TECHNICAL REPORT ON EMISSION FACTORS, EMISSION LIMITS, AND ROUND ROBIN WITH REAL-LIFE TEST PROTOCOL

SUMMARY OF ACTION A5 REPORT

12/2024

PROJECT: HARMONIZING RELIABLE TEST PROCEDURES REPRESENTING REAL-LIFE AIR POLLUTION FROM SOLID FUEL HEATING APPLIANCES

Real-LIFE emissions, Life preparatory project 2020

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Authors: Claudia Schön (TFZ), Hans Hartmann (TFZ), Kamil Krpec (VSB), Isaline Fraboulet (INERIS), Sergio Harb (INERIS), Juho Louhisalmi (UEF), Jarkko Tissari (UEF)

Technical report on emission factors, emission limits, and round robin with real-life test protocol

Summary of action A5 report

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1. Summary of the results of action A5

Within this action, emission limits and emission factors were first summarized from existing literature or own experiments within the consortium. Then, the Real-Life test protocol was developed and validated. Finally, this protocol was applied in screening tests using of 11 market available log wood appliances. Several other measurements tests were additionally performed using the novel dual-filter test method (the “Extended ENPME-method”).

Real-LIFE test protocol development and validation. The novel Real-LIFE test protocol for log wood stoves was developed, defined, validated on two log wood stoves. The Real-LIFE test protocol considers the ignition phase of the stove (2 batches), three batches at nominal load, two batches at 65 % partial load and one overload batch (150 % fuel mass from nominal load), which was achieved by increasing the number of equally sized logs. It is important that the first two batches are performed at natural draught conditions while for the subsequent batches controlled and constant draught conditions are applied at different levels.

The round robin with four participants (all were project partners) was performed using two different log wood stoves. The fuel was provided to all partners in the correct mass and log sizes to avoid any fuel-based influences on the emissions while performing the Real-LIFE test protocol. This Real-LIFE test protocol had been validated within a mini-round-robin organized and evaluated by TFZ. Two log wood stoves were shipped to the partners INERIS, UEF and VSB. Moreover, the fuel, which was procured in one homogeneous delivery, was also provided to all partners in the already correct logs size. Uniform ignition aids were also provided. The goal was that the Real-LIFE test protocol was performed three times for each stove and all data was sent to TFZ for further evaluation. Not all requirements could be considered during this round robin such as the natural draught conditions at the beginning of the Real-LIFE test protocol due to low ceiling heights at some partners testing laboratories. Also, one partner did not always follow the Real-LIFE test protocol causing higher emissions in comparison to the other participating partners. Nevertheless, this round robin showed a coefficient of variation (i.e. standard deviation divided by the mean value) in a low range. For CO emissions, for example, this coefficient of variation (CV) was at about 16 % and 14 % for stove A and stove B, respectively. OGC emissions achieved a CV of 4 % and 16 % for stove A and stove B, respectively. The higher value for stove B was mainly caused by one partner due to late recharging of the stove. NO_X emissions were in the same order of magnitude for this coefficient being as high as 9 % for both stoves. TPM emissions in the hot flue gas achieved a CV of 11 % and 22 % for stove A and stove B, respectively. This round robin proved a good repeatability of the newly developed Real-LIFE test protocol but also pointed out the importance of following strictly the described test protocol as well as a harmonized calculation procedure. With more testing routine and further practise in an adapted testing infrastructure, the method is likely to provide even higher uniformity of results. In general, it can be recommended that round robins using log wood stoves should be conducted more often with more participants.

Real-LIFE emission screening using 11 log wood appliances. The Real-LIFE test protocol was applied to eleven small scale combustion appliances of different ages, different equipment (catalyst, electrostatic precipitator), with or without grate, different sizes of the combustion chamber, various price levels, and so on. The purchase price varied between about 400 € and 8000 €, the combustion chamber size varied between 17 litre and 83 litre and the required log length ranged from 20 cm to 50 cm. The most expensive stove was equipped with a catalyst and an ESP (stove 1). Stove 3 was only equipped with a catalyst. Two appliances were insets (stove 8 and 11). These combustion tests for data base generation were performed by the partners TFZ, VSB and INERIS, while TFZ compiled and summarized all generated data.

The emission behaviour of all appliances was different. While stove 1 released CO emissions as low as 360 mg/MJ for the entire Real-LIFE test protocol (8 batches), stove 9 emitted a much higher level of 3329 mg/MJ of CO. Only three stoves were below 1000 mg/MJ for the entire Real-LIFE test protocol. A few stoves could not handle overload or partial load that well.

The lowest OGC emissions were released by stove 2 being as low as 79 mg/MJ followed by stove 7 with an OGC concentration of 94 mg/MJ. Also stove 1 with OGC emissions of 106 mg/MJ would also fulfil the requirements of the Ecodesign even when applying the challenging Real-LIFE test protocol (Ecodesign values are only determined during nominal load conditions). Highest OGC emissions were released from stove 9 with 431 mg/MJ during the eight batches (i. e. the overload situation).

NO_X emissions varied between 57 mg/MJ for stove 11 and 87 mg/MJ for stove 1. It can clearly be seen that if CO emissions are high NO_X emissions are usually low.

TPM emissions were detected according to EN16510-1:2022 in the hot flue gas at 180 °C at constant sampling speed. The lowest TPM emissions were detected by the stove equipped with an ESP having TPM values of only 4 mg/MJ (stove 1). Stove 2 and 7 also emitted rather low TPM emissions of 21 and 23 mg/MJ which would also fulfil the Ecodesign requirements even when applying the challenging Real-LIFE test protocol. TPM emissions were highest for stove 9 and 11 with values of 60 mg/MJ and 62 mg/MJ, respectively.

Further measurements and evaluations. The extended ENPME method (ENPME plus porous tube diluter and second filter) was only applied to some batches at some stoves. Since not each single batch could be measured, no final evaluation can be made at that stage. Further research and additional TPM measurement equipment is needed.

Four wood pellet stoves were tested at TFZ during nominal load, partial load and during real life operation following the “beReal test protocol” which had been developed in a previous EU project. This protocol can be considered as a proven and validated method for reflecting real life operational practises for pellet stoves. In general, CO and OGC emissions were much lower for pellet stoves compared to log wood stoves. Only for one pellet stove very low TPM emissions of 5 mg/MJ were detected during nominal load and 13 mg/MJ during the “beReal test protocol”.

Coal briquette combustion was only investigated in stove 9 at nominal and partial load since the Real-LIFE test protocol for wood logs could not be applied. CO emissions varied between 1700 and 3400 mg/MJ, OGC emissions between 110 and 570 mg/MJ and TPM emissions between 40 and 200 mg/MJ. This indicates that the emissions during coal combustion are in most cased higher than from wood log combustion.

Finally, data from a previous project at TFZ were evaluated, where automatically fed biomass boilers were tested at nominal load and partial load conditions as well as during real life operation following the load cycle test developed by TFZ and BEST (Austria) some years ago. In total eight pellet boilers and two wood chip boilers without buffer tank had been tested. As expected, the emissions in general were higher during the load cycle test compared to the emissions at nominal load. CO emissions as low as 4 or 5 mg/MJ were achieved during nominal load while the emissions increased up to 626 mg/MJ for one of the pellet boilers applying the load cycle test. Moreover, the OGC emissions were typically below the detection limit at nominal load, but this parameter increased to 39 mg/MJ during the load cycle for one of the pellet boilers. One pellet boiler remained constantly at low TPM emissions of only 3 to 5 mg/MJ during all operation modes, including the load cycle operation. But for one pellet boiler a very pronounced increase in TPM emissions was observed when applying the real-life test of a load cycle, emissions climbed from 7 to 54 mg/MJ.

In summary, it was shown within this action, that the emission behaviour is typically largely different during type test compared to a real-life operation. For determining emission factors, therefore, the Real-LIFE test protocol for log wood stoves which was defined, tested, validated, and comprehensively applied in this project, can be suggested. For automatically charged boilers and pellet stoves, similar protocols had previously already existed, their use can also be recommended.

2. Real-LIFE test protocol procedure for log wood stoves in detail

The Real-LIFE test protocol is a combination of EN 16510-1:2022, Blue Angel Certificate, the beReal test protocol, additional experiences gained, and discussions held over the last years.

The four phases of the Real-LIFE test protocol:

"Ignition phase" (two batches): It starts at room temperature with natural draught of maximum 2 Pa at the EN 16510-1:2022 sampling port, whereby one dust measurement must be carried out over the complete ignition operation (i. e. 2 batches). The TPM sampling starts immediately after the firebox is closed and ends when the reloading criteria of the second batch is reached. At higher TPM emissions, also a stuffed cartridge may be used before the quartz plane filter (if they are rather small such as 47 mm in diameter). This is to extend the sampling duration (no chemical analysis will then be possible, but for this test protocol this is not an issue). Or use larger plane filters to decrease the pressure drop. The fuel mass for ignition (1st batch) should be either according to manufacturer or add 25 % of mass as kindling material to the nominal load mass. Add one or two igniters. Ignition should be done from the top or the bottom depending on the recommendations by the manufacturer. Please note everything in the protocol. Apply natural draft during this ignition phase.

"Nominal load phase" (three batches): Nominal load, where three TPM measurements are carried out according to EN 16510-1:2022 at 12 Pa (tolerance +/- 2 Pa) chimney draft (forced draught), performed in uninterrupted sequence after the “ignition phase”, all batches must be included in the evaluation. The TPM measurements are started immediately after recharging and closing the door and terminated when the recharging criteria is reached. The fuel mass charged is as recommended by the manufacturer representing nominal load while using at least two logs. Log orientation in the combustion chamber is in accordance to the manual.

"Partial load phase" (two batches): "Partial load" is the smallest adjustable power according to the manufacturer's specifications. The fuel mass recharged is according to the manufacturer; otherwise, 65 % of nominal load with minimum two logs. This partial load phase with 65 % fuel load needs to be conducted also in the case the stove has only a label for one heat output!

The chimney draft is modified for the 5th measurement by transition from 12 Pa to the "partial load" draft as specified by the manufacturer or, if this is not specified, to 6 Pa (tolerance: +/-1 Pa) at forced draught. Two TPM measurements are performed and evaluated, these batches follow directly after the nominal load operation.

Do not change air settings unless the manufacturer recommends adjustments.

“Overload phase” (one batch): Overload is performed as nominal load but with the following adjustments: Flue gas draught is set as recommended by the manufacturer to or at least to 14 Pa or at least 2 Pa higher than applied for nominal load. Fuel mass should be at 150 % of the fuel mass at nominal load. The increase in mass shall be done by increasing the number of logs instead of using thicker logs. This will influence the combustion behavior. Air supply should be as for nominal load. Since the overload batch is conducted after two partial load batches, it may be necessary to add some extra air during the first 3 minutes to achieve ignition of the fuel.

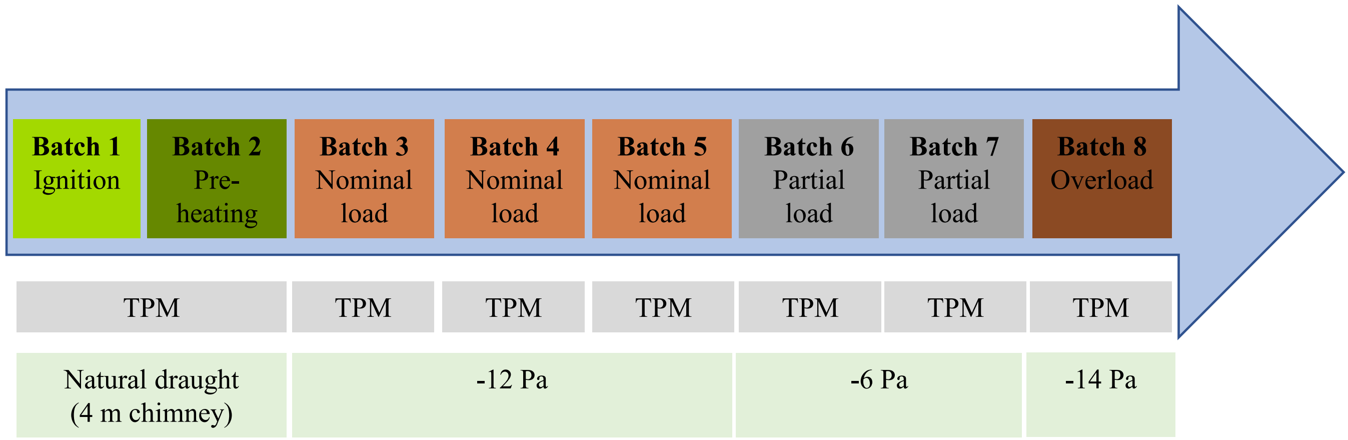

Figure 1: The Real-LIFE test protocol for log wood stoves.

Further method specifications are instructions:

Recharging: The CO_2 criteria is easily detected in most testing laboratories and is therefore chosen as the preferred recharging criteria. But it may cause an increase in ember height. Recharging should be done at (4 ± 0.5) vol-% CO_2. If the CO_2 concentration remains below 12 vol-% during the entire batch, the recharging moment is at (3 ± 0.5) vol-% CO_2. Always record your CO_2 value at recharging.

If an automatic air control is implemented in the stove, recharge the stove at flame extinction or when the recharging signal is given by the control. During partial load operation it may happen that the recharging signal will always be present. In that case, please recharge the stove at (4 ± 0.5) vol-% CO_2 and record it in your testing protocol.

The weight criterion for recharging is excluded. It is not suitable due to high risk of measurement error with the balance. This is because all sampling lines are mounted to the flue gas duct which is connected directly to the stove.

It is highly recommended to perform a pre-test with your own fuel to become familiar with the appliance and the test protocol.

Open the stoves door slowly to avoid flue gases leaving the stove and level out the ember before recharging.

The maximum break between two subsequent TPM measurement of the single batches is 3 minutes! If a filter change would take longer, the stove would cool down too far causing poor reignition of the fuel and higher emission. *The 3 minutes-time limit is crucial!* Any deviation from that this instruction shall be reported in the test protocol!

End of measurement: When the selected recharging criterion is met during the 8th batch.

TPM measurement in hot flue gas with ENPME only:

- The ENPME method is used as reference since this is the TPM determination in EN 16510-1:2022.
- The nozzle of the ENPME probe must be positioned in the centre of the flue gas duct diameter. Constant sampling rate shall be of 10 l/min (STP). During sampling, check the flow rate and adjust if necessary.
- TPM sampling should start right after closing the door after recharging, it ends when the subsequent recharging criteria is met.
- The TPM filter must be changed before closing the door.
- If TPM sampling stops due to too high TPM deposits on the filter, it is allowed to change the filter within 2 minutes. Please note this in the protocol.

- The sampling line shall be cleaned by rinsing three times, first with water and then with acetone. This is done before each measurement day. The sampling line is then dried with compressed air before beginning the measurement campaign. There shall be no brushing of the sampling line. No weight determination of these rinsed deposits is needed.
- The filter holder must be preheated to 180 °C so that the required sampling temperature behind the ENPME probe is always guaranteed! A TPM measurement is necessary for every batch, except for batch 1 and 2 being sampled during one measurement.
- Always perform a leakage check of the TPM sampling line before the first measurement as described in EN 16510-1:2022 (F.3.1.3).
- Rinse the sampling line after each measurement day with pressurized air (100 l/min for 30 seconds on a clean weighted TPM filter) and distribute the mass corresponding to the TPM mass of the measurement as described in F.3.4. Report the determined TPM concentrations without and with deposits in the protocol for final decision about whether the depositions are of importance.
- Rinse the probe with acetone and distilled water after collecting the deposits with pressurized air and don’t consider the liquid any further. This is only to make sure that the next measurements are started with a clean probe.
- Filter media pre-treatment is at 200 °C for at least 1 hour, then the unloaded filters are cooled down in a desiccator for at least 8 hours.
- Filter media post-treatment is at 180 °C for at least 1 hour, then the loaded filters are cooled down in a desiccator for at least 8 hours.
- Note: If one or more TPM measurement fails, the entire test protocol/testing day needs to be repeated.

Air adjustments

- Air adjustments may be done after the first batch since during this first batch more air is needed for good combustion. At the beginning of the second batch, the final setting shall be made according to the manufacturer’s instructions. Air adjustments during the first 3 minutes are allowed in EN 16510-1:2022, A.4.7.3 but this shall be accomplished latest after 3 minutes. Do not forget it! Please always state any deviation in the test protocol.
- Read the user instructions manual for air adjustment.
  No air adjustments are necessary for stoves with automatic air control unless the user manual gives some exclusion, e.g. for the case that fuel does not ignite. Some stoves have an additional handle to be operated in that case.

Experimental setup

The flue gas duct must be **4.0 m height**, and the sampling ports must be in accordance with EN 16510-1:2022. The standstill draft before ignition should not exceed 2 Pa. Natural draught has to be applied during the first two batches („ignition phase“). Higher ducts will cause higher flue gas draught during natural draught and shorter ducts will cause lower flue gas draughts which may influence the emission behavior during the first two batches.

Conditions of the appliances to be tested

- The appliance shall not be completely new (must be pre-used)
- An operation of at least 10 hours at nominal is required before performing the test protocol. This is the procedure recommended in the Norwegian Standard NS 3058:1994
  Air leakage rate has to be determined before setting up the appliance, it should be also repeated after the combustion tests.

Fuel

- Use hard wood with bark (e. g. beech) at a moisture content of 10-15 w-%.
- Log length is chosen according to user manual.
- Chose the number of logs according to user manual.
- Chose the weight per log according to the user manual depending on tested heat output of the batch.

Parameters measured (obligatory):

- Determine O_2 or CO_2 for recharging the stove and for recalculation the emissions to the 13 % O_2-basis. O_2 shall not be detected by an FTIR device!
- CO is measured without cutting-off any peaks (check the range of your analyser!). Otherwise, the CO emissions will be underestimated! This is a crucial requirement!
- Determine NO_X preferably with single component analyser.
- OGC is determined at (180 ± 10)°C using an FID. An FTIR device is not suitable for OGC determination because this will lead to higher OGC values.
- OGC calibration gas: suggested is propane in nitrogen. State the choice in protocol.
- No determination of flue gas velocity is required since a non-proportional sampling of TPM is performed (EN 16510-1:2022).

Calculation

- CO emissions: Follow section A.6.2.6 in EN 16510-1:2022.
  - Calculate average value of CO in ppm and multiply it by 1.25 to convert it into mg/m³.
  - Calculate average value of O_2 in vol-%.
  - Multiply CO value in mg/m³ with (21 - 13)/(21 – average O_2).
- NO_X emissions: Follow section D.5 in EN 16510-1:2022.
  - Calculate average value of NO_X in ppm and multiply it by 2.05 to convert it into mg/m³.
  - Calculate average value of O_2 in vol-%.
  - Multiply NO_X value in mg/m³ with (21 - 13)/(21 – average O_2).
- OGC emissions: Follow section E.4.3 in EN 16510-1:2022.
- TPM emissions are weighted according to the batch duration.

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Harmonizing reliable test procedures representing real-LIFE air pollution from solid fuel heating appliances - **Real-LIFE Emissions** project.

Project Partners

- University of Eastern Finland (UEF)
- Technical University in Ostrava (VSB)
- The French National Institute for Industrial Environment and Risks (INERIS)
- Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ)

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