DEVELOPMENT OF A TEST PROCEDURE TO REFLECT THE REAL LIFE OPERATION OF PELLET STOVES

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ABSTRACT: Emission and energy efficiency thresholds of certification standard testing procedures for biomass room heating appliances tightened considerably during the last decades. This caused an enormous technological improvement in current stoves. As a consequence, recent pellet stoves perform excellently under type test conditions. In contrast, typical real life emissions show significantly higher values under usual operation conditions. Consequently, type testing procedures may not account for real life stove operation and, thus, do not allow to distinguish between low- and high-tech appliances. Therefore, the presented research aimed at the development of a testing method for pellet stoves that better reflects the real life operation and to support innovative pellet stoves that perform well under typical operational conditions. Based on an online survey and field observations an advanced real life testing procedure for pellet stoves was established reflecting real life user behavior and also regarding different load levels and the ignition phase. The respective method was evaluated at the test bench using different pellet stoves.
Keywords: Small scale application, solid biofuel, pellet stove, emissions, quality standards.

1 INTRODUCTION AND OBJECTIVES

Small-scale residential solid biomass combustion units can have major impact on ambient air quality due to emissions of potentially hazardous pollutants [1]. To increase air quality requirements while simultaneously supporting an increasing amount of small scale biomass heating applications it is crucial to ensure the operation of these appliances at low emissions of compounds such as carbon monoxide (CO), organic gaseous carbon (OGC) and particulate matter (PM). To reach this aim, the requirements for emissions measured during type testing tightened considerably leading to an extensive technological progress thus allowing the appliances to reach the respective threshold values on the test stand. But on the contrary current type testing procedures do not reflect an operation in real-life [2] and no evaluation of the appliance's technological quality concerning emissions and efficiency in daily use can be drawn.

Pellet stoves are used as main or important sources for heat supply and might gain even higher importance with an increasing number of low-energy-buildings where reduced heat demand is foreseen [3]. For pellet stoves the discrepancy between standard tests and real life operation is given by the fact that standard tests are performed at stable load and under stationary conditions over 2 to 3 hours duration per load level regarded [4]. Neither first ignition, start-stop phases nor load changes or cleaning intervals are considered while in real life operation they occur frequently. Therefore, real life emissions with typically higher values under usual operation conditions are caused by the combustion system's technology and the fuel quality, but may also be attributed to the end-user's operational misbehavior [5].

To differentiate between appliances that operate poorly or optimal under real life conditions a refined test method for pellet stoves was developed reflecting typical operation conditions and user behavior as they are found in real life appliances. This method should then support further technological improvement leading to sophisticated appliances and setting a new standard for clean and efficient small-scale pellet combustion systems.

2 MATERIAL AND METHODS

2.1 Online survey

A European online survey was performed to investigate and assess typical stove operation modes and end-user behavior under real life conditions [6]. The multi-lingual online survey raised 28 questions and was conducted over a 14 weeks duration. For pellet stoves 183 responses mainly from 4 European countries (Italy, Germany, Austria, Sweden) were received.

Topics of the questionnaire comprised aspects related to the heating appliance:

- its age,
- its heat output,
- hot water production (stove with water jacket);

parameters referring to the installation of the stove:

- the area heated with the stove,
- the supply of combustion air,
- the chimney to which the stove is connected;

but also significant influencing aspects due to user behavior during operation:

- operation hours in total, per day, per heating cycle,
- the controlling of the heat output and individual adjustment of the heat output by the user,
- usage pattern over the year,
- fuel type, purchase and consumption,
- servicing of the stove.

Both, voluntary and mandatory questions were raised in the survey that was supplemented by drawings. The survey was available in Danish, Dutch, English, French, German, Italian and Swedish language. It's distribution was carried out by a network of the project partners of the 'beReal' project.

2.2 Field monitoring

Simultaneously, field monitoring was conducted using 9 pellet stoves (5 stoves without water jacket, 4 with water jacket) to collect operational data focusing on the identification and the assessment of real life conditions and operational patterns. Monitoring was carried out by determining the flue gas temperature in a time interval of 1 min with a surface thermocouple attached to the flue gas pipe. On average, the monitoring duration lasted over a three months period. The stoves observed had an age of 1 to 8 years and featured a heat output of 8 kW to 15 kW.

The evaluated parameters of highest interest comprised the number of heating phases

- in total,
- per month of observation and
- per day;

the duration

- of a heating phase,
- of the starting phase,
- of the burnout,
- of the cooling period and
- of the standby phase until next ignition;

the mean and maximum temperature

- during starting phase and
- during regular operational phase

as well as the duration above a certain temperature threshold. With this particular time frame and the respective temperature level in correlation to the maximum temperature the load level and its respective duration were estimated. An example on how the developed evaluation routine was applied is shown in Figure 1.

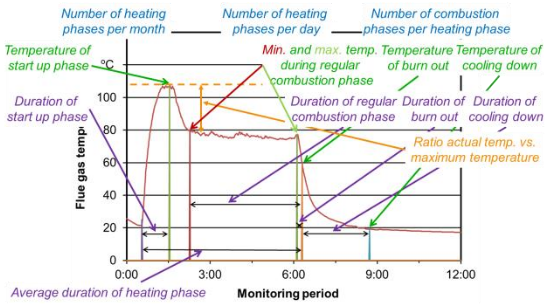


Figure 1: Evaluation of field monitoring data from pellet stoves

2.3 Definition of suitable test method

To investigate the influence of various operational phases on a stove's emission level several measurements were performed to define a suitable testing procedure. The appliance used for all tests which are displayed here was a usual pellet stove representing current state-of-the-art technology (end-user market product, pellet stove without water jacket, cup burner with mobile grate, nominal heat output of 8 kW, automatic cleaning operation every hour).

One aspect considered comprised emission measurements during ignition and heat up phase and also during burnout phase after having shut off the stove. The tests started directly when starting the stove's operation in cold stage. Four successive PM measurements each lasting over 15 min were performed during the heating-up phase. Afterwards six successive PM measurements each over a sampling duration of 30 min were performed during constant nominal load. One final PM measurement was performed over a period of 15 min during the burnout phase directly after switching off the stove.

Cleaning intervals are also influencing the stove's emission level. Where a stove exhibits such cleaning operation they usually occur in regular periods (every couple of hours, at shut down) to reduce the amount of ash and slag sticking to the grate and to ensure an air intake free of deposits. Therefore, the pellet feeding is interrupted for a short duration while the air intake is increased by a higher fan speed to achieve an intensive burnout of the residues on the grate. To assess the influence of these cleaning intervals 6 successive PM measurements were performed during nominal load operation each lasting over a period of 30 min. The cleaning interval usually lasted over 1.5 to 2.0 min. Due to the cleaning interval at every hour every second PM measurement indicates a result with cleaning interval leading to three repetitions with and three repetitions without considering the cleaning interval. This measurement was repeated using three different fuels.

According to current certification standard tests it is required to perform measurements over a defined period of time at both constant nominal load level and at constant partial load. Nevertheless, stoves usually do exhibit various partial load stages. To examine the influence of different partial load settings 3 repetitions of PM measurements were performed over a duration of 30 min at constant load level at 100 %, at 65 % and at 30 % load. Only periods without cleaning interval were considered.

2.4 Development of beReal method for pellet stoves

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

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

2.5 Validation of method

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

At six different pellet stoves (appliances according to DIN EN 14785 [4]) on four test benches (RTD partners and notified bodies from Austria, Germany and Sweden) the respective method was validated. All appliances were typical installations representing the current state-of-the-art. The heat output was in the range of 6 kW to 10 kW.

At all installations comparative measurements as described in standard methods (DIN EN 14785 [4]) were conducted by performing three measurement repetitions at nominal load operation and three repetitions at partial load operation (minimum settable load) each lasting over a 30 min period under constant conditions. Measurements with the test cycle according to the new beReal test method were repeated three times for calculating the mean values.

Measurements according to the new method were evaluated according to the respective method concept with one volume-weighted average value calculated for the complete cycle. The mean values were calculated out of three repetitions of the method measurement. Repeatability was evaluated by calculating the coefficient of variation *r* according to Equation 1.

$$r = \frac{s}{\bar{x}} * 100 \qquad \text{Equation 1}$$

where *s* is the standard deviation and $\bar{x}$ is the mean value.

3 RESULTS AND DISCUSSION

3.1 Online survey

Due to the vast number of data gained from the survey only a glimpse on the most important aspects required for the definition of the method is presented here.

With most responses from Sweden, Germany, Austria and Italy a variety of typical installation conditions and usage patterns due to different climate zones were covered. As indicated in Figure 2 the largest group of users contributing to the online survey was from Italy (79 %).

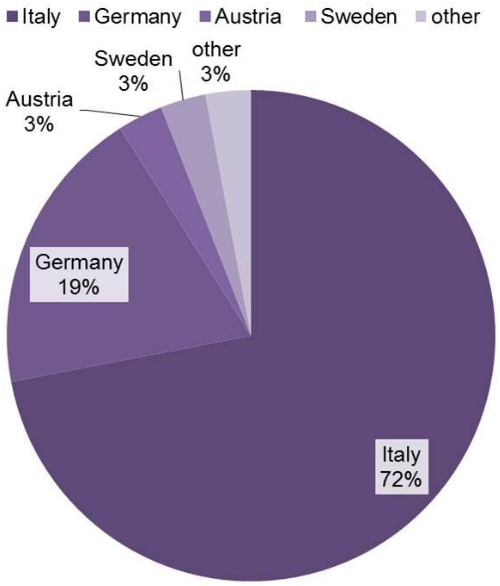


Figure 2: Question concerning current residence: “In which country do you live?” (n=174)

One question raised concerned the production of hot water for heat distribution into other rooms. Figure 3 indicates that almost two thirds of the respondents (62 %) claimed to have a pellet stove without water jacket which is therefore the most important installation to focus on in the method. Another topic considered referred to additional heating systems used in the installation room. With 28 % of the respondents stating that the pellet stove is the only heating system and 59 % responding that the pellet stove is used as primary heating system in the installation room the pellet stove has a major role as heat supply and might be used intensively (Figure 3).

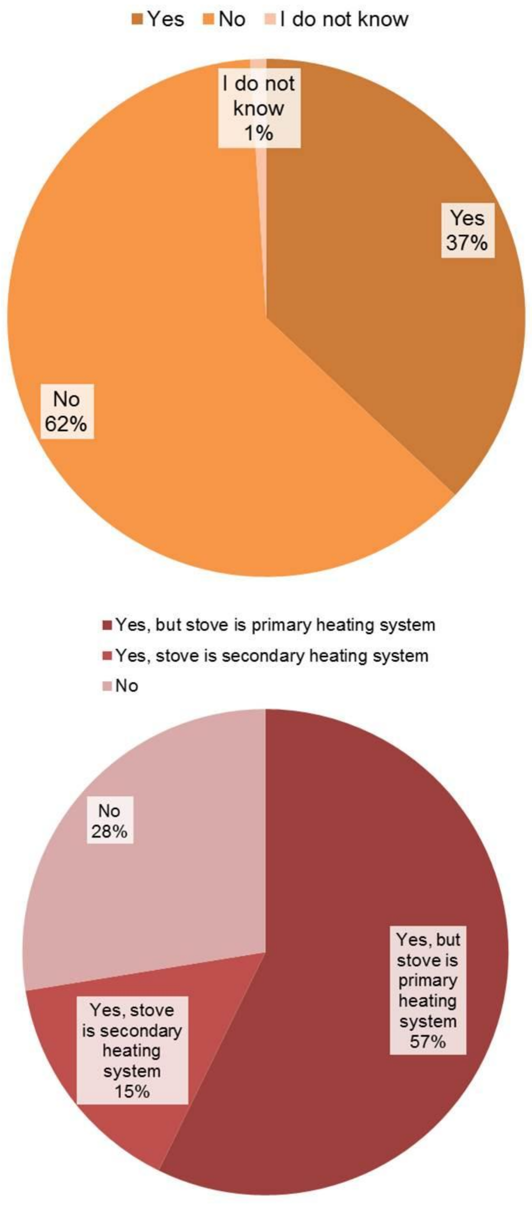


Figure 3: Top: Question concerning water jacket: "Does your stove produce hot water for heat distribution outside the installation room?" (n=174); Bottom: Question concerning additional heating systems: “Is the installation room additionally heated by another heating system?” (n= 183)

The survey revealed a mean age of the appliances of 3 years and a mean heat output of 11 kW. This rather low age might among others be related to the fact that the survey was performed as online questionnaire which might have been more attractive for younger participants.

As 79 % of the pellet appliances were installed in houses instead of apartments, non-residential buildings or other kinds of buildings this might give an indication for the high heat output of the stoves.

Concerning the appliance's operation the question was raised how the heat output of the stove is controlled. 36 % responded that their stove is controlled by a room thermostat, 35 % of the respondents stated that they adjust the heat output directly on the stove control panel while 25 % of the survey participants use a clock timer to control the stove operation. Independently of this question it was also asked whether the stove's heat output was adjusted at the control panel during operation. As can be seen from Figure 4, 66 % of the stove users adjust their heat output which means that they do not solely operate their appliance at a constant load level but also load changes with transient phases will occur. In connection to this question the heat output to which the stove is usually adjusted to on the control panel was investigated. It became apparent that only 8 % of the respondents apply mainly highest power level while 31 % adjust mainly a reduced power level and 53 % use their stove in mixed operation (Figure 4). These outcomes underline the high share of partial load operation in which the stoves are operated in correlation to the reduced portion of operation in constant nominal load. Additionally, it is most likely that the stove is not only operated at one partial load level but that various load levels are selected.

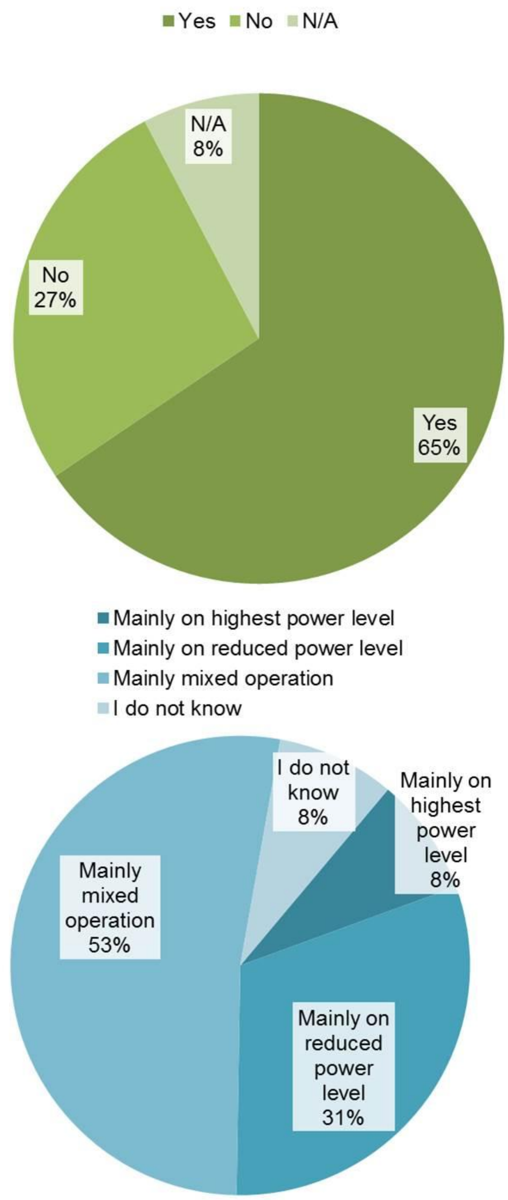


Figure 4: Top: Question concerning heat output adjustment: "Do you adjust the heat output during stove operation by using the control panel?" (n=183); Bottom: Question concerning the level of heat output adjustment: "Which is normally the heat output of your stove if you adjust the heat output on the control panel?" (n= 120)

In contrast to the standard test method for pellet stoves in practice frequent manual adjustments of controlling parameters and variable partial load levels are applied without maintaining constant conditions over longer periods.

3.2 Field monitoring

The field monitoring covered a wide range of all typical heating days during a heating season. A user profile of the recorded flue gas temperature at a pellet stove monitored over a period of approximately three months is given in Figure 5.

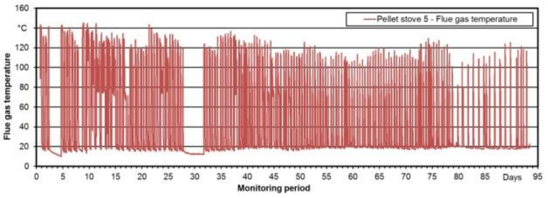


Figure 5: Exemplary user profile over the observation period

When focusing on single days of operation the user profile becomes more distinct, as shown in Figure 6.

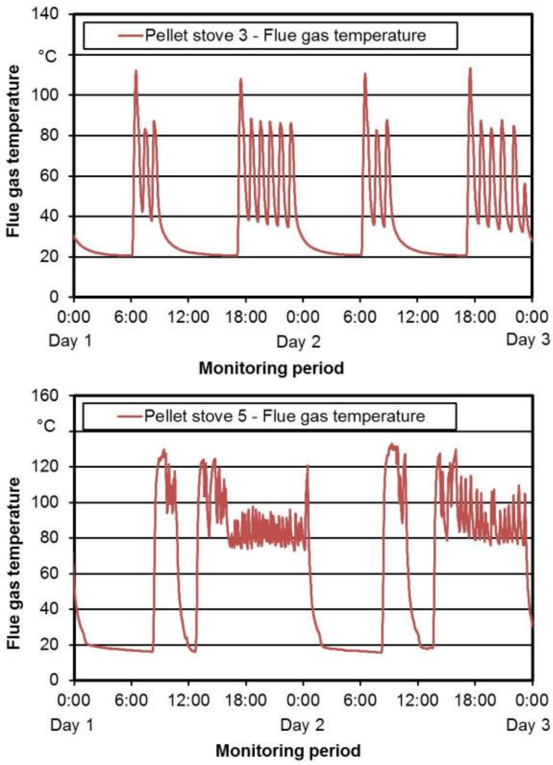


Figure 6: Detail of the user profile at two pellet stoves

With regularly occurring cold and warm starts, operation in nominal and in partial load, load changes with transient phases or modulating operation mode, various operational conditions were observed at different types of pellet stoves.

To define certain load regimes in the stove's operation every temperature value during observation period was related to a maximum temperature quantile of the respective stove (99.8 % of temperature values are below that certain stove dependent temperature). This temperature ratio was considered as an estimated load level, the respective allocation can exemplarily be derived from the course of the flue gas temperature in Figure 7.

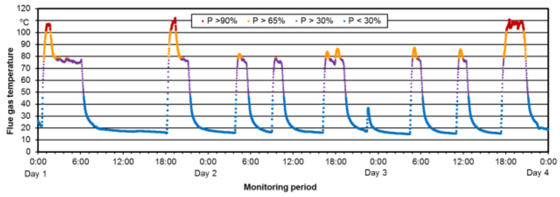


Figure 7: Different load level regimes at an exemplary user profile

The evaluation of user profiles displays that nominal load duration accounts for only about 10 % of the total operation time while operation in low partial load regime (load in the range of 30 % to 65 %) amounts to about 51 % and high partial load (load in the range of 65 % to 90 %) amounts to about 39 % of the operation time (Figure 8).

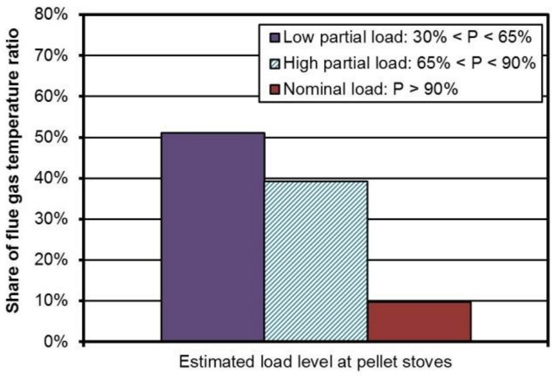


Figure 8: Evaluation of mean operation time in roughly estimated load levels (n = 4 replications)

It becomes obvious that a consistent operational mode does not exist and the profiles are highly user dependent according to personal needs.

Basic assumptions in terms of considering only steady state operation or the exclusion of the ignition phase as it is the case in current standards do not prevail in practice and need to be questioned.

3.3 Definition of suitable test method

The findings of measurements performed during start and stop phase are compared in Figure 9. Due to unreliable oxygen contents (O_2) for calculation during start and stop phase only the absolute values of emissions [in mg] without correlation to 13 % O_2 are depicted here. The duration between starting the stove and the actual ignition of fuel lasts between five and eight minutes. The actual burnout phase after switching off the stove and reaching 20 % O_2 content in the flue gas lasts between 3 and 5 min.

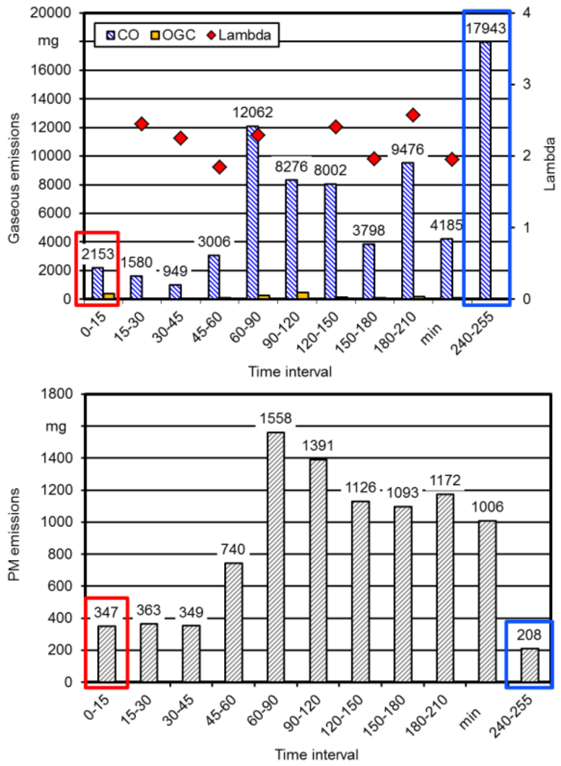
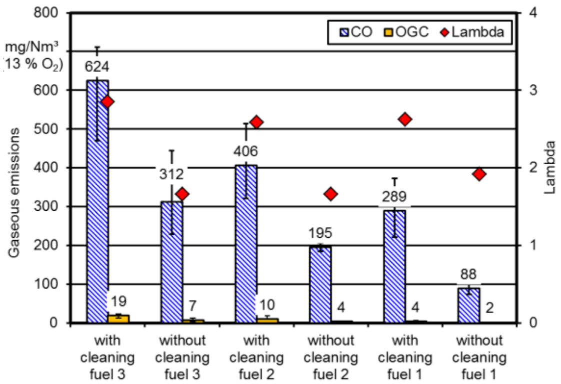


Figure 9: Gaseous (top) and PM (bottom) emissions emitted during start and stop phase

It becomes evident that considerable CO, OGC and PM emissions already occur in the first phase after starting the stove as well as in the final phase after turning off the stove even if these phases are shorter than the nominal load phases. Especially during the ignition phase high amounts of OGC and PM emissions occur, they are summed up to a total share of 21 % (OGC) and 4 % (PM), related to the complete cycle. The burnout phase exhibits an enormously increased contribution to the total CO emission, their share adds up to 25 % of the whole cycle. Deviations during nominal load phase need to be attributed to the stove's automatic cleaning operation that occurs every hour.

A comparison of results from investigating the influence of cleaning interval is given in Figure 10.



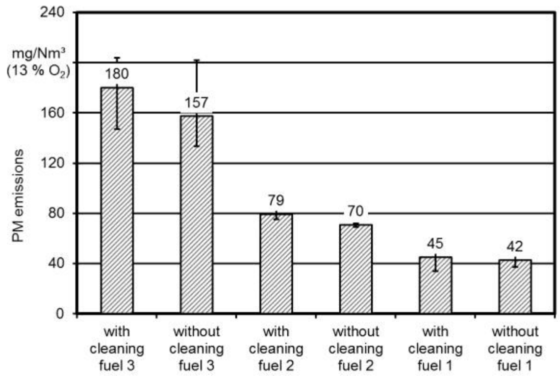


Figure 10: Influence of measurement period with and without cleaning interval on CO and OGC (top) and on PM (bottom) emissions (n = 3)

Obviously the emissions of CO, OGC and PM increase significantly when including the cleaning interval into the observation period: CO emissions without cleaning interval are only in the range of 50 % to 69 % compared to emissions with cleaning interval. For OGC emissions the deviation is in the range of 59 % to 65 % when comparing the measurement without and the one with cleaning interval while for PM emissions the deviation shows results from 5 % to 13 %.

Results from analyzing the influence of different load levels are compared in Figure 11.

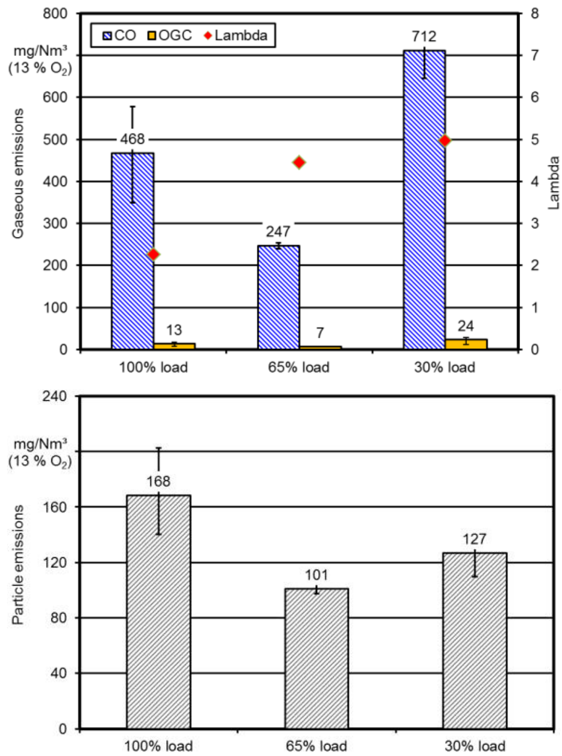


Figure 11: Influence of various load levels on CO and OGC (top) and on PM (bottom) emissions (n = 3)

It becomes apparent that a mean partial load of 65 % exhibits lowest CO, OGC and PM emissions while these emissions increase at nominal load and even further increase at low partial load of 30 %. This can be explained by a lower fuel input and therefor a lower energy input that causes reduced emissions at 65 % load. In contrast at reduced low load level of 30 % the combustion chamber temperature is too low while increased O_2 content results in a high lambda value both leading to a non-optimal conversion of the fuel, an incomplete combustion and therefore increased emissions of CO, OGC and PM.

3.4 Development of beReal method for pellet stoves

It was shown that consistent operational modes do not exist in in real life (Chapter 3.1 and 3.2). Therefore the assumptions to only consider steady state operation in a real life relevant test needs to be questioned, and ignition phase shall be regarded, too. Aiming at a high transferability from real life operation to test stand measurements a so called "beReal" testing cycle was developed.

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

Intending to represent typical user behavior, the real live test cycle at its current state was defined as follows:

- It consists of four combustion phases: 1a, 1b, 2, 3 (Figure 12).
- Three defined load levels are applied: 100 % or the maximum user-settable load level, 65 % or the mean settable load level between minimum and maximum load, 30 % or the lowest settable load level.
- Two intermediate standby phases are included: S1 between phases 1b and 2 and S2 between phases 2 and 3.
- Load change operation occurs from phase 1a to 1b.
- The cycle therefore exhibits one cold start (at phase 1a),
- two warm starts (at phases 2 and 3) and
- three burn-out phases (after phases 1b, 2, and 3).

The test cycle's is depicted in Figure 12, the duration of each phase is given in Table I.

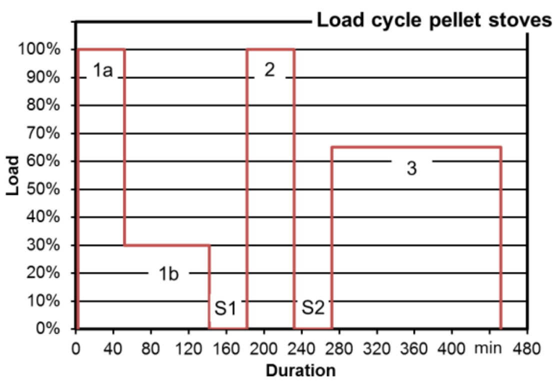


Figure 12: Scheme of load cycle of the beReal method for pellet stoves

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

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

This test cycle fulfills the following requirements as derived from the survey and field testing:

- Ignition and burnout phases are regarded.
- Intermediate phases (standby S1 and S2) are regarded and enable to perform warm starts.
- Load changes during operation are considered.
- As in real life the higher partial load phase (65 %) occurs at the end of the heating cycle.
- The load phases are proportionally allocated according to real life user profile evaluations.
- Stable conditions at constant flue gas temperature are reached only over short periods.
- The nominal load phase is rather short, just as in real life.
- The introduction of one longer operation phase (phase 3) forces the stove to perform a cleaning operation during the measurement.

The relatively long load cycle of 7.5 h also contributes to a high repeatability of the measured results.

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

- Constant chimney draught of -12±2 Pa, maintained also during standby mode to reach typical warm start temperatures as seen in the field.
- The stove shall be positioned on a scale, mass decoupling shall be realized downstream of the measurement section (Figure 13).
- Measuring section diameter in accordance with DIN EN 14785 [4] (diameter d_1 of 100 mm for flue gas socket ≤ 100 mm as is typical for pellet stoves).
- Measurement section as given in DIN EN 14785 [4] can be applied with exception of the PM measurement position: PM shall be measured in a distance of 3x diameter of measurement section (3x d_1) downstream to gaseous analysis measurement (Figure 13) to avoid leakage due to replacement of PM measurement devices during the cycle.
- Flue gas temperature measured by centrally placed thermocouple (instead of using a suction pyrometer).
- Flue gas velocity measured continuously: required speed for volume flow measurement: > 1 m/s, uncertainty < 10 % of measured value (reduction of inlet section and increase of measurement range of velocity meter due to a permitted reduction of the cross section of flue gas measurement section downstream to the draught measurement position).
- Continuous flue gas sampling during total measurement cycle according to DIN EN 14785 [4] (data logging interval: ≤ 10 s).
- Thermal efficiency calculation according to

DIN EN 14785 [4] (default value for combustible constituents in residues q_r of 0.2 % can be applied).

- PM sampling: gravimetric out stack measurement of total PM emissions in hot undiluted flue gas, sampling volume flow proportional to flue gas volume flow, sampling device heated to 180°C, pre and post-conditioning of filtration material for 1 h at 180°C and > 8 h at 20°C, 0 % r.H. (with volume-flow proportional sampling only one PM sampling is required during phases 1a and 1b).
- PM sampling period starts with starting the pellet stove (via stove control panel) and lasts until O_2 content in the flue gas has reached 20 % after turning off the pellet stove (via control panel) after phases 1b, 2, and 3.
- Always the same evaluation is period considered for gaseous emissions, PM emissions, and thermal efficiency determination (standing losses during standby are neglected).
- Calculation of average values by weighting the results derived in the single measurement phases according to their produced flue gas volumes; this is done using average values in mg/Nm³ related to 13 % O_2. The weighting of gaseous emissions and thermal efficiency related to the flue gas volume is required due to changing load levels between phase 1a and 1b, thus causing variable combustion conditions while flue gas temperature and O_2 content may vary largely leading to differing flue gas volumes.

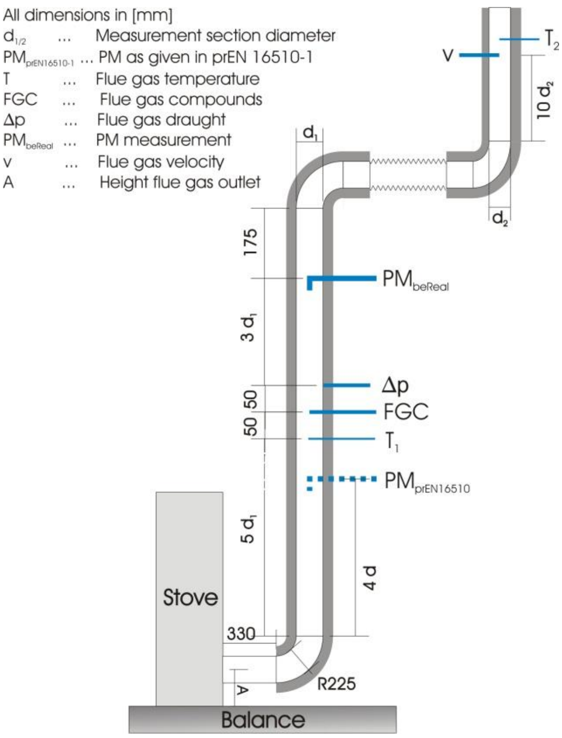


Figure 13: Sketch of the measurement section as considered for beReal method

3.5 Validation of method

For the comparison between official type test values (results from notified body that were provided by the stove manufacturer – 'official type test'), comparatively performed type test measurements at RTD partners conducted according to the respective standard [4] ('RTD type test') and measurements according to the beReal method ('beReal test') the mean values from 6 tested stoves are given in Table II, while the results of the ratio between RTD type tests and official type tests respectively RTD type test and beReal method are given in Table III. A graphical comparison of measurement results is given in Figure 14 with an overview on CO results compared for all 6 tested pellet stoves. Mean values on CO, OGC, PM, and thermal efficiency are illustrated in Figure 15.

Table II: Comparison of results from validation measurements: Mean values (n = 6 stoves) from official type tests ('oTT'), comparatively performed type tests at RTD partners ('RTD TT') and beReal tests ('beReal') for nominal load ('NL') and partial load ('PL') (emission values for CO, NO_x, OGC, and PM related to 13 % O_2)

	oTT - NL	oTT - PL	RTD TT - NL	RTD TT - PL	beReal test
CO [mg/Nm³]	135	253	201	1559	540
NO_x [mg/Nm³]	108	107	121	99	112
OGC [mg/Nm³]	5	7	5	82	19
PM [mg/Nm³]	22	26	31	60	46
η [%]	91	92	77	70	79

Table III: Comparison of results from validation measurements: Ratio of mean values (n = 6 stoves) of RTD type tests and official type tests as well as RTD type tests and beReal method for nominal load and partial load

	RTD TT/ oTT (NL)	RTD TT/ oTT (PL)	RTD TT - NL/ beReal	RTD TT - PL/ beReal
CO	149 %	615 %	37 %	289 %
NO_x	112 %	92 %	108 %	88 %
OGC	92 %	1156 %	24 %	433 %
PM	141 %	234 %	66 %	131 %
η	85 %	75 %	97 %	88%

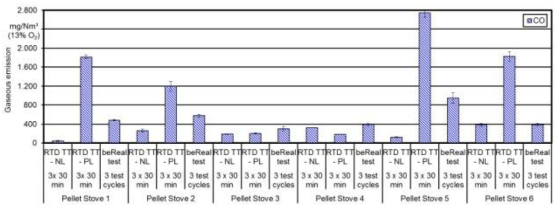


Figure 14: Mean values of validation measurements for RTD type tests at nominal load ('RTD TT – NL'), partial load ('RTD TT – PL'), and with beReal method ('beReal') for CO results at all 6 pellet stoves investigated (n = 3 repetitions)

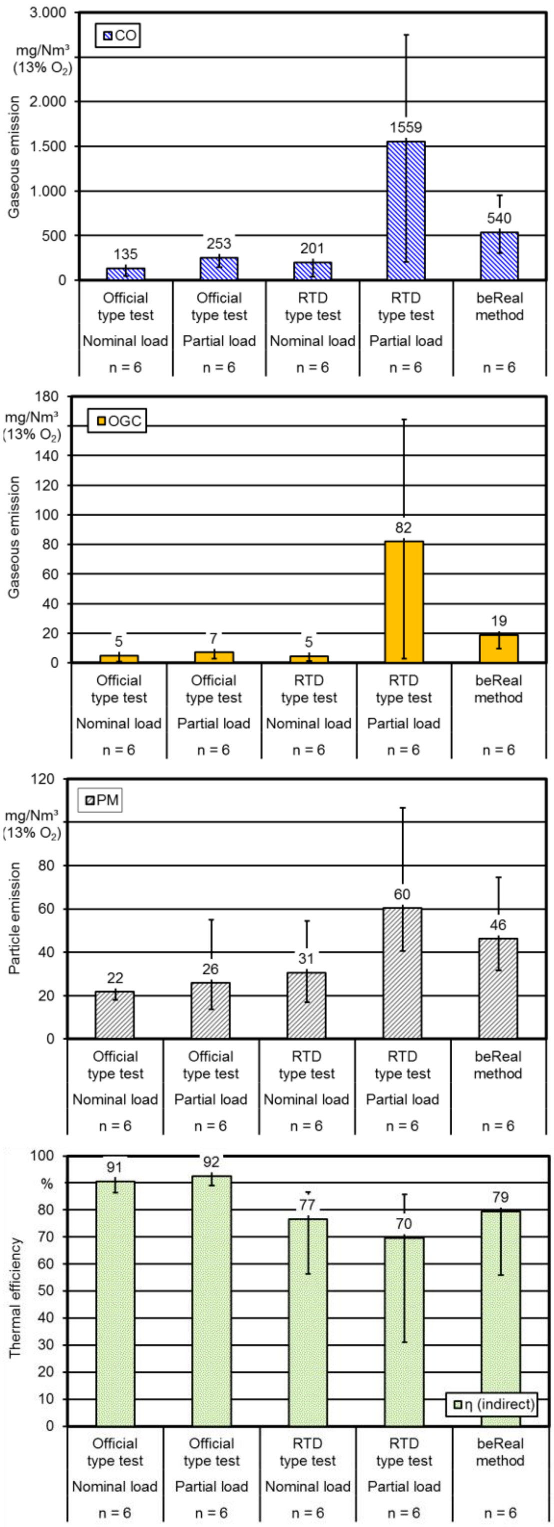


Figure 15: Mean values of validation measurements: CO (1st row), OGC (2nd row), PM (3rd row), thermal efficiency η (4th row) for official type tests (nominal and partial load), RTD type tests (nominal and partial load), and beReal tests (n = 6 stoves)

It becomes obvious that the RTD partner's type tests showed mostly higher results compared to official type test results which were exceeded by up to 149 % for nominal load and by up to 1156 % for OGC in partial load. This underlines the difficulty of repeating the type test measurement accurately. Results of measurements according to the beReal method exhibited usually higher values than those for RTD type tests at nominal load, but values were lower compared to RTD type tests at partial load. This indicates that the beReal method might reflect various operational conditions not worse than the current standard procedure. Nevertheless, there is no repeated ratio between type test result and beReal result and therefore, no constant factor can be calculated which could be applied to the type test result to indicate the beReal result.

In terms of coefficient of variation r it became apparent that for measurements according to the beReal method the validation revealed a high repeatability with mean r below 10 % for CO, NO_x, and PM emissions and thermal efficiency. Only for OGC emissions a lower repeatability with an increased coefficient of variation of 15.4 % was seen. This behavior has to be attributed to the low level of absolute emission values and also to significantly increased OGC emissions during load changes and partial load operation compared to nominal load operation which deviates significantly between each of the single test runs. For thermal efficiency beReal measurements did show best absolute results and best results for repeatability. These findings are also given in Figure 16.

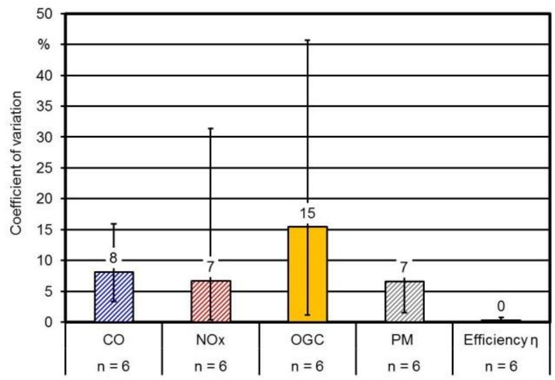


Figure 16: Coefficient of variation r: Mean values reached in beReal tests (n = 6 stoves)

4 CONCLUSIONS

The newly developed test method for pellet stoves provides the benefit of reflecting real life operation in a proven and comprehensive way. Furthermore, chances for selective evaluation of several "ideal" and constant operational phases with the aim of calculating favorable results from the selected data are here consequently excluded; this is because the suggested new test cycle can only be evaluated completely and without leaving out any data. The method's repeatability was also shown to be quite high, however, there is evidence for some stronger impact given by variable fuel properties, even if all pellets always fulfill the A1 quality requirements of the fuel standard DIN EN ISO 17225-2 [7]. This fuel variability will become evident when the stove test is performed by other laboratories. Further research is therefore needed in order to provide means for specifying the required test fuel in a more specific way.

When testing pellet stoves according to the beReal method, highly advanced appliances having low emissions in real life will distinguish more obviously from low quality appliances. However, it is quite obvious that the performance data of the beReal tests should not be compared to official type testing results. Thus, any existing legislative benchmarks or legal emission limits cannot directly be applied for tests results from a beReal test. The beReal test results rather require an individual frame of evaluation. Such frame could for example be implemented in a certification scheme for high quality pellet stoves.

Furthermore, the developed beReal test cycle can also provide the "blueprint" for measurement procedures which aim at assessing emission factors of pellet stoves on a test bench. This is possible because the beReal method elaboration had been guided by the target of reflecting real life operation as it had comprehensively been observed in the field.

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7 LOGO SPACE

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