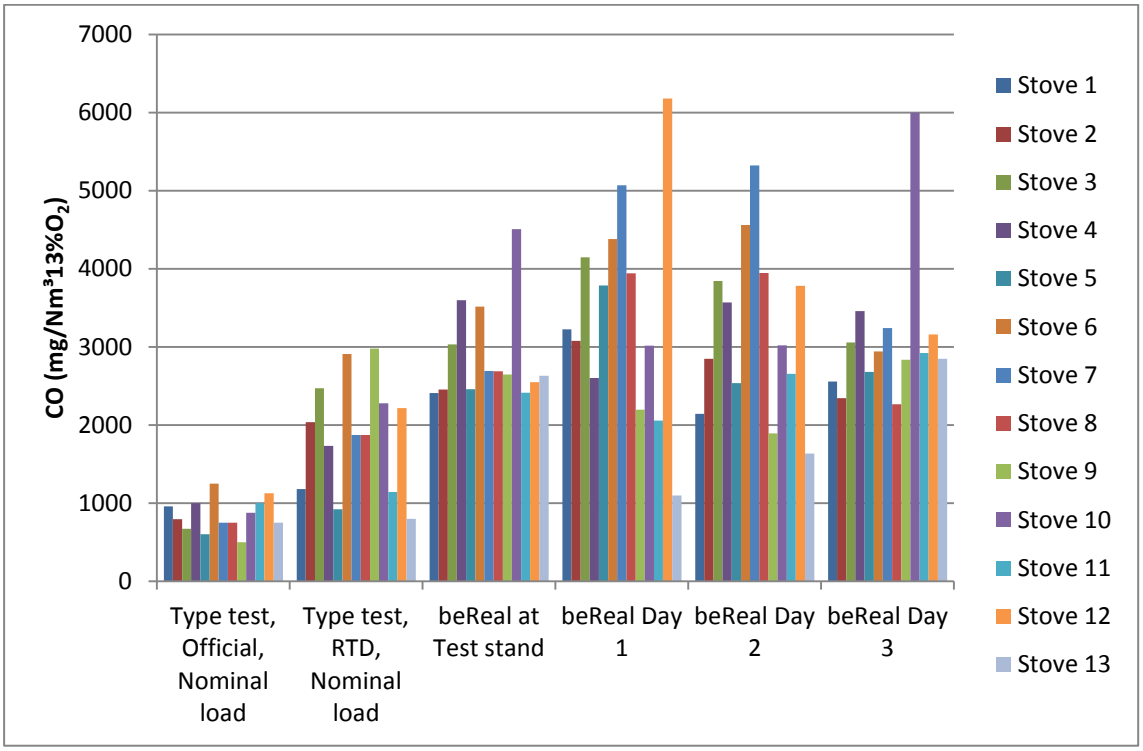

Figure 4. CO emissions from thirteen firewood stoves from different test procedures.

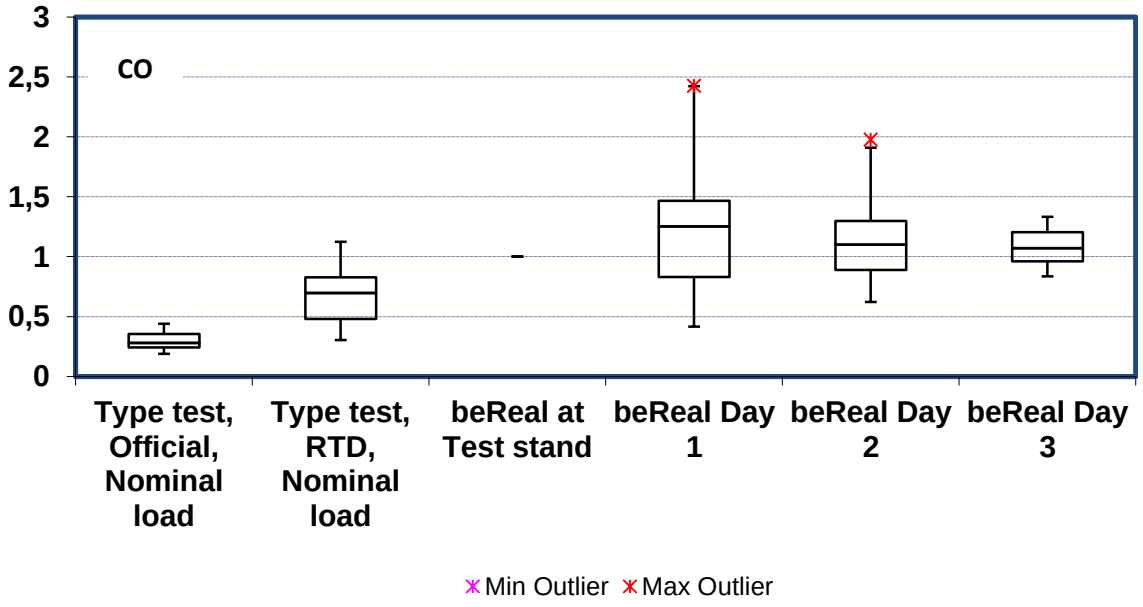

Figure 5. Box-and-whisker diagram showing CO emissions from firewood stoves. The number of values for all categories is 13. Outliers result from stove 12 on day 1 and stove 7 on day 2. All values are relative to the result gained from the beReal method measurement at the test stand. Therefore the value for beReal at test stand is set to 1.0.

Looking at the PM emissions in Figure 6, Figure 7 and Table 3 we see the same tendency that official type test measurements lead to lowest emission results for all stoves, and type test measurements performed by the RTD partners at the test stand result in the next lowest values

for 4 stoves. The highest emission results are found during the field days, for three stoves at day 1, two stoves at day 2 and five stoves at day 3. Two stoves have PM emissions close to 60 mg/Nm^3 for all procedures and four stoves are close to 60 mg/Nm^3 except for one procedure where the value is higher.

Looking at Figure 6 there is a spread in measured emissions from less than 10 mg/Nm^3 (official type test) to 150 mg/Nm^3. The spread during the field days are of the same magnitude for different days.

The box-and-whisker diagram (Figure 7) shows the same tendencies as explained above with lowest values for type test results. The spread in results is largest for day 1 but the difference between the three days in the field is small.

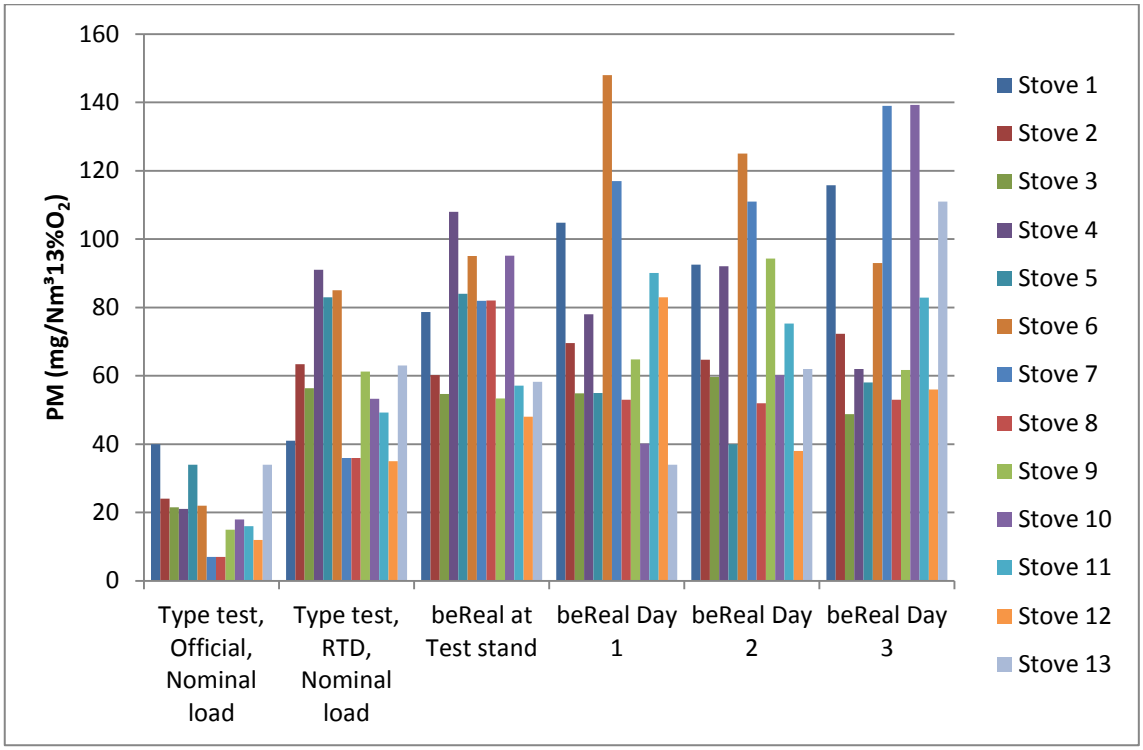

Figure 6. PM emissions from thirteen firewood stoves from different test procedures.

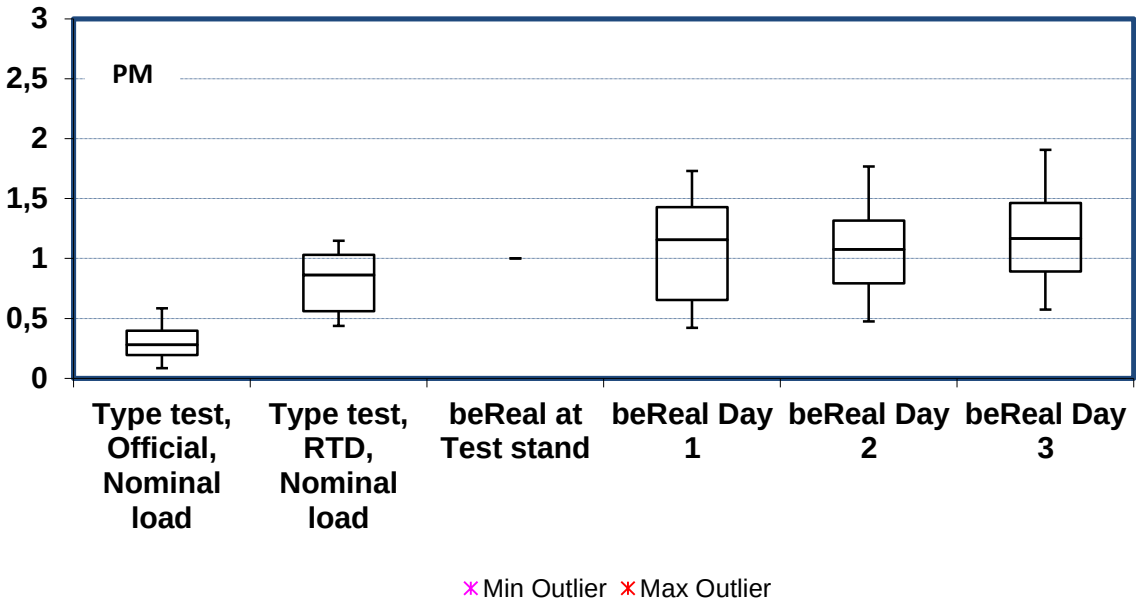

Figure 7. Box-and-whisker diagram showing PM emissions from thirteen firewood stoves. The number of values for all categories is 13. All values are relative to the result gained from the beReal method measurement at the test stand. Therefore the value for beReal at the test stand is set to 1.0.

Looking at the OGC emissions in Figure 8 we see the same tendency that official type test measurements result in lowest emissions for all stoves while type test measurements performed by RTD partners at the test stand show the next lowest results for ten stoves. The highest emissions is found during the field days, but there is a large spread between the results. Stove 6 and stove 10 have high emissions of OGC, see Table 4, as well as high emissions of CO.

Looking at Figure 8, the stoves 1-4 exceed 400 mg/Nm³ for OGC in each test procedure except for the official type test.

The box-and-whisker diagram in Figure 9 shows the same tendencies as explained above with lowest values for type tests, the largest spread for day 1 and day 2 and a similarity between beReal at the test stand and day 3 in the field.

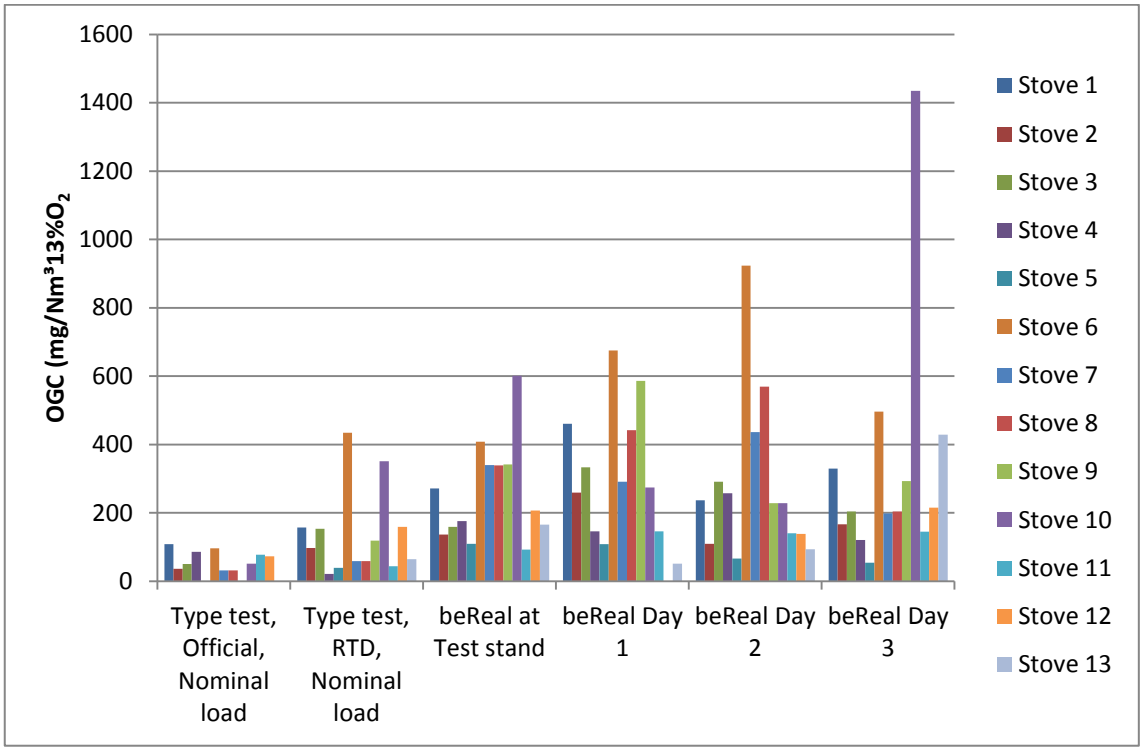

Figure 8. OGC emissions from thirteen firewood stoves from different test procedures

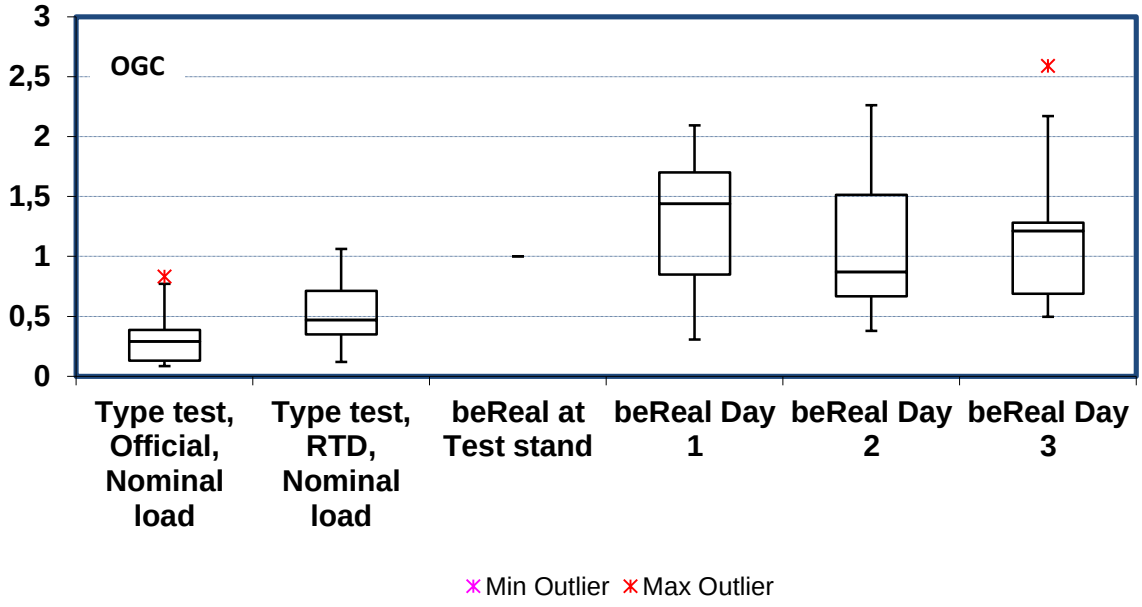

Figure 9. Box-and-whisker diagram showing OGC emissions from firewood stoves. The number of values for official type test results is 10, for beReal Day 1 is 12, and for all other categories it is 13. Outliers are from different stoves. All values are relative to the result gained from the beReal method measurement at the test stand. Therefore the value for beReal at the test stand is set to 1.0.

The calculated efficiencies are highest for the official type tests, see Figure 10 and Figure 11. The average in Table 4 is 81% for the official type test and 70% for type test done by RTD partners and beReal in test stand. From the field days the average is 65%.

The largest spread in the results is seen from the field testing days. The lowest value is found for stove 7 with 62% on average and the best for stove 10 and stove 11, with 74%.

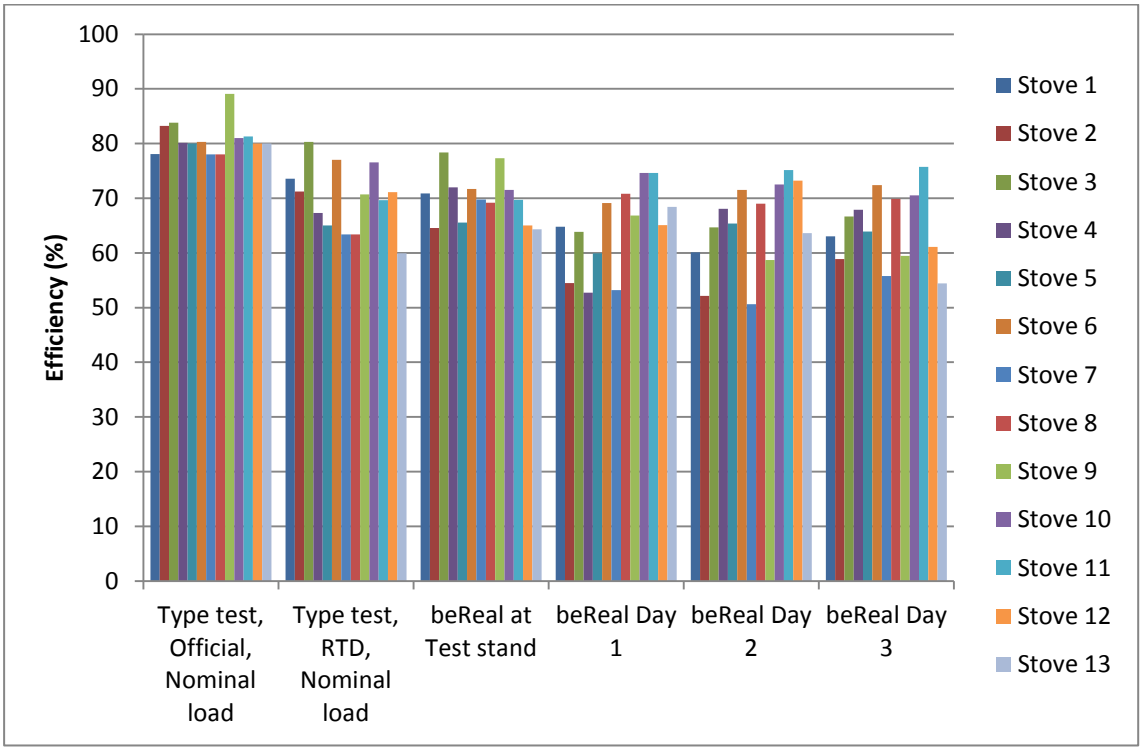

Figure 10. Efficiencies of thirteen firewood stoves from different test procedures.

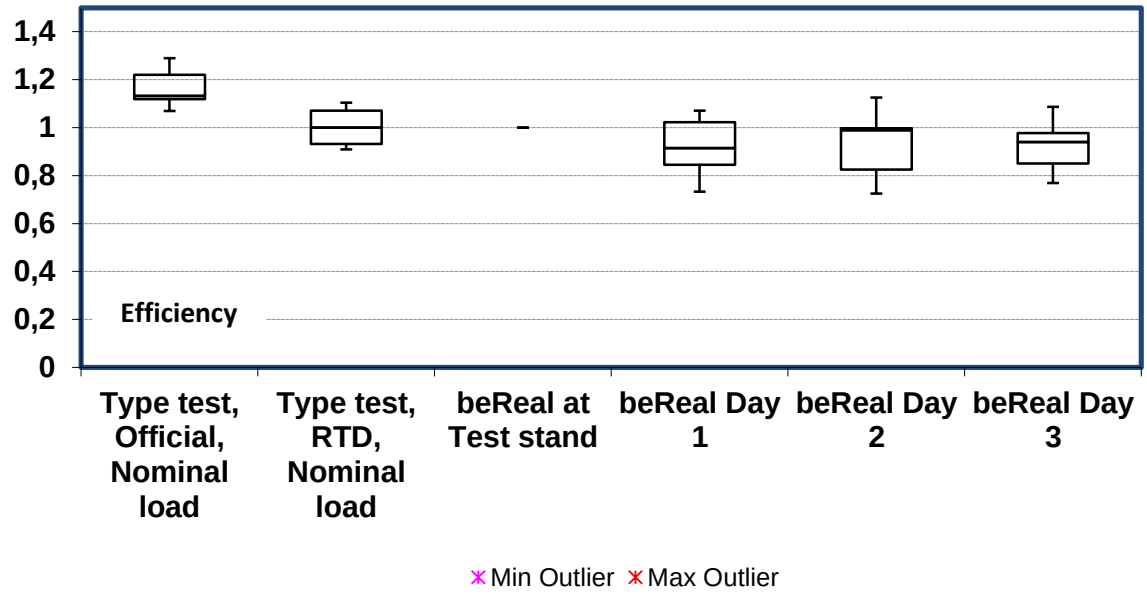

Figure 11. Box-and-whisker diagram showing efficiencies of thirteen firewood stoves. The number of values for all categories is 13. All values are relative to the result gained from the beReal method measurement at the test stand. Therefore the value for beReal at test stand is set to 1.0.

Table 3. Average values for emissions and efficiencies versus procedures, firewood stoves.

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

Table 4. Average values for emissions and efficiencies versus stoves, firewood stoves

Stove	CO ($mg/Nm^3 13\% O_2$)	PM ($mg/Nm^3 13\% O_2$)	OGC ($mg/Nm^3 13\% O_2$)	Efficiency (%)
Stove 1	2078	79	260	68.4
Stove 2	2257	59	134	64.1
Stove 3	2869	49	199	72.9
Stove 4	2659	75	135	68.0
Stove 5	2163	59	75	66.6
Stove 6	3258	95	505	73.7
Stove 7	3157	82	226	61.8
Stove 8	2577	47	274	70.0
Stove 9	2174	58	314	70.4

Stove 10	3282	68	490	74.3
Stove 11	2031	62	107	74.4
Stove 12	3168	45	132	69.3
Stove 13	1626	60	161	65.1

3.2 Pellet stoves

Four pellet stoves were tested at the test stand and in the field. The number of values is four for all measurements. As four measurement values are a small basis for statistical evaluation, no box-and-whisker diagrams are presented. The results in the bar graphs shall therefore be considered rather qualitatively than quantitatively. However, as pellet stoves are known for a stable operation and combustion behaviour, the results can still be used to indicate results.

The efficiency values are best for the official type test. However, the differences between the different methods are quite small, see Figure 12, Figure 13, Figure 14, and Table 5. Efficiency results are given in Figure 15. Stove three has the highest emission values for CO and OGC but also the highest efficiency.

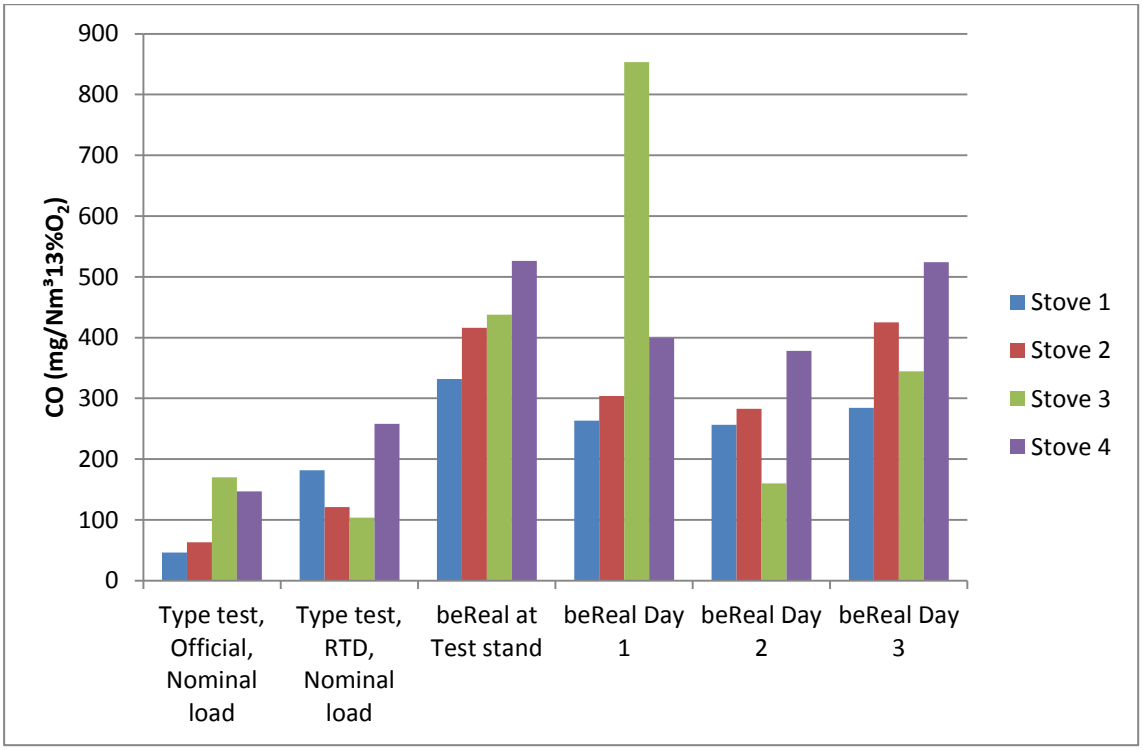

Figure 12. CO emissions from four pellet stoves from different test procedures.

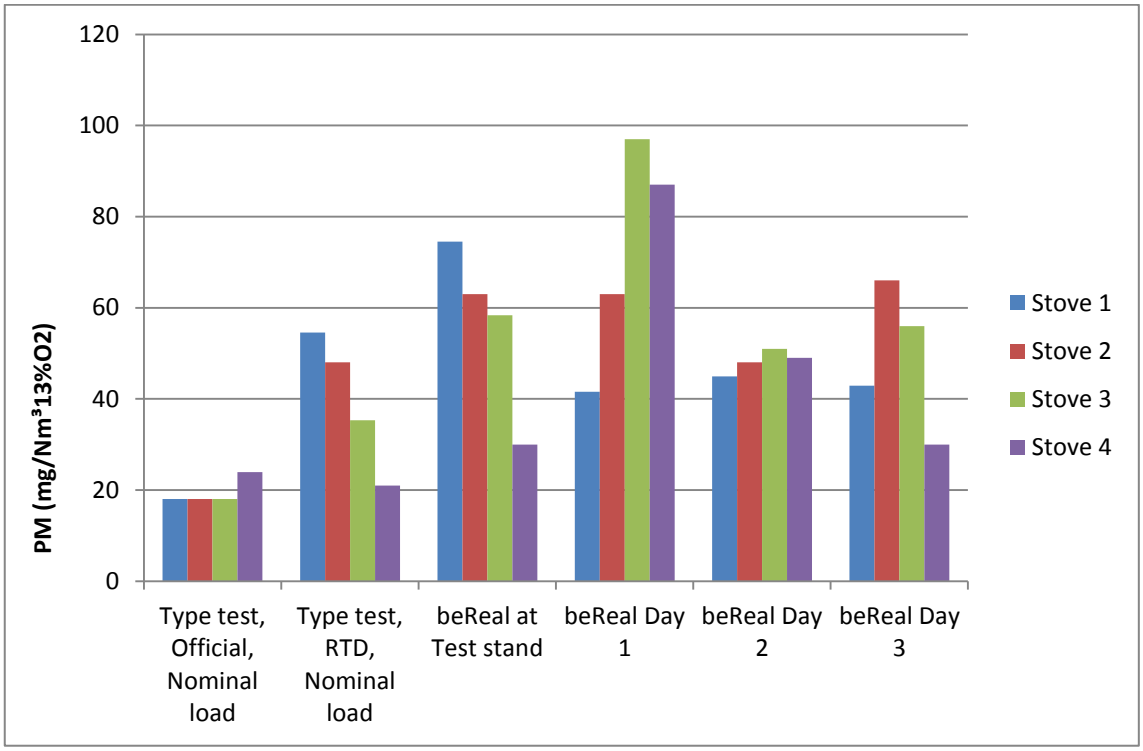

Figure 13. PM emissions from four pellet stoves from different test procedures.

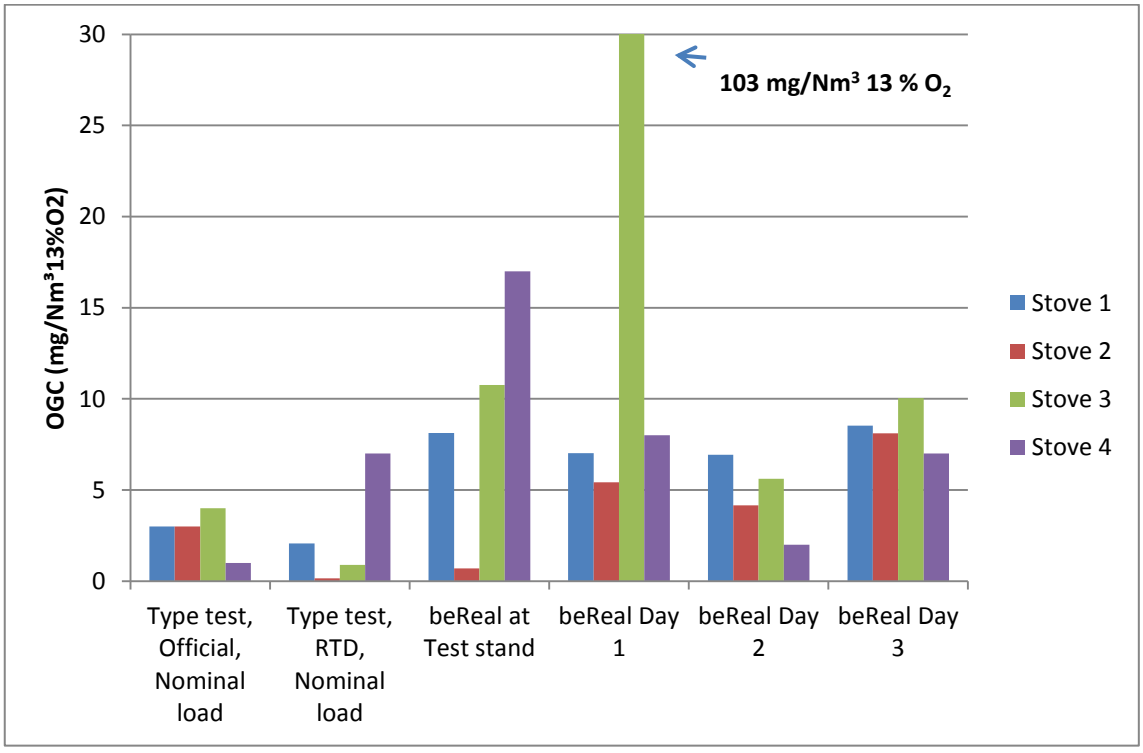

Figure 14. OGC emissions from four pellet stoves from different test procedures.

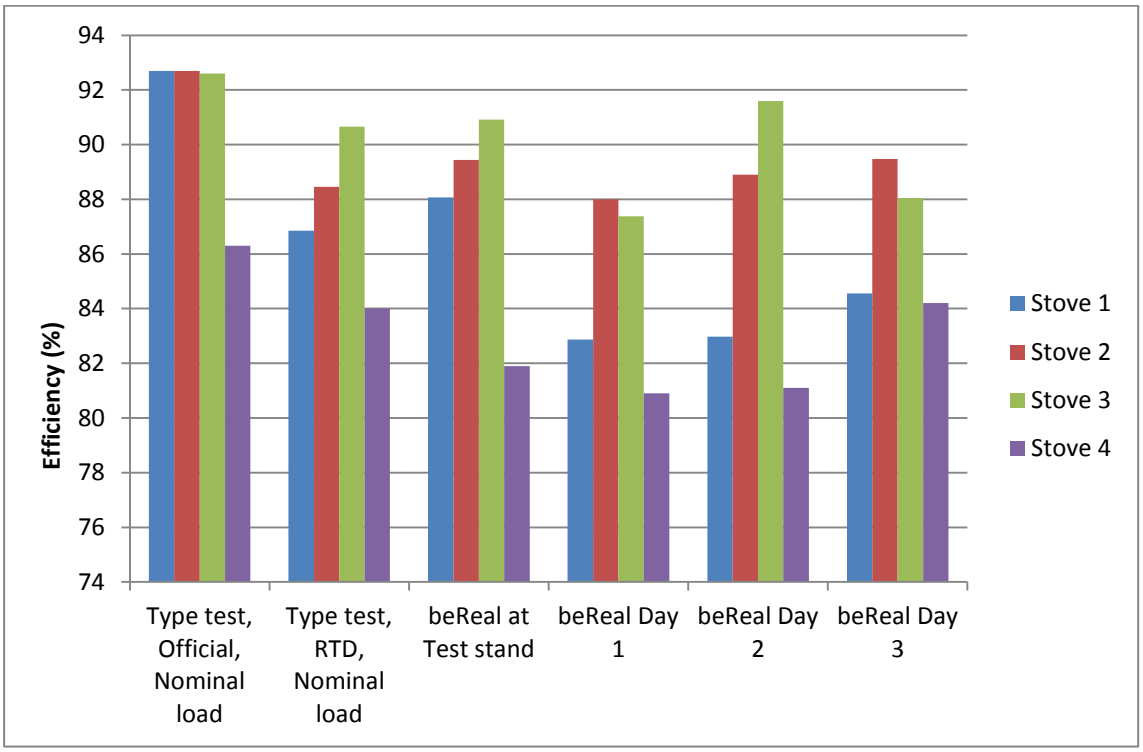

Figure 15. Efficiencies of pellet stoves from different test procedures.

Table 5. Average values for emissions and efficiencies versus procedures, pellet stoves.

	Type test, Official, Nominal load	Type test, RTD, Nominal load	beReal at Test stand	beReal Day 1	beReal Day 2	beReal Day 3
CO ($mg/Nm^3 13\%O_2$)	107	166	428	455	269	394
PM ($mg/Nm^3 13\%O_2$)	19	40	56	72	48	49
OGC ($mg/Nm^3 13\%O_2$)	3	3	9	31	5	8
Efficiency (%)	91	87	88	85	86	86

Table 6. Average values for emissions and efficiencies versus stoves, pellet stoves

Stove	CO ($mg/Nm^3 13\%O_2$)	PM ($mg/Nm^3 13\%O_2$)	OGC ($mg/Nm^3 13\%O_2$)	Efficiency (%)
Stove 1	227	46	6	86
Stove 2	269	51	4	89
Stove 3	345	53	22	90
Stove 4	372	40	7	83

4 Summary and Discussion

The following parameters were measured and/ or calculated: CO, OGC, PM and efficiency for thirteen firewood stoves and four pellet stoves. The tests were arranged to give answers to the following questions:

- Is it possible to perform laboratory tests that truly reflect normal field conditions?
- Is it possible to improve combustion results by giving instructions to the end user?
- How much does the fuel quality influence the combustion results at pellet stoves?
- How do type test results differ from beReal results and do they differ by a constant factor?

4.1 Firewood stoves

Even though there is a spread in results, some general conclusions can be drawn. For the emissions, the official type test results are lower than the beReal results, and the type tests performed at the RTD test stand (by RTD partners) is lower than the beReal results. This becomes obvious from the box-and-whisker diagrams in Figure 5, Figure 7 and Figure 9 and from Table 3 with the given average values. Results from beReal at the test stand and the three field days are on a slightly higher, but between themselves, on a comparable level.

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

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

The efficiencies are best for the official type tests. Type tests made by RTD partners and the beReal results at the test stand are the same; the beReal value in the field shows almost the same result. As shown in the appendix, thermal efficiency tends to decrease at higher draught conditions. The effect depends most probably on appliance specifics.

Results from beReal tests performed in the field using the test fuel and coached by the RTD partner (day 3) are close to results from beReal performed in laboratory and this indicates that it is possible to perform laboratory tests that truly reflect normal field conditions.

For the firewood stoves, the emissions improved between day 1 and day 2. In addition, the spread in the results diminished. During these days, the same fuel was used. This indicates that an immediate and considerable benefit is gained due to improved combustion results by giving instructions to the end user.

In Table 7 the emission results from the official type tests are divided with the results from beReal at lab stand (column 2-5) and the emission results from the RTD type tests are divided with the results from beReal at lab stand (column 6-9). From the results, it becomes obvious that no constant factor can be applied to the official type test result to reach the beReal result.

Table 7. Comparison between the results from official type tests and beReal measurements at test stands, and between RTD type tests and beReal at test stands for firewood stoves.

	Official Type test / beReal @ test stand				**RTD Type test / beReal @ test stand**			
Stove No.	**CO**	**OGC**	**PM**	**efficiency**	**CO**	**OGC**	**PM**	**efficiency**
1	0,40	0,40	0,51	1,10	0,49	0,58	0,52	1,04
2	0,32	0,26	0,40	1,29	0,83	0,71	1,05	1,10
3	0,22	0,32	0,39	1,07	0,81	0,96	1,03	1,02
4	0,28	0,49	0,19	1,11	0,48	0,12	0,84	0,93
5	0,24		0,40	1,22	0,37	0,36	0,99	0,99
6	0,36	0,24	0,23	1,12	0,83	1,06	0,89	1,07
7	0,28	0,09	0,09	1,12	0,70	0,17	0,44	0,91
8	0,28	0,09	0,09	1,13	0,70	0,17	0,44	0,92
9	0,19		0,28	1,15	1,11	0,30	1,26	0,90
10	0,19	0,08	0,19	1,13	0,50	0,68	0,65	1,06
11	0,41	0,83	0,28	1,17	0,37	0,33	0,81	0,99
12	0,44	0,35	0,25	1,23	0,87	0,77	0,73	1,09
13	0,29		0,58	1,24	0,30	0,39	1,08	0,93
Mean	***0,30***	***0,29***	***0,30***	***1,16***	***0,64***	***0,51***	***0,83***	***1,00***
st.d.	*0,08*	*0,22*	*0,15*	*0,06*	*0,23*	*0,30*	*0,25*	*0,07*

4.2 Pellet stoves

It should be taken into consideration that the number of tested pellet stoves is only four, so the statistical basis is small.

For the pellet stoves, the widest spread in emission results is found for day 1 in the field, when the end users are using their usual fuel. The spread of results is lower on day 2 when the fuel is changed to test fuel.

For pellet stoves, the typical OGC emissions are in a rather low range, except stove 3 on day 1. Sometimes the measured emission values are close to the measurement uncertainty of the measurement device. Low measurement values lead to difficulties in an exact measurement of OGC and lead to high uncertainties and large factors when comparing two values even if they are in the same range of measurement values.

Results from day 3 in the field shall be compared to the beReal result at the test stand because the same fuel is used with the beReal method in the field. The difference is small. For the pellet stoves, there are few possibilities to influence the combustion and the difference between day 2 and day 3, where the end user is coached by the RTD partner, is small.

The efficiencies are best for the official type test, but the differences are small.

Results from beReal tests performed in the field using the test fuel (day 3) are close to results from beReal measurements performed at the test stand and by that it is shown that it is possible to perform laboratory tests that truly reflect usual field conditions.

It is clear that the choice of fuels influences the combustion result. For the pellet stoves, there is a difference between day 1 and day 2 when the fuel is changed. Obviously, pellets used by the RTD partners show improved results both in terms of emissions and in efficiency. In addition, the spread of the results is lower and the level of the median value improved compared with day 1, which indicates an optimum behaviour and increased operation reproducibility.

In Table 8 the emission results from the official type tests are divided with the results from beReal at lab stand (column 2-5) and the emission results from the RTD type tests are divided with the results from beReal at lab stand (column 6-9). From the results, it becomes obvious that no constant factor can be applied to the official type test result to reach the beReal result.

Table 8. Comparison between the results from official type tests and beReal measurements at test stands, and between RTD type tests and beReal at test stands for pellets stoves.

	Official Type test / beReal @ test stand				**RTD Type test / beReal @ test stand**			
Stove No.	**CO**	**OGC**	**PM**	**efficiency**	**CO**	**OGC**	**PM**	**efficiency**
1	0,14	0,37	0,24	1,05	0,55	0,25	0,73	0,99
2	0,15	4,35	0,29	1,04	0,29	0,23	0,76	0,99
3	0,39	0,37	0,31	1,02	0,24	0,08	0,61	1,00
4	0,28	0,00	0,80	1,05	0,49	0,41	0,70	1,03
Mean	***0,24***	***1,27***	***0,41***	***1,04***	***0,12***	***0,08***	***0,22***	***0,31***
st.d.	*0,10*	*1,78*	*0,23*	*0,01*	*0,13*	*0,12*	*0,06*	*0,02*

4.3 Differences between type tests and beReal, and between official type tests and type tests performed by beReal partners

For the firewood stoves, the emissions from the beReal test method are largely higher than the official type test results; this was expected because the beReal method considers emissions during the whole batch (from opening the stove door for recharging until the next opening of the door) and also takes partial load operation into consideration. The type test method only takes into account a stationary phase of the combustion. In the beReal-procedure eight successive batches are included. In contrast, in the type test, three non-consecutive batches are chosen out of an unlimited number of batches.

5 Appendix 1: Effect of connecting pipe on thermal efficiency/ Additional tests: Effect of different draught levels (at pellet stoves)

5.1 Effect of length of connecting pipe

To evaluate the effect of the connecting flue gas pipe (the influence of the flue gas pipe between stove outlet and chimney inlet) on the thermal efficiency, measurements and calculations were performed.

- Calculation of thermal heat losses using the temperature 33 cm downstream of the outlet (T_{core}).
- Calculation of thermal heat losses using the temperature just before the chimney entry downstream of the flue gas outlet ($T_{chimney\ inlet}$).

See Figure 16 for position of temperature measurements.

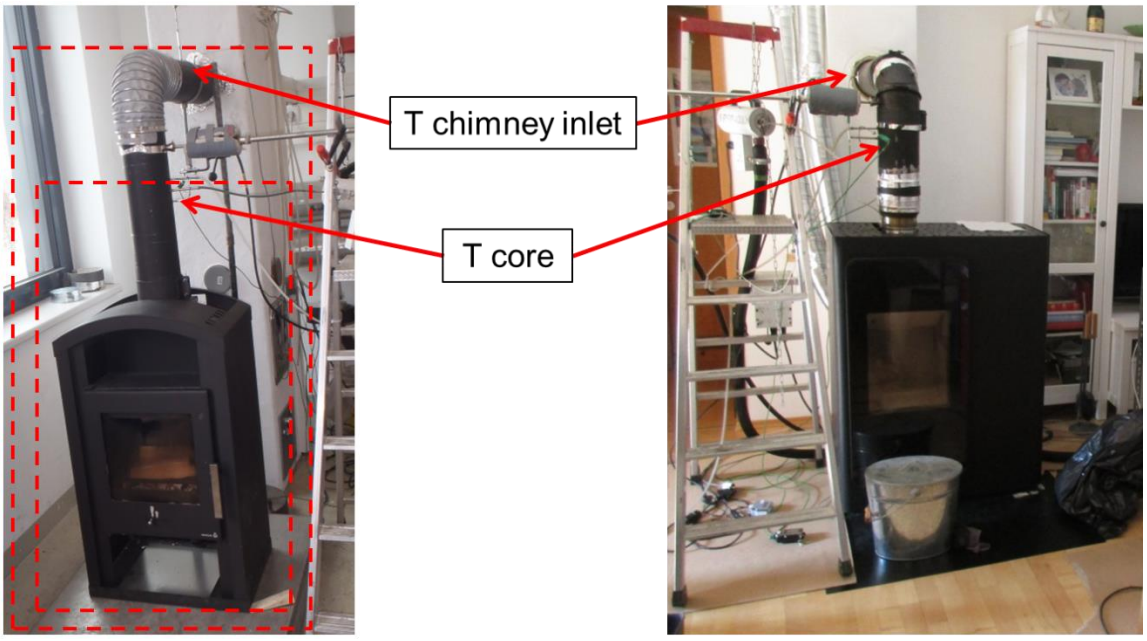

Figure 16. Position of (T_core) and (T_chimney_inlet).

The measurements showed clearly better efficiencies at evaluation with $T_{chimney\ inlet}$, see Figure 17. The difference correlates with the distance, but the seemed linearity is incidental, since the physical correlation is an exponential function, not a linear. Anyhow, in real life efficiency is higher with longer pipe, because more heat can dissipate into the room.

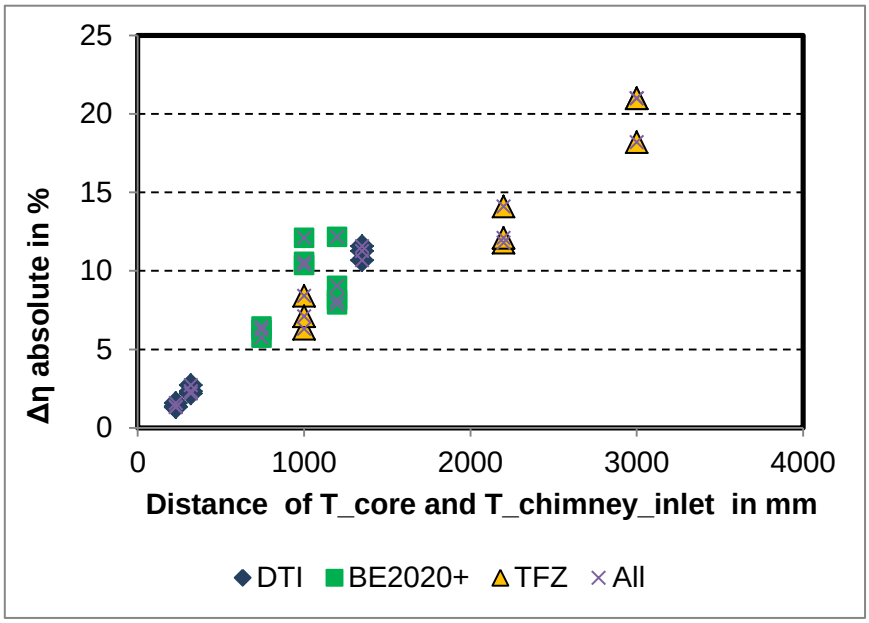

Figure 17. Difference in efficiency as function of distance between the temperature measurements.

5.2 Effect of draught conditions

To evaluate the effect of draught on emissions and efficiency at pellet stoves additional tests were performed. The beReal cycle was applied to three different pellet stoves at 12 Pa, 24 Pa and 48 Pa. Data from the measurements are found in Table 11.

For pellet stove 1, no clear correlation of gaseous emissions (CO and OGC) and higher draught level could be found, see Figure 18 and Figure 19. For pellet stove 2, the gaseous emissions decreased at higher draught level. For pellet stove 3 the gaseous emissions increased at higher draught level.

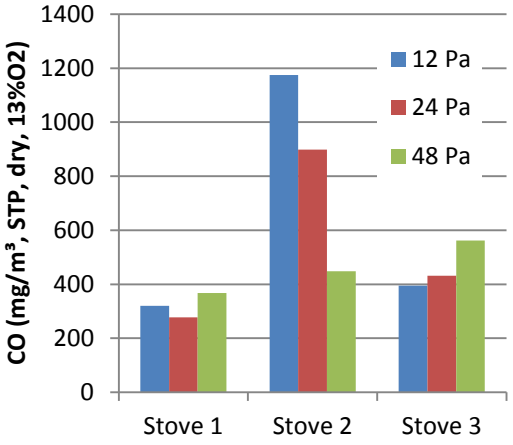

Figure 18. Results from CO measurements.

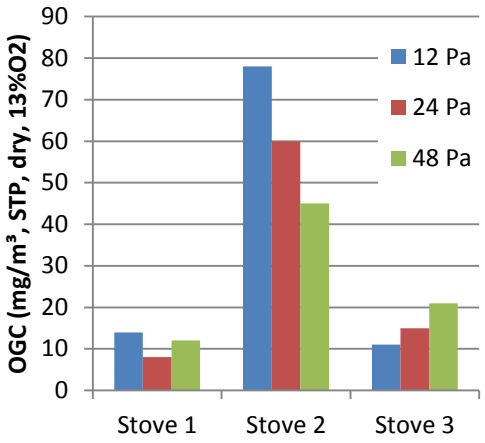

Figure 19. Results from OGC measurements.

For pellet stoves 1 and 2 the PM levels were on a comparable level independent of draught, see Figure 20. For pellet stove 3 no clear correlation between PM emissions and higher draught level could be found, but an increase compared to 12 Pa.

The efficiency decreased for pellet stove 1 at higher draught levels, see Figure 21. For pellet stove 2 no effect could be seen of draught level on efficiency. For pellet stove 3 no clear correlation could be found.

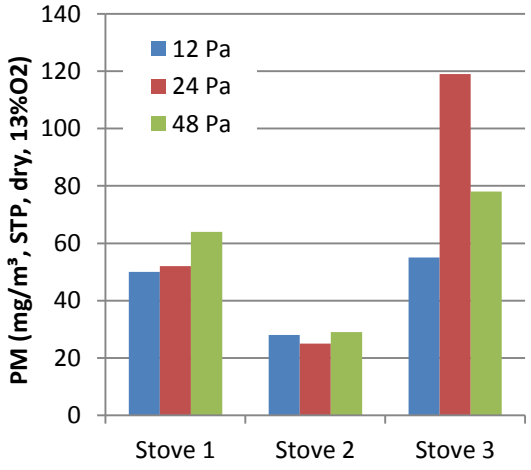

Figure 20. Results from PM measurements.

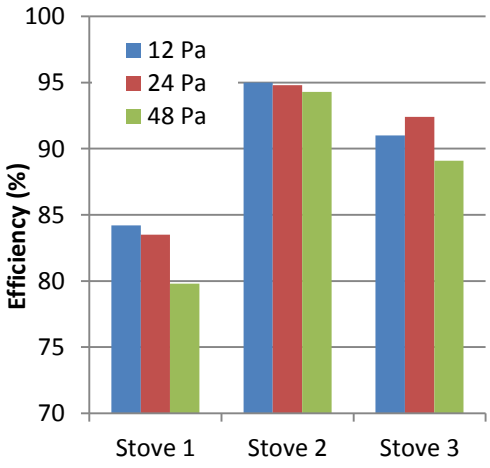

Figure 21. from efficiency calculations.

5.3 Summary of additional tests

It is clear that higher draught conditions can influence the combustion quality of pellet stoves. No general trend was found for the tested appliances. It seems like emissions can increase, decrease or remain equal at higher draught conditions. Thermal efficiency tends to decrease at higher draught conditions. The effect depends most probably on appliance specifics.

6 Appendix 2: Data from the tests

Results from the tests are given in Table 9 for firewood stoves, and in Table 10 for pellet stoves.

Table 9. Results from the tests on firewood stoves. The numbering is not in accordance with any presentation. N.A .= not available

	Evaluation with time weighted values				
	Test	**CO**	**OGC**	**PM**	**efficiency**
		(mg/Nm³13%O_2)	**(mg/Nm³13%O_2)**	**(mg/Nm³13%O_2)**	**(%)**
Stove 1	Type test, Official	959	108	40	78.1
	Type test, RTD	1180	157	41	73.5
	beReal at test stand	2410	272	79	70.9
	beReal Day 1	3223	460	105	64.8
	beReal Day 2	2143	236	93	60.1
	beReal Day 3	2554	329	116	63.0
Stove 2	Type test, Official	792	36	24	83.2
	Type test, RTD	2035	97	63	71.2
	beReal at test stand	2454	136	60	64.5
	beReal Day 1	3075	259	70	54.5
	beReal Day 2	2845	109	65	52.2
	beReal Day 3	2342	166	72	58.8
	beReal Day 3a	3238	253	83	49.6
Stove 3	Type test, Official	672	51	22	83.8
	Type test, RTD	2470	154	56	80.3
	beReal at Test stand	3033	159	55	78.4
	beReal Day 1	4146	333	55	63.8
	beReal Day 2	3841	291	60	64.6
	beReal Day 3	3054	204	49	66.7
Stove 4	Type test, Official	1000	86	21	80.1
	Type test, RTD	1732	21	91	67.3
	beReal at test stand	3595	176	108	72.0
	beReal Day 1	2599	146	78	52.8
	beReal Day 2	3570	257	92	68.1
	beReal Day 3	3459	121	62	67.9
Stove 5	Type test, Official	600	N.A.	34	80.0
	Type test, RTD	920	39	83	65.0
	beReal at test stand	2459	109	84	65.6
	beReal Day 1	3784	108	55	59.9
	beReal Day 2	2534	66	40	65.4
	beReal Day 3	2678	54	58	63.9

Stove 6	Type test, Official	1250	96	22	80.3
	Type test, RTD	2907	434	85	77.0
	beReal at test stand	3513	408	95	71.7
	beReal Day 1	4379	675	148	69.1
	beReal Day 2	4559	923	125	71.5
	beReal Day 3	2940	496	93	72.4
Stove 7	Type test, Official	750	32	7	78.0
	Type test, RTD	1872	58	36	63.4
	beReal at test stand	2689	339	82	69.7
	beReal Day 1	5069	291	117	53.2
	beReal Day 2	5320	436	111	50.6
	beReal Day 3	3242	198	139	55.8
Stove 8	Type test, Official	750	32	7	78.0
	Type test, RTD	1872	58	36	63.4
	beReal at test stand	2689	339	82	69.2
	beReal Day 1	3943	442	53	70.8
	beReal Day 2	3946	569	52	69.0
	beReal Day 3	2264	204	53	69.9
Stove 9	Type test, Official	500	N.A.	15	89.1
	Type test, RTD	2979	119	61	70.7
	beReal at test stand	2647	342	53	77.3
	beReal Day 1	2196	586	65	66.8
	beReal Day 2	1891	228	94	58.7
	beReal Day 3	2834	293	62	59.5
Stove 10	Type test, Official	875	51	18	81.0
	Type test, RTD	2278	351	53	76.1
	beReal at test stand	4506	601	95	71.5
	beReal Day 1	3016	274	40	74.6
	beReal Day 2	3018	228	60	72.5
	beReal Day 3	5999	1435	139	70.5
Stove 11	Type test, Official	1000	77	16	81.3
	Type test, RTD	1142	44	49	69.0
	beReal at test stand	2413	93	57	69.7
	beReal Day 1	2057	146	90	74.4
	beReal Day 2	2656	140	75	72.5
	beReal Day 3	2920	145	83	70.5
Stove 12	Type test, Official	1125	73	12	80.0
	Type test, RTD	2216	159	35	71.1
	beReal at test stand	2547	207	48	65.0
	beReal Day 1	6180	N.A.	83	65.1
	beReal Day 2	3780	138	38	73.2
	beReal Day 3	3157	215	56	61.1

Stove 13	Type test, Official	750	N.A.	34	80.0
	Type test, RTD	798	64	63	59.9
	beReal at test stand	2629	166	58	64.3
	beReal Day 1	1097	51	34	68.4
	beReal Day 2	1635	93	62	63.6
	beReal Day 3	2848	429	111	54.4

Table 10. Results from the tests on pellet stoves. The numbering is not in accordance with any presentation.

	Evaluation with time weighted values				
	Test	**CO**	**OGC**	**PM**	**efficiency**
		(mg/Nm³13%O_2)	**(mg/Nm³13%O_2)**	**(mg/Nm³13%O_2)**	**(%)**
Stove 1	Type test, Official, Nominal load	46	3	18	92.7
	Type test, Official, Partial load	171	3	20	97.3
	Type test, RTD, Nominal load	182	2	55	86.9
	Type test, RTD, Partial load	191	2	39	86.3
	beReal at Test stand	332	8	75	88.1
	beReal Day 1	263	7	42	82.9
	beReal Day 2	256	7	45	83.0
	beReal Day 3	2554	329	116	63.0
Stove 2	Type test, Official, Nominal load	63	3	18	92.7
	Type test, RTD, Nominal load	121	0	48	88.5
	beReal at Test stand	416	1	63	89.4
	beReal Day 1	304	5	63	88.0
	beReal Day 2	283	4	48	88.9
	beReal Day 3	425	8	66	89.5
	Type test, Official, Nominal load	63	3	18	92.7
Stove 3	Type test, Official, Nominal load	170	4	18	92.6
	Type test, Official, Partial load	148	3	16	91.7
	Type test, RTD, Nominal load	41	1	35	85.0
	Type test, RTD, Partial load	1817	122	111	80.5
	beReal at Test stand	438	11	58	90.9
	beReal Day 1	854	103	76	87.4
	beReal Day 2	160	6	40	91.6

	beReal Day 3	344	10	49	88.0
Stove 4	Type test, Official, Nominal load	147	1	24	86.3
	Type test, RTD, Nominal load	258	7	21	84.0
	beReal at Test stand	526	17	30	81.9
	beReal Day 1	399	8	87	80.9
	beReal Day 2	378	2	49	81.1
	beReal Day 3	524	7	30	84.2

Table 11. Results from measurements on three pellet stoves with three different draughts. Fuel used is the pellet normally used by RTD partner at test stand.

	Pellet stove 1			**Pellet stove 2**			**Pellet stove 3**		
	12 Pa	**24 Pa**	**48 Pa**	**12 Pa**	**24 Pa**	**48 Pa**	**12 Pa**	**24 Pa**	**48 Pa**
CO (mg/m³, STP, dry, 13%O_2)	320	278	367	1175	898	448	395	432	562
OGC (mg/m³, STP, dry, 13% O_2)	14	8	12	78	60	45	11	15	21
NOx (mg/m³, STP, dry, 13% O_2)	201	202	218	121	119	119	120	95	106
Eta (%)	84.2	83.5	79.8	95	94.8	94.3	91	92.4	89.1
PM (mg/m³, STP, dry, 13% O_2)	50	52	64	28	25	29	55	119	78
T_flue gas (°C)	152	154	156	68	71	73	101	98	108
O_2 (%)	14.5	14.7	15.8	11.6	11.9	12.7	13.5	12.2	13.6
Lambda	3.2	3.3	4	2.4	2.5	2.8	2.9	2.5	3.3
average THO (kW)	5.48	5.09	5.21	7.11	7	7.09	3.97	4.48	4.05

7 Literature

[1] EN 13240:2001 + AC:2003: Roomheaters fired by solid fuel – Requirements and test methods, Austrian institute for standardization, Vienna, 2003

[2] EN 14785:2006: Residential Space heating appliances fired by wood pellets – Requirements and test methods, Austrian institute for standardization, Vienna, 2006

8 List of figures

9 List of tables