report

beReal

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Deliverable D3.3

Final Report: Definition of Suitable Measurement Methods and Advanced Type Testing Procedure for Real Life Conditions

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1 Introduction

This deliverable (D3.3) aims at the presentation and summary of the final test methods for testing of firewood and pellet room heating appliances according to beReal.

The described test methods were elaborated in WP3 and adapted via a comprehensive validation process in WP5. Within extensive test stand measurements and field tests but also in a European Round Robin with external participating research institutes the method description was analyzed and additionally adopted in terms of an easy applicability and adaption at various test stands without difficulty. Further detailed information about the development and validation process can be found in D3.2 ("*Draft report: Definition of suitable measurement methods and advanced type testing procedure for real life conditions*") and D5.2 ("*Report on experimental validation of advanced type testing procedure and viability analysis for other technologies*"). A description of the execution of the field demonstration can be found in D7.3 ("*Documentation and evaluation of field data demonstration*") while the procedure and results of the Round Robin are given in D8.1 ("*Report on Round Robin tests*").

The web based online tool for standardized data analysis of beReal tests was developed in WP4. Detailed information about the online tool can be found in D4.1 ("*Web based calculation tool*") as well as D4.2 ("*Documentation for quality assurance (QA) and definition of documentation regulations*").

Link to the web based calculation tool: http://bereal.bioenergy2020.eu/

This deliverable was elaborated by BIOENERGY 2020+ (BE2020+) with collaboration of TFZ Straubing (TFZ).

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2 Scope and General Requirements

The beReal Test Method can be applied to local room heating appliances according to the definitions in

- EN13240 [1] respectively prEN 16510-1 [3] and prEN 16510-2-1 [4]
- EN14785 [2] respectively prEN 16510-1 [3] and prEN 16510-2-6 [5]

Water jacket appliances and insets are NOT included in the first stage of the beReal method.

Extension to other direct heating appliances has to be considered in future development. The results of the viability analysis revealed that the beReal test approach in principal is applicable also to other batch wise operated heating appliances. However, currently there is insufficient data available about typical real life operation of other technologies.

Provision of the stove

Appliances must be end user marketed products. This means that they must be functionally and technically identical with serial products. Testing appliances have to be operated before the beReal test for at least 6 h.

Remark: Pre-operation outside the testing lab can be accounted for this requirement.

Measurements to be performed

The beReal method for firewood room heaters is applied according to the QuickUserGuide (QUG) which must be provided unchanged (including photographs and graphs) with the product to the end customer. Any required changes have to be approved by the testing body in advance. Detailed information on the QUG can be found in D4.2. Measurements at pellet stoves have to be performed according the respective beReal test cycle for pellet stoves.

3 beReal Test Method – Firewood

3.1 Description of Test Procedure

Generals

The beReal test procedure for firewood room heaters consists of eight consecutive batches starting from cold conditions with the ignition batch, followed by nominal and part load batches as well as the cooling down phase until the flue gas temperature (T_1) reaches 50°C (Figure 1).

- Batch 1 (– 2): Ignition (and preheating)
- Batch 2 (3) – 5: Nominal load operation (100 %)
- Batch 6 – 8: Part load operation (50 %)
- Cooling down: until T1 = 50°C

Part load operation is defined by using 50 % of batch mass of nominal load operation. Further specification for part load operation (number of pieces, placement in combustion chamber, air settings) must be provided by the manufacturer in the QuickUserGuide (QUG).

Remark: beReal testing without part load operation is not possible!

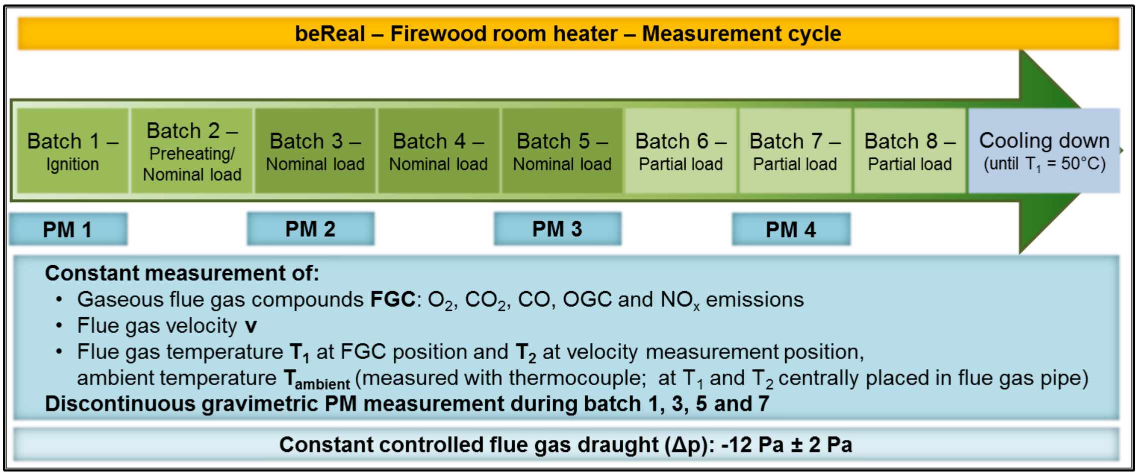


Figure 1: Scheme of test procedure for beReal Test Method - Firewood

Source: BIOENERGY 2020+

Recharging procedure

Conditions for ignition (i.e. ignition mode (top-down / bottom-up), fuel requirements (mean value for size, weight and number of logs, kindling material) have to be defined by the manufacturer in the QUG (example given in Figure 2). Refilling is defined according to CO_2 flue gas measurement. Threshold values of 4.0 % CO_2 and 25 % CO_{2max} define the recharging time.

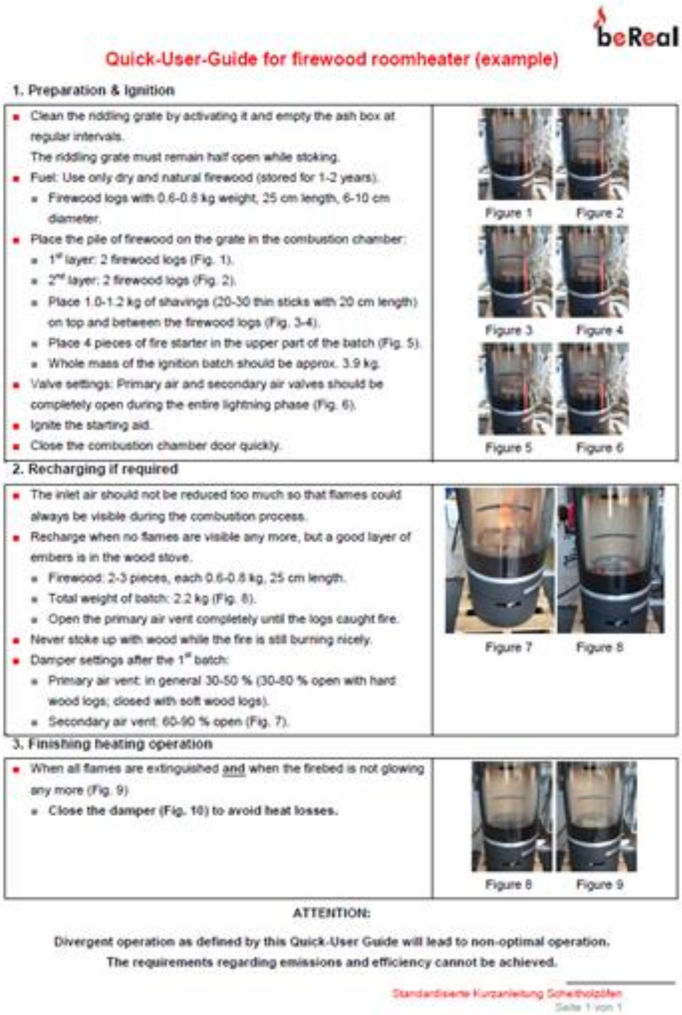
<u>Option</u>: Recharging at 3.0 % CO_2 absolute when CO_{2max} was below 12.0 % <u>and</u> when flames are extinguished at that time. Otherwise the measurement should be continued until 25 % of CO_{2max} is reached when flames are still visible at 3.0 % CO_2.

The exact point of recharging is reached as soon as the actual CO_2 value in the flue gas has fallen below the threshold CO_2 value over a duration of 30 seconds.

If the appliance is equipped with an automatic control indicating the recharging time, this signal shall be followed rather than following the procedure described above.

The recharging procedure (position of wood logs, air valve settings, …) has to be defined by the manufacturer in the QUG.

Poking, raking, and levelling out of the firebed before recharging is allowed.



beReal

Quick-User-Guide for firewood roomheater (example)

1. Preparation & Ignition

- Clean the riddling grate by activating it and empty the ash box at regular intervals.
  The riddling grate must remain half open while stoking.
- Fuel: Use only dry and natural firewood (stored for 1-2 years).
  - Firewood logs with 0.6-0.8 kg weight, 25 cm length, 6-10 cm diameter.
- Place the pile of firewood on the grate in the combustion chamber:
  - 1st layer: 2 firewood logs (Fig. 1).
  - 2nd layer: 2 firewood logs (Fig. 2).
  - Place 1.0-1.2 kg of shavings (20-30 thin sticks with 20 cm length) on top and between the firewood logs (Fig. 3-4).
  - Place 4 pieces of fire starter in the upper part of the batch (Fig. 5).
  - Whole mass of the ignition batch should be approx. 3.9 kg.
- Valve settings: Primary air and secondary air valves should be completely open during the entire lightning phase (Fig. 6).
- Ignite the starting aid.
- Close the combustion chamber door quickly.

Figure 1 Figure 2 Figure 3 Figure 4 Figure 5 Figure 6

2. Recharging if required

- The inlet air should not be reduced too much so that flames could always be visible during the combustion process.
- Recharge when no flames are visible any more, but a good layer of embers is in the wood stove.
  - Firewood: 2-3 pieces, each 0.6-0.8 kg, 25 cm length.
  - Total weight of batch: 2.2 kg (Fig. 8).
  - Open the primary air vent completely until the logs caught fire.
- Never stoke up with wood while the fire is still burning nicely.
- Damper settings after the 1st batch:
  - Primary air vent: in general 30-50 % (30-50 % open with hard wood logs; closed with soft wood logs).
  - Secondary air vent: 60-90 % open (Fig. 7).

Figure 7 Figure 8

3. Finishing heating operation

- When all flames are extinguished <u>and</u> when the firebed is not glowing any more (Fig. 9)
  - **Close the damper (Fig. 10) to avoid heat losses.**

Figure 8 Figure 9

ATTENTION:

Divergent operation as defined by this Quick-User Guide will lead to non-optimal operation.
The requirements regarding emissions and efficiency cannot be achieved.

Standardisierte Kurzanleitung Scheitholzöfen
Seite 1 von 1

Figure 2: Example of a QUG (firewood roomheater)

Source: TFZ Straubing

The combustion chamber door shall be closed and locked immediately after refilling. The maximum time for refilling is 60 seconds.

Air inlet flap settings

After <u>1st / 2nd batch</u>: Only one manual adjustment of air inlet flap settings after 1st respectively 2nd batch is permitted and is defined by the manufacturer.

During <u>nominal load batches</u> (2nd/ 3rd to 5th batch) no manual adjustment of air inlet flap settings is allowed.

During <u>part load batches</u> (6th to 8th batch) one manual adjustment of air settings is permitted according to the QUG at the start of the 6th batch (part load settings).

Adjustments done by automatic control systems are allowed permanently.

At the end of the heating cycle the adjustment has to be done according to manufacturer's specifications given in the QUG. Closing the flaps (e.g. at 4.0 % & 25 % criterion of last batch or at 3.0 % CO_2 when the flames are extinguished) is only allowed when indicated by the manufacturer.

3.2 Test Fuels and Fuel Requirements

Test fuels are provided by testing bodies. End customer marketed fuels have to be used. The type and constitution of the fuel has to be defined by the manufacturer in the QUG and must not contradict the beReal requirements. It is not allowed that manufacturers supply the fuel.

General requirements

Type: Beech (preferably) or birch firewood; Water content shall be 15 ± 3 %.
Size: One value for the firewood length shall be defined in the QUG.
Amount of bark: The fuel to be used shall be natural wood. The decision on fuel with or without bark shall be left to the testing institute.
Fire starter: Mandatory is the use of a bio-based fire starter. Attention: paper and liquids are not allowed. Maximum mass of fire starters is limited to 3 % of the ignition batch mass (wood logs including kindling material).

Kindling material

Type: Either spruce, beech or birch wood.
Definition of kindling material: slim pieces of wood sticks produced from regular wood logs. The maximum amount of kindling material is 25 % of the ignition batch mass (wood logs including kindling material).

Ignition batch

The minimum batch mass of the ignition batch (wood logs without kindling material) shall be ≥ 80 % of the batch mass representing nominal load.

Nominal load batch

Defined by the manufacturer should be the size and number of firewood pieces and the weight of fuel for whole batch. Mass for each wood log is defined as total batch mass divided by number of pieces. Tolerable mass difference between single logs is 10 % of calculated mean log mass.

Part load batch

Part load is defined by using 50 % of mass of the nominal load batch. Number of firewood pieces, size and placement in combustion chamber are defined by the manufacturer in the QUG. Equal fuel requirements as mentioned for nominal load are valid for part load batch operation.

3.3 Experimental Set-up

Experimental set-up (compare with prEN 16510-1 [3]) (Figure 3):

Stove outlet:

- 330 mm uninsulated flue gas duct
- 350 mm insulated flue gas duct
- Temperature measurement T_1 with an unshielded thermocouple (no pyrometer temperature allowed) is used for thermal efficiency determination
- 50 mm insulated flue gas duct
- flue gas compound measurement (FGC)
- 50 mm insulated flue gas duct
- flue gas draught measurement (Δp)
- 3x d_1 insulated flue gas duct
- PM measurement (deviation from standard: particle sampling will be done downstream the gas sampling)
- 175 mm insulated flue gas duct
- Reduction of the flue gas duct diameter
- Flue gas velocity v and temperature T_2 measurement, distance to v measurement according to requirements of measurement device.
- Measurement of ambient temperature is required ($T_{ambient}$)

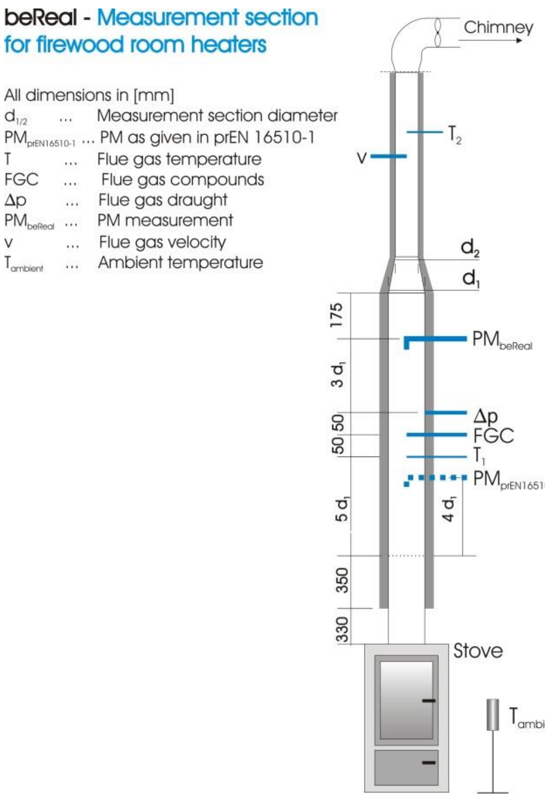


Figure 3: Scheme of test stand for beReal testing of firewood roomheaters

Source: TFZ Straubing

<u>Remarks:</u>

- Mass decoupling is not necessary but reductions shall be realized downstream the lower measurement section.
- The distance of 3x d_1 between static pressure position and PM sampling position leads to an overall distance in the insulated flue gas pipe of 8x d_1 (including mounted measurement probes).
- An extraction fan shall be fitted after the sampling section, which shall maintain a constant flue gas draught and which shall carry exhaust gases clear of the test area.

3.4 Measurements

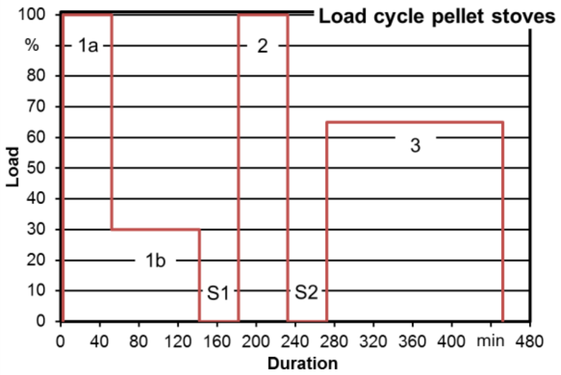
The description of the measurements to be performed as well as the respective specifications are given in chapter 5.

4 beReal Test Method – Pellets

4.1 Description of Test Procedure

Pellet stoves are tested according to beReal by applying a test cycle including three operating phases under three different load settings.

The recording of measurement parameters is launched with starting the stove operation (e.g. when pushing the start button for ignition). The duration of specified phases 1a, 2, 3 starts when the CO concentration in the flue gas reaches 10 ppm (°) (see Figure 4 and Figure 5).



Phase	Operation	Load level*	Duration°
1a	Cold start	High load *	50 min
1b	Load change	Low load *	90 min
S1	Standby	0%	40 min
2a	Warm start	High load *	50 min
S2	Standby	0%	40 min
3	Warm start	Medium load *	180 min

Figure 4: Scheme of test procedure for beReal Test Method – Pellet

° … The duration of specified phases 1a, 2, 3 starts when the CO concentration in the flue gas reaches 10 ppm

Source: TFZ Straubing

- * High load = maximum heat output level adjustable by end user,
- * Low load = minimum heat output level adjustable by end user,
- * Medium load = heat output level adjustable by the end user closest to the calculated mean between high and low load.

Phase 1 (1a and 1b):

PM sampling is started just before starting the pellet stove. The heat output level shall be adjusted to ‘High load’ (° 1a). 50 min after the phase starting point the load setting shall be adjusted to ‘Low load’ level (° 1b). With the end of phase 1b the stove shall be turned off, PM sampling continues until the measured O_2 content reaches 20.0 %.

Remark: Only one PM sampling is required during that phase but a volume-flow proportional sampling (in optimum an isokinetic sampling) is mandatory.

Stand by 1:

During the standby phase the flue gas draught shall be maintained at -12 ± 2 Pa. The standby phase lasts 40 min or as long as a re-ignition of the stove is possible.

Phase 2:

The heat output level shall be adjusted to ‘High load’. PM sampling shall start just before restarting the pellet stove. With the end of the defined duration the stove has to be turned off, PM sampling continues until the measured O_2 content reaches 20.0 %.

Stand by 2:

During the standby phase flue gas draught shall be maintained at -12 ± 2 Pa. The standby phase lasts 40 min or as long as a re-ignition of stove is possible.

Phase 3:

The heat output level should be adjusted to ‘Medium load’. PM sampling shall start just before restarting the pellet stove. With the end of the defined duration the stove shall be turned off, PM sampling continues until the measured O_2 content reaches 20.0 %.

Measuring conditions:

- The stove’s cleaning intervals shall not be deactivated during the measurement.
- Automatic controls like room thermostats must not be activated during the beReal test, instead the load levels described above shall be set manually (e.g. by directly controlling the stove).

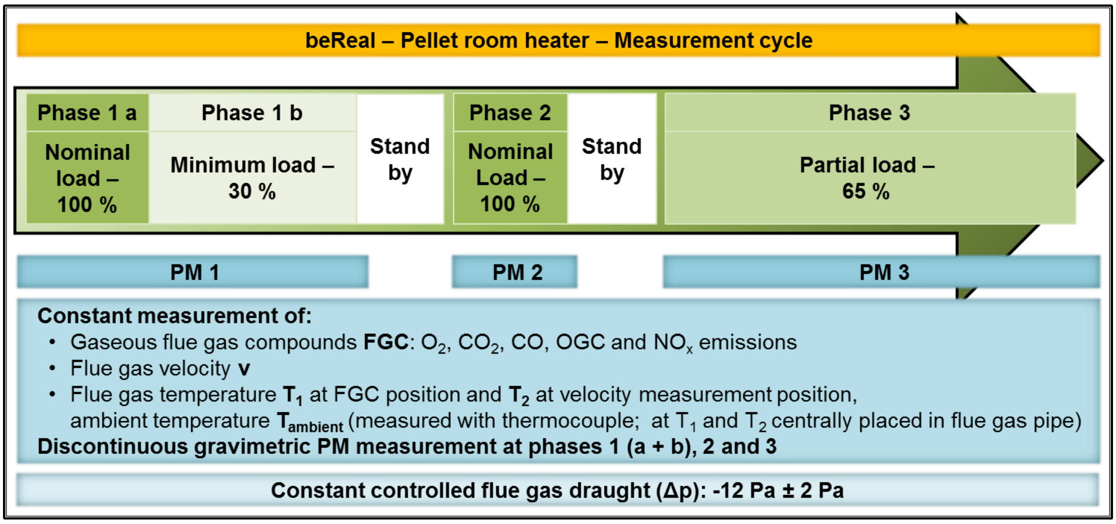


Figure 5: Illustration of beReal measurement test procedure for pellet room heaters.

Source: TFZ Straubing

4.2 Test Fuels and Fuel Requirements

Certified EN Plus A1 Pellets have to be used. It is not allowed that manufacturers supply the fuel. Test fuels are provided by the testing bodies. End customer marketed fuels have to be used. Brand, labels and date of acquisition has to be documented to prove a repeatable quality.

4.3 Experimental Set-up

Experimental set-up (compare with prEN 16510-1 [3]) (Figure 6):

Stove outlet:

- 330 mm uninsulated flue gas duct
- 350 mm insulated flue gas duct
- Temperature measurement T with an unshielded thermocouple (T_1)
- 50 mm insulated flue gas duct
- Flue gas compound measurement FGC
- 50 mm insulated flue gas duct
- Flue gas draught measurement Δp
- 3x d_1 insulated flue gas duct
- PM measurement
  (Attention: deviation from standard: particle sampling will be done downstream the gas sampling)
- 175 mm insulated flue gas duct
- Decoupling and reduction of the flue gas duct diameter
- Flue gas velocity v and temperature T measurement (T_2)

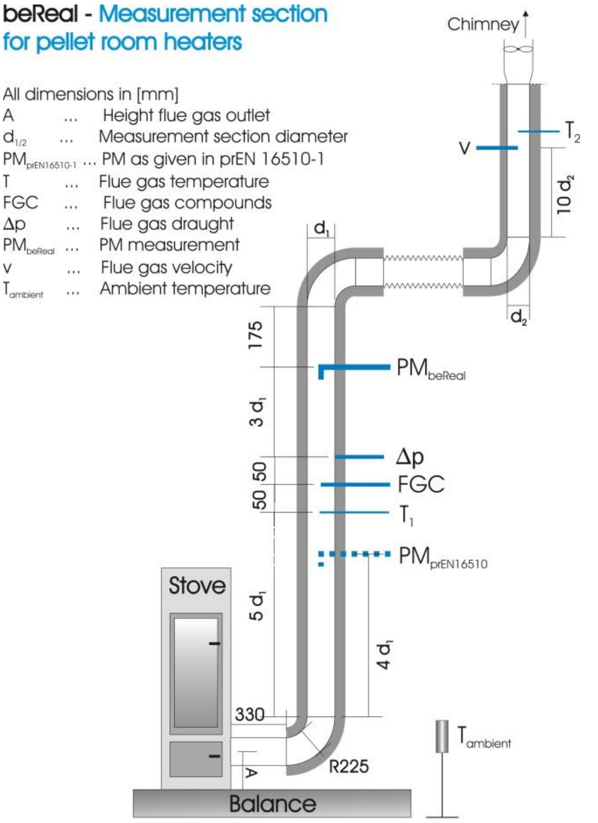


Figure 6: Scheme of test stand for beReal testing of pellet stoves

Source: TFZ Straubing

Remarks:

- Measurement of ambient temperature is required (as given in prEN 16510-1 [3]) ($T_{ambient}$)
- The stove shall be positioned on a balance.
- Mass decoupling is necessary but shall be realized downstream the lower measurement section.
- The distance of 3x d_1 between static pressure position and PM sampling position leads to an overall distance downstream to the bow (and in the insulated flue gas pipe) of 8x d_1 (including mounted measurement probes).

- An extraction fan shall be fitted after the sampling section, which shall maintain a constant flue gas draught and which shall carry exhaust gases clear of the test area.

4.4 Measurements

The description of the measurements to be performed as well as the respective specifications are given in chapter 5.

5 Test Methods and Measuring Procedure

The following chapter describes the measurement instructions with test methods and measuring procedures for both beReal methods – Firewood and Pellets.

5.1 Flue Gas Measurements

Gaseous measurements:

Gas sampling nozzle instead of suction pyrometer for gas analysis is strongly recommended. Measurements: CO, CO_2, O_2, OGC as THC, NO and NO_2 as NO_x

Continuous measurement is required. The logging interval is ≤ 10 s. The procedures for measuring NO_x and OGC as described in Annex E and Annex F in prEN 16510-1 [3] shall be considered.

Remarks:

- It has to be ensured that the respective measurement ranges are chosen appropriately for the amount of emissions awaited. The uncertainty of the measurement equipment (gas analyzers) have to correspond to the definitions as given in prEN 16510-1 [3]. The respective requirements concerning uncertainty of measurement as summarized in Table I shall be guaranteed. The maximum expected values for the parameter(s) to be measured must be within the measurement range of the test equipment used. A fast flue gas suction rate of the gas analyzer shall be secured.
- The OGC measuring method might lead to a high variation of results (operation and calibration of FIDs (e.g. lean vs. rich flame, concentration of calibration gas, oxygen content of calibration gas/ cross sensitivity with other gases, …), no standardized measurement routine is yet available, OGC concentration might be at the lowest level of the measurement range). Any influencing circumstances (flue gas composition, components of the set-up, calibration gas, …) shall be considered and a measurement performance according to best practice shall be ensured.

Flue gas velocity:

Continuous measurement is necessary during the whole measurement cycle. The uncertainty of the velocity measurement shall be < 10 % of measured value. Usually, this requirement can only be achieved by reducing the diameter of the flue gas pipe downstream the measurement section and measuring velocity within this part.

A verification and correction of the measured flue gas velocity by comparing the measurement results with the results of calculating the flue gas velocity out of the fuel composition is essential to avoid errors due to measurement failures and uncertainties (e.g. due to clogging of the measurement device). The respective calculation routine is given in chapter 6.2.

Remark: Flue gas flow conditions need to be respected in terms of a profile factor, which shall be determined as a function of at least five measurement points in the awaited measuring range.

Flue gas draught:

The chimney draught at the measuring point must be set to -12 Pa and must be maintained under all operating conditions (8 batches and cooling down phase until T_1 = 50°C, respectively phase 1a to 3). Throughout the whole test duration the actual draught should not vary by more than 2 Pa on average from the value specified.

PM measurements:

The following procedure shall be applied: Gravimetric out-stack PM measurement during batches 1, 3, 5, 7, respectively during phases 1a+1b, 2 and 3 according to VDI 2066-1 [6]. Sampling volume flow shall be performed proportional to flue gas volume flow preferably at isokinetic or at over-isokinetic conditions. The sampling nozzle shall be chosen accordingly.
The measurement position is $3xd_1$ ± 5 cm downstream to the static pressure measurement.

- For firewood room heaters the PM sampling starts before lighting the first fuel batch (batch 1) and ends before opening the combustion chamber door for recharging the next batch. The PM sampling shall last over the whole batch duration.
- At the pellet stoves the PM sampling duration shall last over the whole phase duration during each of the phases respectively (1a+1b, 2 and 3). The PM sampling is finished when the O_2 content in the flue gas reaches 20.0 vol.-%. The same evaluation period is considered for gaseous emissions and particle sampling.

During the complete PM measurement the filter casing and probe shall be continuously heated to 180 ± 3 °C. If available a temperature controlled sampling line should be used.

Equipment:

- Plane filter: Particle retention rate > 99 % (e.g. DOP Test). Size of filter is not defined.
- Filter cartridge: The use of filter cartridges is optional. Sampling periods over whole batches have to be ensured.
- Rinsing of the sampling probe: 3x rinsing with acetone.

Filter treatment:

- Pre-treatment and post treatment of stuffed filter cartridges and plane filters: Heat up in open transport glass containers at180 °C for 1 h,
- Cool down in desiccator for > 8 h, Weigh filter cartridges and plane filters on a balance with a resolution of minimum 0.1 mg.
- Rinsing solution: The weighing container is stored until the acetone is evaporated (e.g. in a drying oven at 115 °C or in an extractor hood).
- The weighing container is treated together with the filter materials at 180 °C for 1 h and in the desiccator for > 8 h.

Combustible constituents in the residue

For pellet stoves a default value of 0.2 % for heat losses due to combustible constituents in the residue will be used (as given in the prEN 16510-2-6 [5]).

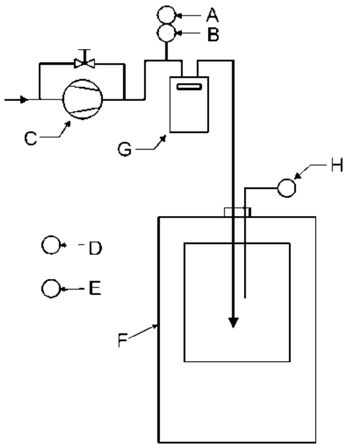
For the firewood stove another approach is used. The future beReal method will apply a new approach for determining the combustible constituents in the residues. After the testing cycle inclusive cooling down phase all residues need to be removed out of the stove and have to be weighed. For calculation of the amount of combustible constituents and their losses in terms of efficiency see chapter 6.2.

5.2 Ambient Room Temperature

The ambient room temperature of the test laboratory shall be measured as given in prEN 16510-1:A1.1 [5] at a point lying on a circumference of a circle with a radius of (1.2 ± 0.1) m traced from the side of the appliance, at a height of (0.50 ± 0.01) m above the platform scale and away from any direct radiation. For measurement of the ambient room temperature, a thermocouple or other temperature measuring device shall be placed, protected from radiation by an open ended cylindrical metal screen, with open ends and made of polished aluminum or material of equivalent reflectivity, nominal 40 mm in diameter and 150 mm long.

5.3 Leakage Check

Leakage testing is performed for all types of appliances including room air dependent and independent operation. Performance of leakage checks prior to (as received, several hours of heating operation required) and after beReal measurements at 5 Pa, 10 Pa and 15 Pa (with one repetition for each condition) according to the measurement procedure for leak tightness tests in prEN 16510-1: A 4.10.2.2 Appliance leak tightness test [3](Figure 7):



Key

A	micromanometer	E	room temperature measurement
B	gas temperature measurement	F	test appliance
C	gas control valve	G	gas flow meter
D	barometric pressure measurement	H	micromanometer

Figure 7: Scheme of test method for leakage check
Source prEN 16510-1:2013 [3]

"… *The inside overpressure shall be determined by an appropriate device which is designed with a volumetric measurement tool for the determination of the leak tightness. … The appliance is tested at ambient temperature … . The appliance is tested with adjusters (e.g. combustion air controls, flue dampers, air inlet dampers), if existing, set to the most unfavorable adjustment in terms of leakage*."[3]

5.4 Data Evaluation

An automatic evaluation is done by calculating the volume-weighted measurement results for emissions and efficiency with an online tool (available via: http://bereal.bioenergy2020.eu/). The exact data evaluation procedure is described in chapter 6.

5.5 Summary of Measuring Methods and Required Uncertainties

The used measuring equipment must be selected in a way that the requirements concerning uncertainty of measurement as summarized in Table I are guaranteed. The maximum expected values for the parameter(s) to be measured must be within the measurement range of the test equipment used.

Continuous measurements

All parameters, with the exception of particle emissions, must be measured at intervals of no more than 10 s.

Required values to be measured:

- Ambient conditions: ambient air pressure and ambient temperature
- Flue gas properties: flue gas temperature, static pressure (or chimney draught), flue gas velocity
- Flue gas analysis: gaseous components (CO, O_2, CO_2, NO_x (NO and NO_2), OGC) and particle emissions (PM)
- Fuel: properties (elemental composition, calorific value, moisture content, ash content)
- Fuel consumption

Ambient conditions

Ambient air temperature shall be measured continuously. The thermocouple or other temperature measuring device shall meet the uncertainty of measurement requirements of ≤ 2 K as specified in Table I.

Ambient air pressure shall be measured at least once (ideally continuously) throughout the testing period. If significant fluctuations can be expected it shall be measured repeatedly or continuously. Uncertainty of measurement regarding air pressure should not exceed ± 10 mbar and regarding ambient temperature should be no more than ≤ 2 K.

Flue gas temperature

Flue gas temperature must be measured continuously, with a maximum uncertainty of measurement of ≤ 5 K. It was decided to use a thermocouple that is centrally placed in the flue gas pipe.

Static pressure/ chimney draught

Static pressure is to be measured with an uncertainty of measurement of ≤2 Pa. For the determination of draught a pipe with an inner diameter of 6 mm shall be inserted in the measurement section (Figure 3, Figure 6). The pipe end must fit flush with the inside wall of the measurement section.

Gaseous components

Measurement of the gaseous components CO, O_2, CO_2, NO_x with regard to dry flue gas and OGC with regard to moist flue gas shall be performed continuously. Calibration of the FID instrument for the determination of OGC should be done using propane (preferably in a mixture with about 20 % oxygen in nitrogen). Moreover, it has to be ensured that the temperature of OGC measurement and the sampling line are at 180 °C. The uncertainty of measurement with regard to the measuring installations is for:

- CO: ± 10 % of the measured value, but max.
  - ± 10 ppm at a measuring range of 500 ppm
  - ± 45 ppm at a measuring range of 3,000 ppm
- O_2 and CO_2: ± 0.4 vol.- %
- NO_x: ± 5 % of the measured value, but max. ± 15 ppm

- OGC: ± 5 % of maximum value of measurement range.

Materials used for gas sampling lines and the connection of sensors must be suitable to withstand the expected temperature levels and must not be susceptible to react with flue gases or allow any diffusion. There must be no leaks throughout the whole test sampling system.

Remark: The measurement uncertainties indicated here exceed the requirements given in the prEN 16510-1 [3] to reflect state of the art in measurement devices and measuring accuracy.

Particle emission

Following the measuring protocol VDI 2066-1 [6] measurements shall be performed in the hot flue gas using out-stack gravimetric measurement principle. Uncertainty of dust measurements may be ± 15 % of the measured value at a maximum and in any event no more than 8 mg/m³ or ± 0.1 mg PM filter mass absolute as given in the prEN 16510-1 [3]. Results from measurements must be related to the dry flue gas flow.

Accuracy of measurement and measurement range

Table I summarizes all relevant parameters with suggested accuracy as well as measurement ranges for firewood room heaters and pellet stoves.

Remark: The measurement uncertainties indicated here exceed the requirements given in the prEN 16510-1 [3] to reflect state of the art in measurement devices and measuring accuracy.

Table I: Maximum uncertainty of measurement and minimum required measurement ranges for the beReal test method

Measurement value	Unit	Max. uncertainty of measurement	Suggested measurement range
Ambient air pressure	mbar	± 10 mbar	
Ambient temperature	°C	≤ 2 K	
Flue gas temperature	°C	≤ 5 K	0 – 1,000 °C
Static pressure	Pa	≤ 2 Pa	
O_2 content	vol.-%	± 0.4 vol.-%	0 - 21 vol.-%
CO_2 content	vol.-%	± 0.4 vol.-%	0 - 20 vol.-%
CO	vol.-%	± 10 % of measured value, but with a maximum of: ± 10 ppm at a measuring range of 500 ppm; ± 45 ppm at a measuring range of 3,000 ppm	At least 15,000 ppm (higher values can be cut off, but has to be stated in report)
NO_x content	ppm	± 5 % of measured value, but max. 15 ppm	up to 500 ppm
OGC (organic gaseous carbon content)	ppm	± 5% of maximum value of current measurement range	10,000 ppm
Particle emissions	mg/m³	± 15 % of measured value, but max. 8 mg/m³ (without O_2 correction)	
Fuel supply for room heaters (manually)	kg	up to 7.5 kg ± 5 g, above 7.5 kg ± 10 g	
Fuel mass for pellet stoves continuously	kg	± 0.1 % of measured value	
Ash mass	kg	± 0.5 g	
Flue gas velocity	m/s	± 0.5 m/s	0 – 10 m/s

6 Data Evaluation

The data evaluation will be implemented in an automatic web-based data calculation tool (http://bereal.bioenergy2020.eu/).

Remark: Currently (10/ 2016) a draft tool is already available for beReal project partners, but the latest developments of the method are not implemented yet.

The emission evaluation is mostly based on the calculations of the prEN 16510-1 [3]. The results for emissions are mean values including all eight batches respectively all four phases of the beReal test cycle.

For efficiency determination a thermodynamic approach is used, which contains for firewood room heaters all eight batches and the cooling down phase, for pellet stoves the four phases of the beReal test cycle are included. For the calculations of the specific heat capacity (c_p) and density (ρ) standard values of c_p and ρ for dry air are used and temperature compensated according to the following Table II and the formula described in chapter 6.2.

Table II: Specific heat capacity of dry air at defined temperatures ([7]). At a temperature in between the value of c_p is interpolated.

Temperature (°C)	c_p of dry air
0	1.005
100	1.011
200	1.025
300	1.045
400	1.070
500	1.093

6.1 Emission Evaluation

The emissions of the beReal cycle are batch-wise respectively phase-wise volume weighted results for firewood room heaters respectively pellet stoves. The following formulae shows the calculation for the volume weighting for firewood stoves (for pellet stove the calculation can be applied analogue – instead of the batches 1 to 8 the values should be referred to the four phases 1a, 1b, 2 and 3).

$$E_{volume\ weighted} = \frac{\sum_{i=batch1}^{batch\ 8} E_i\ V_{i,STP}}{\sum_{i=batch\ 1}^{batch\ 8} V_{i,STP}}$$

$$V_{i,STP} = \dot{V}_{i,operation}\ t_i\ \frac{273.15}{(273.15 + T_2)}\ \frac{p_{flue\ gas}}{1013.25}$$

$$\dot{V}_{i,operation} = \frac{d^2\pi}{4}\,\boldsymbol{v}$$

$E_{volume\ weighted}$…volume weighted flue gas concentration of one parameter (E = Emission) (ppm)

E_i…average flue gas concentration of one parameter for the respective batch (1…8) (ppm)

$V_{i,STP}$…total flue gas volume (at standard conditions) of the respective batch (1…8) (m^3_{STP})

$V(t)_{i,operation}$…wet volume flow of flue gas of the respective batch (1…8) (m^3/s)

t_i…duration of respective batch (1…8) (s)

T_2…flue gas temperature at measuring point T_2 (velocity measurement) (°C)

$p_{flue\ gas}$…absolute pressure of the flue gas (hPa)

d…diameter of the velocity measurement section (m)

v…velocity of flue gas (m/s)

The weighting interval is still under discussion and will be elaborated in the future. All emission values are calculated in the unit of mg/m³ (STP, dry, 13 % O_2).

An implementation of the cooling down phase for emission evaluation is still under discussion and will be defined in the future.

Carbon monoxide (CO)

As described above CO is measured continuously in parts per million (ppm) of dry flue gas. The following formula shows the calculation method for the conversion to mg/m³ (STP, dry, 13% O_2):

$$\boldsymbol{CO_{mg/m^3(STP,dry,13\%\,O2)}} = \boldsymbol{CO_{ppm}}\ \mathbf{1.25}\ \frac{\mathbf{(21-13)}}{\mathbf{(21-}\boldsymbol{O_{2,mean}}\mathbf{)}}$$

CO_{ppm} …volume weighted flue gas CO concentration (ppm)

$O_{2,mean}$…volume weighted O_2 concentration of batches 1 to 8 respectively phases 1a to 3, in %

Organic gaseous carbon content (OGC)

OGC is measured as methane- or propane-equivalents, in ppm in moist flue gas. The conversion formulae for methane-equivalents and propane-equivalents are given below:

Methane-equivalents:

$$\boldsymbol{OGC_{mg/m^3(STP,dry,13\%\ O2)}} = \frac{\boldsymbol{OGC_{ppm}\ 12}}{\boldsymbol{22.4}} \frac{\boldsymbol{(21-13)}}{\boldsymbol{(21-O_{2,mean})}} \frac{\boldsymbol{G_W}}{\boldsymbol{G_D}}$$

Propane-equivalents:

$$\boldsymbol{OGC_{mg/m^3(STP,dry,13\%\ O2)}} = \frac{\boldsymbol{OGC_{ppm}\ 36}}{\boldsymbol{22.4}} \frac{\boldsymbol{(21-13)}}{\boldsymbol{(21-O_{2,mean})}} \frac{\boldsymbol{G_W}}{\boldsymbol{G_D}}$$

$$G_w = \frac{C - C_r}{0.536\left(CO_{2,mean} + CO_{mean}\right)} + 1.24\,\frac{9\,H + W}{100}$$

$$G_D = \frac{C - C_r}{0.536\left(CO_{2,mean} + CO_{mean}\right)}$$

$$C_r = \frac{(m_{residues} - m_{fuel}\ a\ 1.2)}{m_{fuel}}\ 100\ \%$$

OGC_{ppm} …volume weighted flue gas OGC concentration (ppm)

$O_{2,mean}$…volume weighted, measured mean O_2 concentration of batches 1 to 8 respectively phases 1a to 3 (vol-%)

$CO_{2,mean}$…volume weighted, measured mean CO_2 concentration of batches 1 to 8 respectively phases 1a to 3 (vol-%)

CO_{mean}…volume weighted, measured mean CO concentration of batches 1 to 8 respectively phases 1a to 3 (vol-%)

C…carbon content of fired fuel (%, w.b.)

C_r…carbon content of residues referred to the quantity of the fired test fuel (% of mass)

H…hydrogen content of fired fuel (%, w.b.)

W…water content of fired fuel (%, w.b.)

$m_{residues}$…total mass of residues taken out of the stove after the beReal test cycle (kg)

m_{fuel}…total mass of fired test fuel (kg)

a…ash content of fired fuel (-)

Nitrogen oxide (NO_x)

NO_x can be measured by the gas analyzer in three different ways:

- As total NO_x

- As NO and NO_2
- As c * NO

To evaluate the NO_x result the following formula is applied:

$$\boldsymbol{NO_{x,mg/m^3(STP,dry,13\%\,O2)}} = \boldsymbol{NO_{x,ppm}\ 2.05\ \frac{(21-13)}{(21-O_{2,mean})}}$$

$NO_{x,ppm}$ …volume weighted flue gas NO_x concentration (ppm)

$O_{2,mean}$… volume weighted, measured mean O_2 concentration of batches 1 to 8 (vol-%)

If the gas analyzer is measuring NO and NO_2 separately, or only NO, the NO_x value can be calculated as follows:

$$NO_{x,ppm} = NO_{2,ppm} + NO_{ppm}$$

$$NO_{x,ppm} = c\ NO_{ppm}$$

Whereas *c* is a correction factor to respect the usual amount of NO_2 in the flue gas.

Particulate matter (PM)

As output of the gravimetric measurements in batch 1, 3, 5 and 7 the total sum of sampling probe in mg and the sum of the sucked flue gas volume of the gas meter at a certain temperature and pressure are given. With the following formula the PM concentration is calculated:

$$\boldsymbol{PM_{mg/m^3(STP,dry,13\%\,O2)}} = \boldsymbol{\frac{\sum(m_{filter,end}-m_{filter,start})}{\sum V_{gasmeter}}\ \frac{(21-13)}{(21-O_{2,mean})}}$$

$$V_{gasmeter} = \left(V_{gasmeter,end} - V_{gasmeter,start}\right)\frac{273.15}{(273.15+T_{gasmeter})}\ \frac{p_{ambient}}{1013}\ C_f$$

$m_{filter,end}$…mass of filter (planefilter and cartridge) at the end of sampling (mg)

$m_{filter,start}$…mass of filter (planefilter and cartridge) at the start of sampling (mg)

$O_{2,mean}$…volume weighted, measured mean O_2 concentration of the period under consideration (vol-%)

$V_{gasmeter,end}$…gas meter reading at the end of sampling (m³)

$V_{gasmeter,start}$…gas meter reading at the start of sampling (m³)

$T_{gasmeter}$…mean temperature of the gas meter during sampling (°C)

$P_{ambient}$…mean ambient air pressure (hPa)

C_f…Dry gasmeter calibration factor, standard value = 1 (-)

6.2 Efficiency Evaluation

Similar to the standard evaluation thermal efficiency (η) is determined in an indirect way via calculating the following losses:

- Thermal heat losses in the flue gas (q_a)
- Chemical heat losses in the flue gas (q_b)
- Losses due to combustibles in the residues (q_r)

$$\boldsymbol{\eta = (100 - q_a - q_b - q_r)}$$

For the beReal efficiency calculation these losses are calculated as described below.

Thermal heat losses (q_a)

For thermal heat losses calculation a thermodynamic approach is applied. Therefore, the velocity measurement is used for determining the mass flow of the flue gas. Furthermore a mean c_p is evaluated and the temperature difference between the surrounding and flue gas is calculated. Therefore, the following formulae can be applied:

$$\boldsymbol{q_a = \frac{\int \dot{Q}_{th.,flue\,gas}}{Q_{fuel}}\,100\%}$$

$$Q_{fuel} = m_{fuel}\,H_{u,fuel}$$

$$\dot{Q}_{th.,flue\,gas} = \dot{m}_{flue\,gas}\,c_p\,dT$$

$$\dot{m}_{flue\,gas} = \frac{d^2\pi}{4}\,\boldsymbol{v}\,\rho_{flue\,gas}$$

$$\rho_{flue\,gas} = \rho_{STP}\,\frac{273.15}{(273.15 + T_2)}\,\frac{p_{ambient} + 0.12}{1013}$$

$$dT = T_1 - T_{ambient}$$

$Q(t)_{th.,flue\,gas}$…thermal energy flow of the flue gas (kJ/s)

Q_{fuel}…thermal energy of the fired test fuel (kJ)

m_{fuel}…total mass of fired test fuel (kg)

$H_{u,fuel}$…net calorific value of the fired test fuel (kJ/kg)

$m(t)_{flue\ gas}$…mass flow of the flue gas (kg/s)

c_p…specific heat storage capacity (kJ/(kg K))

d…diameter of the velocity measurement section (m)

v…velocity of flue gas (m/s)

$\rho_{flue\ gas}$…density of the flue gas (kg/m²)

ρ_{STP}…density of the flue gas at standard conditions (kg/m^2_{STP})

$P_{ambient}$…mean ambient air pressure (hPa)

T_2…flue gas temperature at measuring point T_2 (°C)

T_1…flue gas temperature at measuring point T_1 (°C)

$T_{ambient}$…ambient air temperature (°C)

Chemical heat losses (q_b)

For the evaluation of chemical losses only the CO content in the flue gas is respected. The following formulae are used for the calculation:

$$\boldsymbol{q_b} = \frac{\boldsymbol{Q_{ch.,flue\ gas}}}{\boldsymbol{Q_{fuel}}}\ \mathbf{100}\%$$

$$Q_{ch,flue\ gas} = H_{u,CO} \int \dot{m}_{CO}$$

$$\dot{m}_{CO} = CO_{ppm}\ 1.25\ \frac{d^2\pi}{4}\ \boldsymbol{v}\ \rho_{flue\ gas}\ \frac{273.15}{(273.15 + T_2)}$$

CO_{ppm} …measured flue gas CO concentration (ppm)

$Q_{ch.,,flue\ gas}$…chemical energy of the flue gas (kJ/s)

Q_{fuel}…thermal energy of the fired test fuel (kJ)

$H_{u,CO}$…net calorific value of CO (kJ/kg)

$m(t)_{CO}$…mass flow of CO in the flue gas (kg/s)

d…diameter of the velocity measurement section (m)

v…velocity of flue gas (m/s)

$\rho_{flue\ gas}$…density of the flue gas (kg/m²)

T_2…flue gas temperature at measuring point T_2 (°C)

Losses due to combustibles in the residues (q_r)

In order to avoid an extensive ash analysis a simplified calculation method, using only the weight of the residues, will be used for determining the losses due to combustibles in the residues.

$$q_r = \frac{(m_{residues} - m_{fuel}\ a\ 1.2)\ H_{u,C}}{m_{fuel}\ H_{u,fuel}}\ 100\%$$

$m_{residues}$…total mass of residues taken out of the stove after the beReal test cycle (kg)

m_{fuel}…total mass of fired test fuel (kg)

a…ash content of fired fuel (-)

$H_{u,C}$…net calorific value of carbon (kJ/kg)

$H_{u,fuel}$…net calorific value of the fired test fuel (kJ/kg)

Remark: The factor of 1.2 respects the carbonate content of the ash, which is formed during combustion. This value will be evaluated and could be adapted in the future.

Flue gas velocity (v)

For efficiency determination it is essential that the velocity measurement and the determined flue gas flow factor are correct. Thus, a verification calculation is applied as a quality assurance tool.

In this calculation the combustion formulae for determining the combustion's produced flue gas volume is applied. According to the mass of fired fuel, the elemental composition of the fuel and the oxygen content of the flue gas, the total flue gas volume can be calculated as follows:

$$V_{f,STP,calculated}\ (m^3{}_{STP}) = \dot{V}_{f,STP,fuel}\ m_{fuel} - \dot{V}_{f,STP,\ combustibles}\ m_{combustibles}$$

$$\dot{V}_{f,STP}\ \left(\frac{m^3{}_{STP}}{kg_{fuel}}\right) = 1.87\ c + 0.7\ s + 11.2\ h + 1.24\ w + L_{min}\ \left(\frac{21}{21 - O_{2_{average}}} - 0.21\right)$$

$$L_{min} = \frac{1.87\ c + 5.6\ h + 0.7\ s - 0.7\ o}{0.21}$$

Whereas the elemental composition of the fuel (example) and the combustibles can be found in Table III.

$$m_{combustibles}\ (kg) = m_{residues} x_{combustibles}$$

$$x_{combustibles}\ (-) = \frac{m_{residues}\ -\ m_{fuel}\ \ a\ \ 1.2}{m_{residues}}$$

$V_{f,STP,calculated}$…calculated total volume (moist) at standard conditions of flue (m^2_{STP})

$V(t)_{f,STP,fuel}$…calculated volume flow (moist) at standard conditions of fired fuel (m^2_{STP}/kg_{fuel})

$V(t)_{f,STP,combustibles}$…calculated volume flow (moist) at standard conditions of combustibles in residues (m^2_{STP}/kg_{fuel})

m_{fuel}…total mass of fired test fuel (kg)

$m_{combustibles}$…mass of combustibles in the residues (kg)

$V(t)_{f,STP}$…calculated volume flow (moist) at standard conditions (m^2_{STP}/kg_{fuel})

c…carbon content of fired fuel (%, d.b.)

s…sulfur content of fired fuel (%, d.b.)

h…hydrogen content of fired fuel (%, d.b.)

w…water content of fired fuel (%, w.b.)

L_{min}…stoichiometric minimum air demand (-)

$O_{2,average}$…volume weighted, measured average O_2 concentration of the considered combustion duration (batches 1 to 8 inclusive cool down, respectively phases 1a to 3) (vol-%)

$m_{residues}$…total mass of residues taken out of the stove after the beReal test cycle (kg)

$x_{combustibles}$…combustibles content of residues (-)

a…ash content of fired fuel (-)

Table III: Elemental composition of test fuel (exemplary) and the combustibles, applied at the combustion calculation for verification of the velocity measurement

	Fuel (exemplary)	**Combustibles**
c	0.491	0.883
s	0.0002	0.0002
h	0.06	0.0319
w	0.13	0.06

For pellet stoves the amount of residues is not evaluated. Because of the little mass of residues at this kind of stove, this part ($V_{f,STP,combustibles}$ and $m_{combustibles}$) is neglected at the evaluation of pellet stoves.

In a next step the ratio between the calculated and the measured volume of flue gas is assessed by the factor CF:

$$CF = \frac{V_{f,STP,calculated}}{V_{f,STP,measured}}$$

$$V_{f,STP,measured} = \int \frac{d^2\pi}{4} \boldsymbol{v}\, \rho_{flue\ gas} \frac{273.15}{(273.15 + T_2)}$$

CF…correction factor of the velocity measurement (-)

d…diameter of the velocity measurement section (m)

v…velocity of flue gas (m/s)

$\rho_{flue\ gas}$…density of the flue gas (kg/m²)

T_2…flue gas temperature at measuring point T_2 (°C)

To guarantee good results and an appropriate accuracy of the velocity measurements the CF shall be in a range of 0.8-1.2 (deviation of ±20%). Out of this range the velocity measurement has to be evaluated anew and the beReal test have to be repeated.

In this range of ±20% the CF is used as a correction factor on calculating the thermal (q_a) and chemical losses (q_b) in the flue gas (which depends on the velocity measurement).

$$q_{a,corrected} = CF\ q_a$$

$$q_{b,corrected} = CF\ q_b$$

So the thermal efficiency is calculated as follows:

$$\boldsymbol{\eta = (100 - q_{a,corrected} - q_{b,corrected} - q_r)}$$

Remark: As this approach is newly developed it has to be validated and maybe adapted in the future.

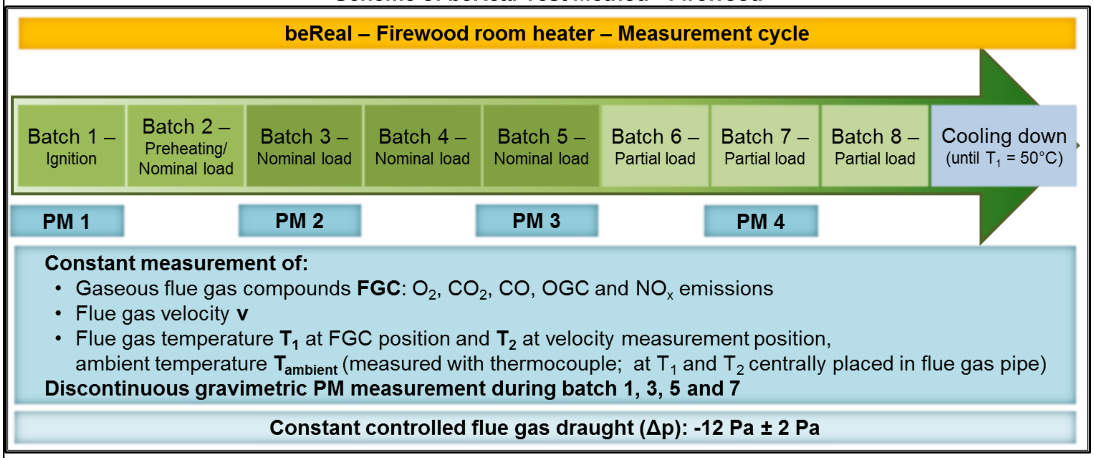
7 Summary – At a Glance

Final BeReal Test Method – Firewood: Descriptions/ Schemes/ Pictures

Test procedure & Measurements & Operation Mode

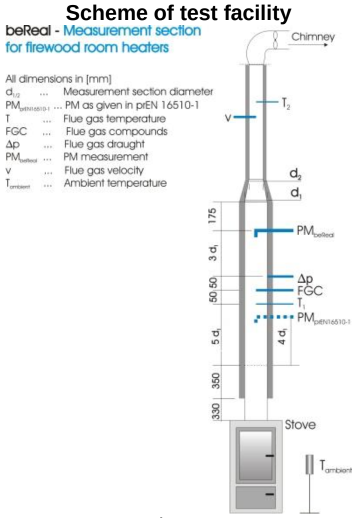
Eight consecutive batches starting from cold conditions (starting with an ignition batch) and cooling down phase until T_1 = 50°C
Batch 1 to 5: nominal load batch mass 100 % / part load batch 6 to 8: batch mass 50 %
Constant flue gas draught over the whole test cycle at 12 ± 2 Pa
Refilling:CO_2 flue gas content either 25 % of maximum CO_2 and 4 % CO_2 absolutely (when maximum CO_2 > 16 %)/ if maximum CO_2 is <12 % ,refilling is allowed at 3 % CO_2 absolutely (if flames already extinguished)
Operation according to an obligatory QuickUserGuide: Definition of relevant operation characteristics by text and pictures: Ignition mode, batch criteria, air inlet flap settings (see Example below)
Continuous gaseous measurements: O_2, CO_2, CO, OGC, NO_x
Discontinuous particulate measurement: Gravimetric out-stack PM measurement in batch 1, 3, 5, 7 (sampling over the whole batch duration)
Continuous temperature measurements: Flue gas temperature with centrally placed thermocouple for determination of thermal flue gas losses (T_1 & T_2) and ambient air temperature according prEN 16510-1 ($T_{ambient}$)

Scheme of beReal Test Method - Firewood



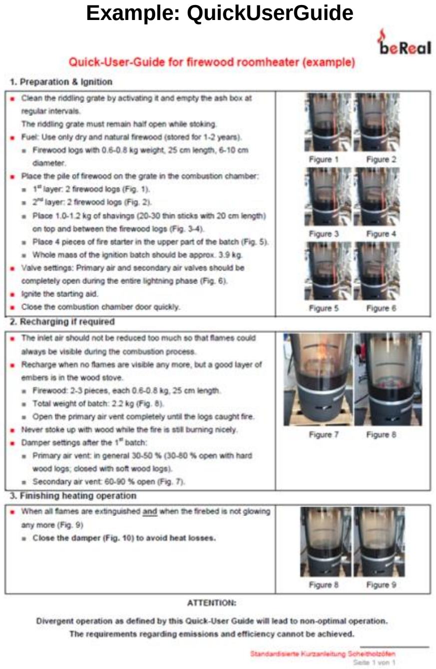
Test facility and QuickUserGuide

Scheme of test facility



Order of measurements: Flue gas temperature (T_1) → gas analysis (FGC) → flue gas draught (Δp) → PM (PM2) → flue gas velocity (v) → flue gas temperature (T_2)

Example: QuickUserGuide


beReal

Quick-User-Guide for firewood roomheater (example)

1. Preparation & Ignition
- Clean the riddling grate by activating it and empty the ash box at regular intervals.
- The riddling grate must remain half open while stoking.
- Fuel: Use only dry and natural firewood (stored for 1-2 years).
  - Firewood logs with 0.6-0.8 kg weight, 25 cm length, 6-10 cm diameter.
- Place the pile of firewood on the grate in the combustion chamber:
  - 1st layer: 2 firewood logs (Fig. 1).
  - 2nd layer: 2 firewood logs (Fig. 2).
  - Place 1.0-1.2 kg of shavings (20-30 thin sticks with 20 cm length) on top and between the firewood logs (Fig. 3-4).
  - Place 4 pieces of fire starter in the upper part of the batch (Fig. 5).
  - Whole mass of the ignition batch should be approx. 3.9 kg.
- Valve settings: Primary air and secondary air valves should be completely open during the entire lightning phase (Fig. 6).
- Ignite the starting aid.
- Close the combustion chamber door quickly.

Figure 1 Figure 2 Figure 3 Figure 4 Figure 5 Figure 6

2. Recharging if required
- The inlet air should not be reduced too much so that flames could always be visible during the combustion process.
- Recharge when no flames are visible any more, but a good layer of embers is in the wood stove.
  - Firewood: 2-3 pieces, each 0.6-0.8 kg, 25 cm length.
  - Total weight of batch: 2.2 kg (Fig. 8).
  - Open the primary air vent completely until the logs caught fire.
- Never stoke up with wood while the fire is still burning nicely.
- Damper settings after the 1st batch:
  - Primary air vent: in general 30-50 % (30-80 % open with hard wood logs; closed with soft wood logs).
  - Secondary air vent: 60-90 % open (Fig. 7).

Figure 7 Figure 8

3. Finishing heating operation
- When all flames are extinguished and when the firebed is not glowing any more (Fig. 9)
  - Close the damper (Fig. 10) to avoid heat losses.

Figure 8 Figure 9

ATTENTION:
Divergent operation as defined by this Quick-User Guide will lead to non-optimal operation.
The requirements regarding emissions and efficiency cannot be achieved.

Standardisierte Kurzanleitung Scheitholzöfen
Seite 1 von 1

Results

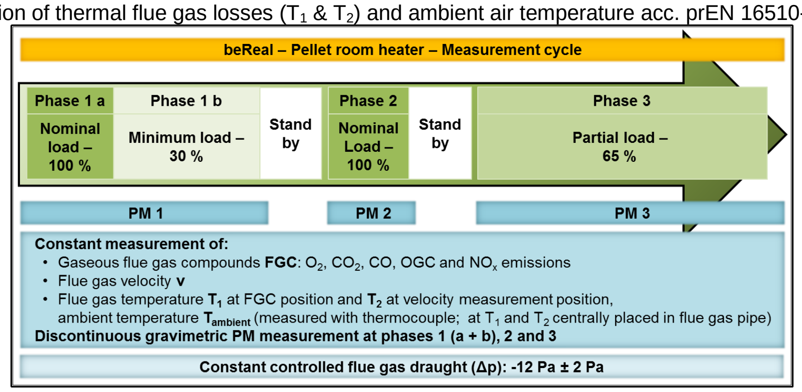
Data analysis by web-based calculation tool: http://bereal.bioenergy2020.eu/
Results for emissions and thermal efficiency represent the performance over the whole test duration.
Test report automatically produced by the online tool (including the overall result acc. to label scheme).

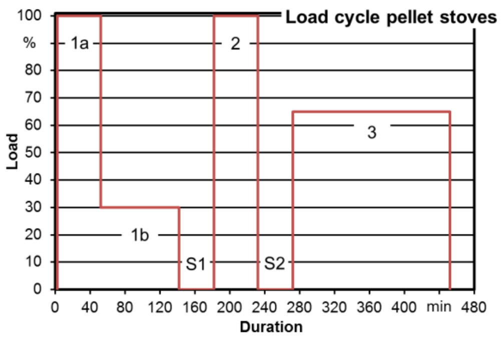
Final BeReal Test Method – Pellet: Descriptions/ Schemes/ Pictures

Test procedure, Measurements & Operation Mode

Testing the pellet stove via a test cycle including maximum (high load), minimum (low load) and medium load settings as well as cold and warm starts.

- Continuous gaseous measurements: O_2, CO_2, CO, OGC, NO_x
- Discontinuous particulate measurement: Gravimetric out-stack PM measurement in each phase (1a, 1b, 2, 3) (sampling over the whole phase until O_2 reaches 20 vol.-% after the respective phase)
- Continuous temperature measurements: Flue gas temperature with centrally placed thermocouple for determination of thermal flue gas losses (T_1 & T_2) and ambient air temperature acc. prEN 16510-1 ($T_{ambient}$)

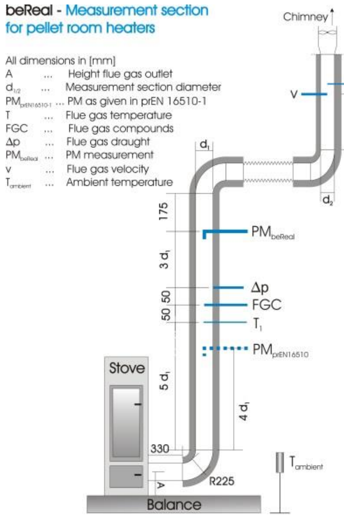




Phase	Operation	Load level*	Duration°
1a	Cold start	High load	50 min
1b	Load change	Low load	90 min
S1	Standby	0%	40 min*
2a	Warm start	High load	50 min
S2	Standby	0%	40 min*
3	Warm start	Medium load	180 min

Remark: Phase duration starts at a CO concentration in the flue gas of 10 ppm.

Test facility



Order of measurements:
Flue gas temperature (T_1)
→ gas analysis (FGC)
→ flue gas draught (Δp)
→ PM (PM2)
→ flue gas velocity (v)
→ flue gas temperature (T_2)

Results

Data analysis by web-based calculation tool: http://bereal.bioenergy2020.eu/
Results for emissions and thermal efficiency represent the performance over the whole test duration.
Test report automatically produced by the online tool (including the overall result acc. to label scheme).

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