Report

Comparison of test method EN 16510-1:2018 with EN-PME test method vs NS 3058-1/2:1994 and NS 3059:1994

EN-PME+EN 16510-1:2018 PM emission test method vs NS 3058-1/2:1994 and NS 3059:1994

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RISE Fire Research
RISE report 20012-72

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Summary

Emissions from combustion processes are of growing concern due to the impact on health and environment. Especially residential biomass heaters are becoming a significant source for emissions to air. Therefore, there is a strong need of a harmonized standard for residential heaters fired by solid fuel, which initiated the work of developing a new standard EN 16510-1, latest published in July 2018. An earlier European research project suggested the EN-PME test method as temporary test method for particles from wood heating. This method is now suggested as test method for EN 16510-1. The verification project to validate this test method measured almost identical amounts of PM compared to the previous heated filter method based on DINplus. RISE Fire Research AS and SINTEF Energy Research participated in the validation project. Parallel testing of NS 3058 with EN-PME and EN 16510-1 with EN-PME were performed. The results showed no correlation between EN 16510-1 with EN-PME and NS 3058, due to the way PM emission are measured (heated filter vs. dilution tunnel) and because of two very different test procedures. This comparison showed that the PM emissions according to NS 3058 where 7 times higher compared to EN-PME. EN 16510-1 only requires testing at nominal heat output with an amount of test fuel declared by the manufacturer vs. NS 3058 which requires testing at four different heat outputs with an amount of fuel calculated from the size of the combustion chamber. Testing at nominal heat output and with a test fuel defined by the manufacturer resulted in significant lower emission. Two Ecodesign wood stoves were tested to investigate the influence of the test procedure. The stoves were tested according to EN 16510-1 and in addition with a test procedure similar to the Norwegian Standard. PM emissions doubled when the test fuel was increased from 1.3 kg to 2 kg at nominal heat output. One stove was tested with NS3058/59 and exceeded the emission limit of 5 g/kg set by Ecodesign for the dilution tunnel method, clearly showing the EN-16510-1 test procedure is not good enough to contribute to the development of better stoves. Most likely future wood stoves will (which are planned to be only tested according to EN 16510-1 with EN-PME) produce more emissions to air when just tested and optimized for one combustion condition than today's Nordic Swan labelled appliances which are tested with NS 3058/59.

EN-16510-1 with EN-PME neither contribute to a simplified emission inventory calculation since condensed particles are not measured. There is no correlation between OGC and condensed particles for modern wood heaters.

There is still a strong need for a harmonized test method reflecting realistic use of a stove and real-life emission. The work should be mainly driven from an environmental point of view and much less by manufactures interests.

Sammendrag

Utslipp fra forbrenningsprosesser er av økende bekymring på grunn av innvirkning på helse og miljø. Spesielt vedfyring i boliger har blitt en betydelig kilde til utslipp til luft. Derfor er det et sterkt behov for en harmonisert standard for vedovner som fyres med fast brensel, noe som initierte arbeidet med å utvikle en ny Europeisk standard, EN 16510-1, sist publisert i juli 2018. Et tidligere europeisk forskningsprosjekt foreslo EN-PME testmetoden som en midlertidig testmetode for partikler. Denne metoden er nå foreslått som testmetode i EN 16510-1. I et verifiseringsprosjekt for å sammenligne EN-PME med den eksisterende DIN-plus metoden, ble det målt nesten identiske mengder PM for alle ovnene som ble testet. RISE Fire Research AS og SINTEF Energy Research deltok i dette valideringsprosjektet. Parallell testing av NS 3058 og EN-PME + EN 16510-1 ble gjennomført. Resultatene viste ingen sammenheng mellom EN 16510-1 + EN-PME og NS 3058, dette både grunnet måten PM-utslipp måles på (oppvarmet filter vs. uttynningstunnel) samt to veldig forskjellige testprosedyrer. Denne sammenligningen viste at PM-utslippene ifølge NS 3058 var 7 ganger høyere sammenlignet med EN-PME. EN 16510-1 krever bare testing ved nominell varmeeffekt med en mengde brensel deklarert av produsenten i motsetning til NS 3058, som krever testing ved fire forskjellige effekter med en mengde brensel beregnet ut fra størrelsen på forbrenningskammeret. Testing på nominell varmeeffekt og med en brenselsmengde definert av produsenten resulterte i signifikant lavere utslipp. To Ecodesign godkjente ovner ble testet for å undersøke innflytelsen av testprosedyren. Ovnene ble testet i henhold til EN 16510-1 og i tillegg iht. testprosedyren i den norske standarden. PM-utslipp ble doblet da mengde brensel ble økt fra 1,3 kg til 2 kg ved nominell varmeeffekt. En ovn ble testet iht. NS3058/59 og overskred utslippsgrensen på 5 g/kg, satt av Ecodesign for uttynningstunnel metoden. Dette viser tydelig at EN-16510-1 testprosedyren ikke er god nok til å bidra til at nye ovner blir bedre når det gjelder utslipp. Mest sannsynlige vil fremtidige vedovner (som planlegges å kun testes i henhold til EN 16510-1 med EN-PME) gi mer utslipp til luft når de bare er testet og optimalisert på nominell effekt, samt for lite mengde brensel, enn dagens svanemerkede vedovner testet iht. NS 3058/59.

EN-16510-1 med EN-PME bidrar heller ikke til en forenklet beregning av nasjonale utslippsinventar, da mengden kondenserte partikler ikke måles. Det er ingen sammenheng mellom OGC og kondenserte partikler for moderne vedovner.

Det er fortsatt et sterkt behov for en harmonisert testmetode som gjenspeiler realistisk bruk av vedovner. Metoden bør hovedsakelig utformes ut ifra miljømessige hensyn, uten at produsentens interesser ivaretas i den grad det gjøres i dag.

1. Introduction

Emissions, especially particle matter (PM), from solid fuel local space heaters (LSH) are of (growing) concern for authorities and public, due to the impact on health, environment and climate. A reliable, traceable and reproducible certification test procedure and -method is needed, able to provide close to real-life emissions. Until now various methods have been in use in Europe to measure the PM emission from solid fuel LSH, which are not compatible with each other. This leads to a situation that it is not possible to compare the performance of LSH with respect to PM emission, when these LSH have been tested with different methods.

Current Commission regulation (EU) 2015/1185 of 24 April 2015 (last revised in 2017) sets Ecodesign requirements for solid fuel LSH as shown in Table 1, including requirements for PM emissions. According to this regulation, the PM emission may be measured by each of the current three methods, i.e.:

1. Heated filter (HF) method (prev. EN 13240:2001 + DINplus + CEN/TS 15883:2009, now EN 16510-1:2018 + EN-PME)
2. Full flow dilution tunnel (FFDT) method (NS 3058:1994 and NS 3059:1994)
3. Electrostatic precipitator (ESP) method (CEN/TS 15883:2009)

Table 1: Emission requirements according to Ecodesign requirements for solid fuel local space heaters ((EU) 2015/1185)[1] being enforced by 2022.01.01

Method	Wood log appliance	Wood pellet appliance	Mineral fuel
Heated filter	40 mg/m^3	20 mg/m^3	40 mg/m^3
FFDT	5 g/kg fuel	2.5 g/kg fuel	5 g/kg fuel
ESP	2.4	1.2 g/kg fuel	5 g/kg fuel

In 2018 the test standard EN 16510-1:2018 – *Residential solid fuel burning – Part 1: General requirements and test methods* was published as a non-harmonized standard. The new standard was supposed to replace the three methods described in the technical specification CEN-TS 15883[2] for emission testing from residential heating by solid fuel. Three methods for particle measurements were described in the standard, Austrian and German particle test method (DINplus), Norwegian particle test method (NS 3058) and UK particle test method.

The published standard EN 16510-1 contain both a heated filter method and in addition a method with full flow dilution tunnel (FFDT). However, it is planned that both methods are replaced by the EN-PME test method.

One of the main reasons that EU strive for a new harmonized standard to certify LSH, is to simplify the development and sales of new products. Today, producers must often develop

[1] https://eur-lex.europa.eu/eli/reg/2015/1185/2017-01-09

[2] CEN/TS 15883:2009 Residential solid fuel burning appliances – Emission test methods

specific LSH for each standard, or end up with an unoptimized product in compliance with two or more standards. This concerns both the European and the US market.

The most important reason for harmonizing European standards is due to the incompatibility between the current PM measurement standards as each test standard uses a specific setup (read “method”, with different sampling location and thereby incomparable physical conditions) and procedure, to sample particles. Neither of these methods are intercomparable, meaning that no correlation between measured results either exist or can be made in the future. This has been proven again and again in previous measurement campaigns across Europe.

A standard contains both methods (instrumentation and operation of such) and procedures (how the appliance should be operated during tests), both being important for the measured result.

The differences between current European standards lead to inequality in performance assessment both by producers, authorities and end-users.

The result from almost 20 years (initiated in 2001) of trying to harmonize the current European standard for the measurement of particulate matter emissions from LSH, the current status is that we still have three standards (it was actually four in a period, according to Ecodesign being; the HF, the ESP and the FFDT, where the main novelty being the EN 16510-1:2018, “almost” (since it is still not harmonized) as an alternative to the current EN 13240:2001/A2:2004 standard (which is still the harmonized one). For a while, the EN 16510-1:2018 included both a HF and a FFDT alternative. However, currently, it only includes the HF method.

CEN (European Committee for Standardization) initiated a project in 2018[3], financed by the Swiss authorities to produce a new sampling probe, to verify the validity of the method in comparison to the current three European methods, named “The validation project”. The measurement procedure, compared to EN 13240:2001 + DINplus, was also slightly changed. During this project, the new EN-PME method was supposed to be tested by notified test laboratories on intentionally 150 different appliances covering all types of solid fuel local space heaters. These tests were supposed to be run for “free”, simultaneously, while performing country specific type approval tests. The goals of the project were:

1. To prove the validity of the method on all types of solid fuel local space heaters, i.e. is the method able to collect a representative sample of particulate matter under type test conditions.
2. To prove that the EN-PME method could replace the current three methods.
3. To create a database with EN-PME emission results from which a possible emission limit under Ecodesign can be proposed.

The results in the current report is part of this validation project, performed through type testing at RISE Fire Research AS in Norway.

[3] https://rrf-online.eu/en/validation-of-the-new-european-method-for-particle-matter-pm-measurement/

In 2018 a new standardisation request under Construction Product Regulation (CPR) was suggested after CEN/TC 295 rejected the earlier standardisation request. In the beginning of 2021it is still waiting for approval.

2. The EN-PME method and EN-PME verification project

In 2016, a consortium of European research institutes (EC project EN-PME-TEST, 2012-2015) published a report regarding a new method for PM measurement, named EN-PME. This standard was, and still is, thought to replace all current European test standards, as the future harmonized EC standard. The consortium claims that this method has a higher reliability, reproducibility and certainty than current methods, based on one single measurement campaign. However, these tests were done on 1 pellet boiler, 1 wood chip boiler and 1 wood log stove, without comparison with existing methods the HF (EN 13240:2001 + DINplus) standard or NS3058-1/2:1994).

Both RISE Fire Research AS and SINTEF Energy Research are participating in the "validation project" to provide comparable test results between the EN 16510-1:2018 + EN-PME method and the FFDT (NS 3058-1:1994/NS 3058-2:1994) type test methodology.

CEN TC 295 working group WG5 ask the Norwegian Notiefied body to provide comparison measurements to verify if EN-PME measurement method satisfies the Norwegian environmental protection level. In 2019 the EN-PME verification project ask for paralell test during Norwegian type tests with EN-PME test method. These data from 5 stoves in 2019 where presented and CEN ask for addiational test with EN16510 and EN-PME for the same stoves. The results where send to CEN. The results where related to many different parameters in both standards that it was not possible to draw conclusion comparing both methods directly. Further test where performed in 2020 investigating mainly the differences in the test procedure which are significantly different for both standards.

Before the EN-PME method can be included in a harmonized standard, it is necessary to determine emission limit values related to this method. Also the method has to be validated for other fuels (e.g. mineral fuel) and other appliances, not covered by the EN-PME-TEST project.

Norway welcomes the development of a single harmonised test method, as suggested in the revision of mandate M/129 "Space heating appliances". However, we are concerned since the suggested test method proposed in M/129, EN-PME-TEST, in its current state do not measure all PM emissions from wood stoves. This is not satisfactory from an environmental, climate and human health perspective. Emissions of particulate matter from wood burning consist of both solid and condensable fractions, where the condensable fraction is mainly formed from unburnt hydrocarbon vapour upon cooling[4]. Additionally, emissions from wood burning highly depend on real life usage patterns. Any method for measuring PM from wood burning should therefore ensure that both the solid and condensable fraction

[4] Amann, et al. 2018. Measures to address air pollution from small combustion sources. https://ec.europa.eu/environment/air/pdf/clean_air_outlook_combustion_sources_report.pdf

of PM are captured, and that the method reflect real-life conditions, to ensure that the actual PM emissions are captured.

The design of measurement methods highly affect the total mass of measured PM, and emission factors derived from dilution tunnel measurement are always higher than the solid particle measurements[5]. SINTEF has compared the heated filter method (HF) according to the current European standard EN 13240 DINplus and the full flow dilution tunnel method (FFDT) according to the Norwegian NS 3058 and found a difference in the mass of particles collected with the FFDT to be on average about 6.5 times higher than the amount of particles collected on the HF[6,7].

The new EN-PME test method, used together with EN16510-1:2018, is similar to the current EN 13240 DINplus. The differences are the temperature of the heated filter, position and length of the sampling probe. In addition, sampling is performed over the whole burn cycle and not only 30 min.

These are the comments from the Norwegian experts on the proposed EN-PME-TEST method[8] which was send as a letter to the CEN WG5 committee.

	Issue	Comment
1	Condensable matter	The proposed method does not apply any form of dilution device and captures only solid PM on a hot filter at 180 °C, thereby missing the condensable part of both the OGC and some inorganics. A recent investigation comparing PM measured with dilution on an ambient filter with PM measured on a hot filter, showed that around 6.5 times more PM in gram per GJ, collects on the ambient filter.
2	TSP vs. apparent PM_{10}	The current method is not matching the Ecodesign Mandate which askes for the measurement of total PM, not PM_{10}. Due to unknown cut-size of the EN-PME-TEST method, it is not even measuring actual PM_{10}. The standard at least needs to state correctly what the test method is doing and attempting to capture.
3	Chimney probing -> emission factors and air quality	The partial flue gas stream sampled using the EN-PME-TEST probe is NOT withdrawn iso-kinetically, i.e., the PM concentration in the flue gas cannot be derived from the mass of the PM collected on the filter. This makes the PM measurements unsuitable as emission factors for national inventories and air quality.
4	Probe length/accuracy	Compared to the current DINplus the probe suggested in EN-PME-TEST is quite long, about 2 m. resulting in significant deposits within the probe (5 to 20% deposits?). Using pressurized air to clean the probe as suggested in the current procedure will probably still lead to

5 Denier van der Gon, H. A. C., Bergström, R., Fountoukis, C., Johansson, C., Pandis, S. N., Simpson, D., and Visschedijk, A. J. H.: Particulate emissions from residential wood combustion in Europe – revised estimates and an evaluation, Atmos. Chem. Phys., 15, 6503–6519, https://doi.org/10.5194/acp-15-6503-2015, 2015.

6 Seljeskog, M. et al. 2016. Factors affecting emission measurements from residential wood combustion, SINTEF. TR A7550 ISBN 978-82-594-3650-4

7 CEN-TC295-WG5_N0190_SP_-_testing_with_HF_and_FFDT_WG6_N0178

8 SINTEF, 2019. CEN/TC 295/WG 5-6 Working group, Norwegian comments to the proposed EN-PME-TEST method - Revised, "Letter to the CEN WG5 committe_08" 2019,

		unnecessary inaccuracy in sampled particle mass. Although heated to 180 °C, some hydrocarbon condensation might still occur, resulting in a sticky surface inside the probe, increased deposition and decreasing the accuracy. However, this statement might be proven wrong if showed so, by a sufficient number of test runs.
5	Immature	Currently there is an ongoing EN-PME validation project (–2019) aiming to compare particle measurement results from EN-PME, vs existing methods, to investigate whether a "calibration" is possible. As of sept. 2019, only a limited number of stoves has been tested with both EN-PME and the Full flow Dilution tunnel (FFDT) in parallel (see note below regarding the available results). Current results show no correlation between the two methods.
6	Organic gaseous compounds	OGC measured by FID is NOT a measure of condensed particulate matter in the flue gas.
7	Accuracy	The accuracy/repeatability of this method is not sufficiently clarified due to the lack of verification. Is the proposed EN-PME-TEST method equal to or better than the current EN 13240 DINplus method in terms of accuracy? What is the accuracy compared to either the dilution tunnel or the ESP methods? For wood pellets, chips and logs.
9	New emission limit requirements	The commission will need to set new limits in Ecodesign for the new EN-PME-TEST method. Due to the method's immaturity and low familiarity among the experts this would probably be a long and cumbersome process.

Any new test procedure should take account for:

	Issue	**Comment**
1	Accuracy/ repeatability	Any new test procedure should seek to improve the accuracy/repeatability compared to DINplus (most comparable to EN-PME-TEST) with at least 50%. Neither the FFDT, nor the HF methods/procedures hold a sufficient degree of accuracy/repeatability in their current state. The accuracy of a test method/procedure should always comply with the currently applicable emission limit regulations.
2	Test fuel	To avoid misuse of a stove, the combustion chamber should be restricted by physical obstacles to avoid unintentional overloading by the end-user, independent of the manufacturers declaration of a specific amount of test fuel. Alternatively, the amount of test fuel should be calculated according to the combustion chamber size similar to the safety test.
3	Low and high heat output testing	If a manufacturer do not declare low or high heat output, the stove should be physically restricted such as not to allow down-throttling to more than e.g. 90 % or increasing to 110 % of the nominal effect.
4	Real life	Any new test method/procedure should endeavour, as closely as possible but still applicable in a laboratory, to mimic real life emissions. A FFDT is capable of mimicking both dilution as well as parts of the atmospheric chemistry responsible for secondary organic aerosol formation. A conventional commercial diluter, e.g. DEKATI, is probably also just as well suited for pure dilution.

		The operating test procedure should also be able to imitate a simplified typical user behaviour, to an extent that is applicable in a laboratory.

Note regarding accuracy: In the recent investigation, comparing FFDT with HF, the average coefficient of variation for all experiments was 30% and 36%, respectively. The CV (coefficient of variation), also known as RSD (relative standard deviation), is a standardized measure of dispersion of a probability or frequency distribution. It is often expressed as a percentage and is defined as the ratio of the standard deviation to the absolute mean. To put the RSD in perspective, random probability results are those with a RSD > 50 %.

Note regarding the condensable fraction: The EN-PME-TEST method suggests measuring OGC by an analyser called flame ionisation detector (FID) as a measure of condensable matter. Our main objections are that this is NOT a qualified measure of the condensable fraction. Depending on the combustion conditions a large part (sometimes up to 60%) of the condensable will consists of inorganics which is not reflected by OGC/FID. Also, a correlation between OGC and/or the solid or condensable fraction has yet to be scientifically proven.

Note regarding the definition of PM10: PM10 and PM2.5 are defined by the International Standards Organisation as follows -> particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter. PM10 corresponds to the "thoracic convention" as defined in ISO 7708:1995 *Air quality — Particle size fraction definitions for health-related sampling*, Clause 6. Based on this definition the EN-PME-TEST method cannot claim to capture PM10 by simply probing in the downstream direction, but rather about 50% of PM10.

3. Main differences between EN 16510-1 with EN-PME and NS 3058

There are two main differences between both methods. Both methods measure different fraction of particle emissions. EN-PME is a heated filter method sampling mainly solid particles in the hot chimney undiluted. In opposite NS 3058 require testing with a full dilution tunnel and capture particulate matter diluted and condensed. Another major difference is the test procedure. NS 3058 require testing at four burn rates (heat output) with standardized spruce timber and the test fuel load is calculated in dependence with the combustion chamber volume. The different burn shall reflect the real life use of a stove.

EN 16510-1 only require testing at nominal heat output which is the optimised operation condition with test fuel declared by the manufacture. Part load testing is only required when declared by the manufacture.

Table 5 shows an overview of all the differences between both methods. Other differences are that the Norwegian standard requires natural draft while the EN 16510-1 test 12 Pa underpressure in the chimney.

Table 2: Differences between EN 16510-1 EN-PME and NS 3058

	TEST METHOD	
	EN 16510-1 EN-PME	NS 3058
Measured PM	Chimney	Isokinetic with a FFDT
Particles	Solid	Solid + condensable
Draft	12 Pa forced	Natural draft
Moisture	15 ± 3 % (dry basis)	19-25 % (dry basis)
Fuel	Beech wood log	Spruce boards
Fuel load	Acc. to manufacture	112 ± 11 kg/m^3 of the firebox volume
Filter temp.	180°C	Max. 35 °C
Tested heat output	Nominal heat output (specified by manufacturer)	4 burn rate categories, low -> max

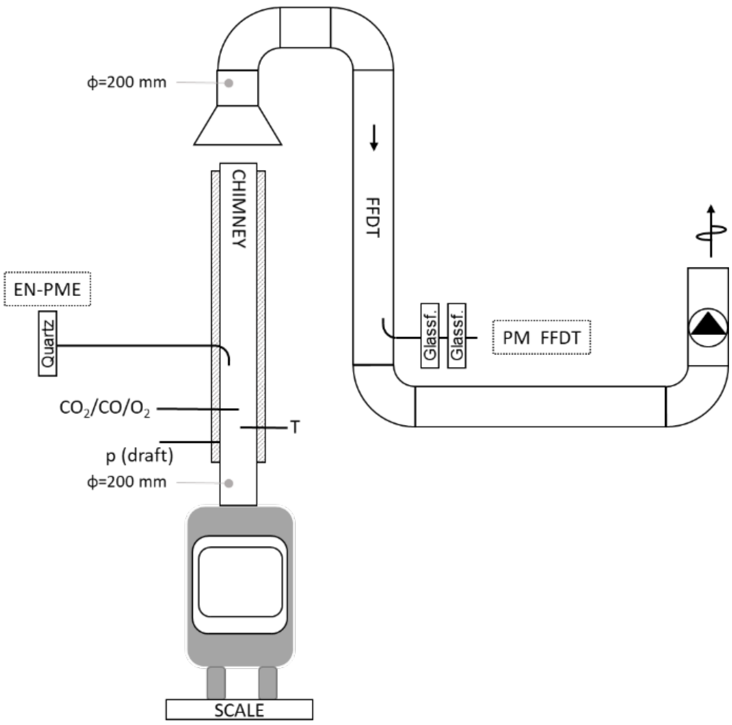

Figure 1: Test facility NS 3058 with EN-PME

4. Method description

Three test campaigns were performed to provide comparison data to compare both methods with focus on the differences of both the particle measuring method and test procedure.

During the first test series 5 stoves with different design and declared heat outputs were tested in accordance with NS 3058/59 and in parallel with the EN-PME test method.

Table 3: Parallel test series in accordance with NS 3058 and EN-PME

	Stove 1	Stove 2	Stove 3	Stove 4	Stove 5
Burn rates	Low, nominal, high	Low	Low, nominal	Low, nominal, high	Low, nominal, high
Heat output [kw]	9.1	5.2	4.7	8.2	7.2
g/kg	2.4	3.1	3.8	3	3.7

The second test series tested the same stoves with EN-PME and test procedure in accordance to EN 16510-1.

Table 4: Test in accordance with EN 16510-1 with EN-PME

	Stove 1	Stove 2	Stove 3	Stove 4	Stove 5
Burn rates	Only high	Nominal, high	Low, nominal	Nominal, high	Nominal,high
Declared heat output [kw]	9	7.7	3.6 (-5.6)	9.4	5.5

In the third test series two stoves were tested in accordance with EN 16510-1 with EN-PME and in parallel particles were sampled with the full flow dilution method. The burn rates were varied and also the amount of test fuel. Since the second test series had just a limited amount of tests performed at low burn rate with low heat output there was here a clear focus at low heat output testing with different fuels loads. Tests were performed both with the fuel size declared by the manufacturer and calculated in accordance with NS 3058 in dependence of the combustion chamber volume. Low heat output tests were run in addition with a smaller amount since this is suggested in the BeReal project[9].

[9] https://cordis.europa.eu/docs/results/606/606605/final1-bereal-final-publishable-report.pdf

Table 5: Declared performances from initial type test

	PM [mg/ Nm³]	OGC [mg/ Nm³]	Heat output [kW]	Fuel declared by manufac-turer [kg]	Combustion chamber volume [dm³]	Fuel calculated in accordance with NS3058 [kg]
		Type test EN13240				
Stove 1	17	68	5.9	1.3	19.8	2
Stove 2	21	29	6.2	1.3	14.8	1.5

Sampling in accordance with EN-PME requires that the flue gas sample is taken at a constant flow of 10 l/min and is led through a sampling train in which solid matter (PME) is collected on a filter. The 2 meter long sampling probe and the filter holder are heated to a temperature of 180 ˚C ± 10 ˚C.

The total mass of solid particulate matter collected on the filter is determined for the whole firing cycle conducted in accordance with the appropriate European Standard EN 16510-1.

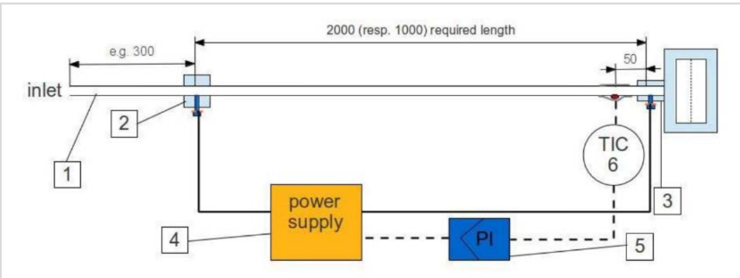

Figure 2: Schematic of the PM_{HF} sampling probe designed within the EN-PME-TEST project[10]

Simultaneously a second sample of the flue gas is taken and led trough a sampling line to a flame ionization detector (FID) for the measurement of the total organic gaseous compounds. The sampling line is heated to a temperature of 180-190 ˚C (pre-filter heated to 180 °C, sampling line heated to 190 °C).

After the outlet of the chimney the flue gas is led into a FFDT according to NS 3058 and measured/calculated according to this standard in parallel as Figure 2 illustrates.

[10] Gaegauf, C.; at al (2015): Messverfahren zur Bestimmung der Partikelemissionen für die Typenprüfung von Festbrennstofffeuerungen – Normenbegleitende Forschung zur Entwicklung einer europäischen Partikelmessnorm, Schlussbericht.

5. Results

Figure 3 shows the results of the Norwegian standard NS 3058 carried out in parallel with the EN-PME test method in the chimney. No correlation between both methods can be derived. The test results for testing in accordance NS 3058 and dilution tunnel were between 1.9 and 4 g/kg particles for the 5 tested stoves, while the emissions with the EN-PME sampling method varied from 3-71 mg/Nm^3. Stove 2 was tested 4 times at the same burn rate resulting in similar emissions when tested with EN-PME test method.

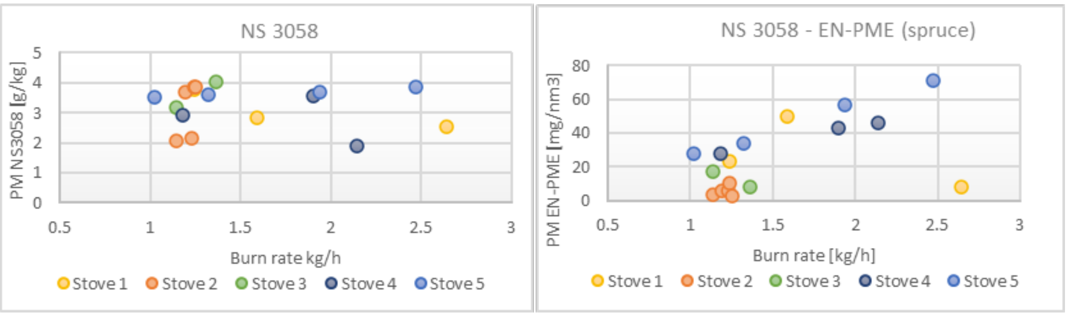

Figure 3: PM emissions of 5 stoves measured in accordance with NS 3058-1 and NS 3058-2 (g/kg dry wood) and in addition EN-PME (mg/Nm^3) simultaneously in relation to the burning rate (kg/h)

The direct comparison of the emission values of EN-PME sampling method and NS 3058 in parallel showed that emissions from the NS measurements with dilution tunnel were all 7 times higher with 108 mg/MJ compared to EN-PME with 14 mg/MJ (Figure 4) looking on all results.

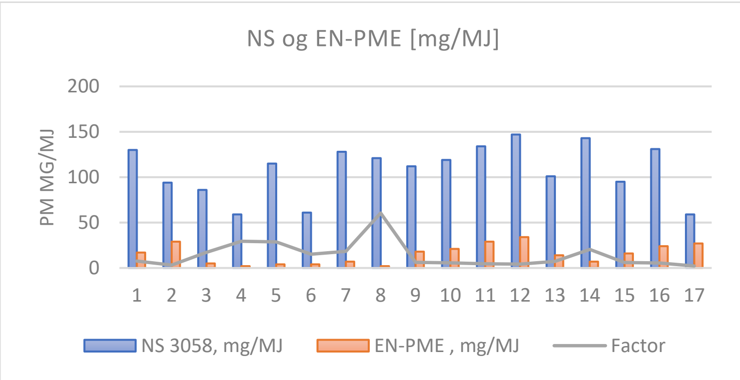

Figure 4: Emission from NS 3058 and EN-PME [mg/MJ]

Additional measurements with EN 16510-1 and EN-PME were performed but without parallel sampling in the dilution tunnel as Figure 5 shows.

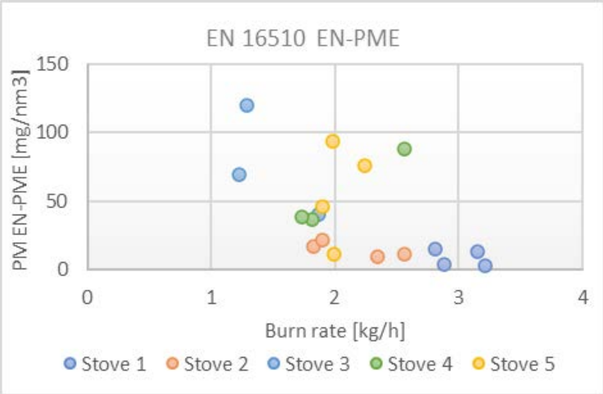

Figure 5: Particle measured in accordance EN 16510-1 with EN-PME with different burn rates

Not each stove was tested at low, nominal and high burn rate. The results show a large variation. Stove 2 showed higher emission at lower burn rate but was the only stove tested at low burn rate. Stove 1 resulted in low emission at high burn rates between 2.9 kg/h and 3.2 kg/h. Stove 5 showed that emissions can vary between 11 mg/Nm^3 and 93 mg/Nm^3 with similar nominal burn rate around 2 kg/h.

Comparing EN-PME measurements for both NS 3058 and EN 16510-1 show that emissions are spread, and no correlation can be derived (Figure 6). OGC emission for spruce (NS 3058) and birch (EN 16510-1) showed also no trend for these 5 stoves.

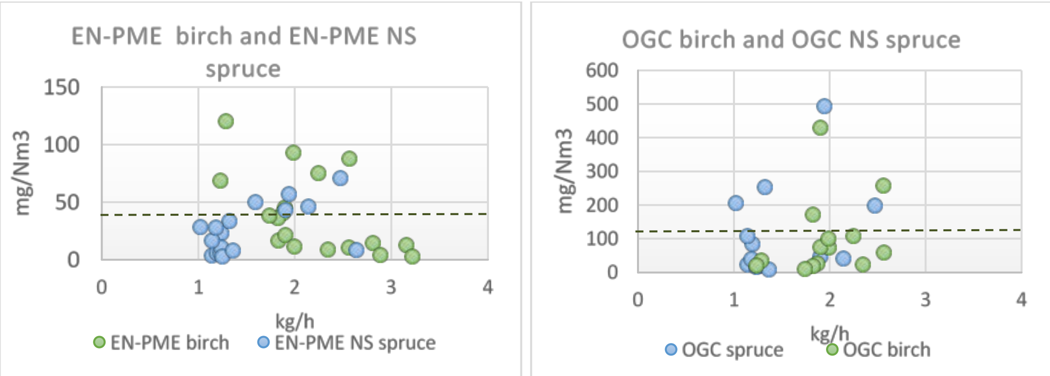

Figure 6: EN-PME and OGC emissions for both spruce (NS 3058) and birch (EN16510-1) in relation to the burning rate (kg/h) with Ecodesign emission limits[1] (dashed line)

Of the 14 measurements of both OGC and PM were ten below the Ecodesign emission limits. Six of the ten tests show low PM emissions on the hot filter and low OGC values but still result in increased condensed PM emissions above 3.2 g/kg up to 4 g/kg when sampled with the full flow dilution tunnel as shown in Figure 7 in the red circles.

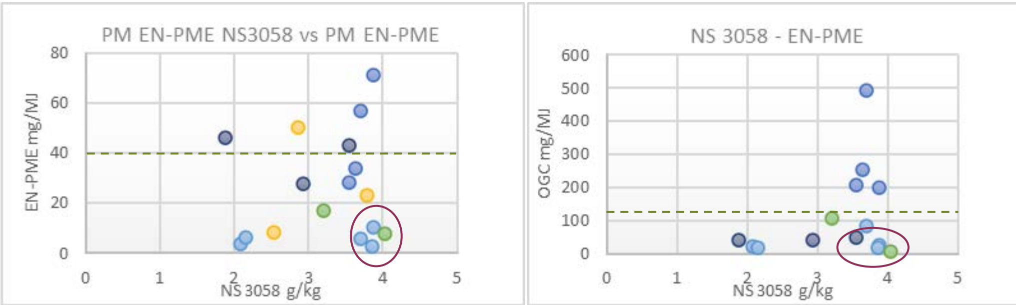

Figure 7: PM NS 3058 in relation to EN-PME (left) and OGC (right) with Ecodesign limits (dashed line)

It is assumed that OGC will give a qualified information about the performance of the stove since condensed particles are formed partly from unburned heavy hydrocarbon. However, these measurements show that even though OGC values are very low, between 9 to 40 mg/Nm^3, it can result in increased particle concentrations up to 4 g/kg when measured with a dilution tunnel. The highest PM emission in the dilution tunnel came from a test with the lowest HF PM and OGC. The stove can show very low emissions with the EN-PME test method but will still have increased emissions to air when the particle and unburned gases are diluted, and condensation takes place.

The results however showed that stoves will pass type approval requirements if they are developed to meet the specification in the test standard. All stoves were developed for the Norwegian market and hence fulfil the Norwegian requirements. The stoves are in addition sold on the European market and fulfil also these requirements.

Investigating different fuels loads at different heat outputs showed large variation when the calculated test fuel differed significantly compared to the declared. Both stoves showed higher emissions with more test fuel as shown in Figure 8. For stove 1 the emissions increased with 122% when ~50% more fuel was used and particles were sampled with EN-PME. When measured with the full flow dilution tunnel the emission increased with 145%. It needs to be emphasized that increasing the test fuel from 1.3 kg to 2 kg for stove 1 does not mean overloading the stove with wood. The combustion chamber size clearly allows operation with much more wood than the calculated 2 kg.

The small combustion chamber of stove 2 resulted in a small fuel increase of 15% when the test fuel was calculated in dependence of the combustion chamber volume. The emission did not increase as much as for stove 1 but still increased with 44% when tested with EN-PME and 32% with FFDT.

Not only low heat output (part load) is an operation condition that result in higher emissions with more fuel but also high heat output (max load).

Figure 8: Results of different fuels loads and heat outputs when tested in accordance with EN16510-1 and PM EN-PME, OGC with parallel sampling in the full flow dilution tunnel in accordance with NS3058 and calculating in g/kg

Additional tests with NS 3058/59 were completed for stove 1. These results show that the stove does not fulfil the requirement set by Ecodesign of 5 g/kg with a weighted emission of 7.2 g/kg.

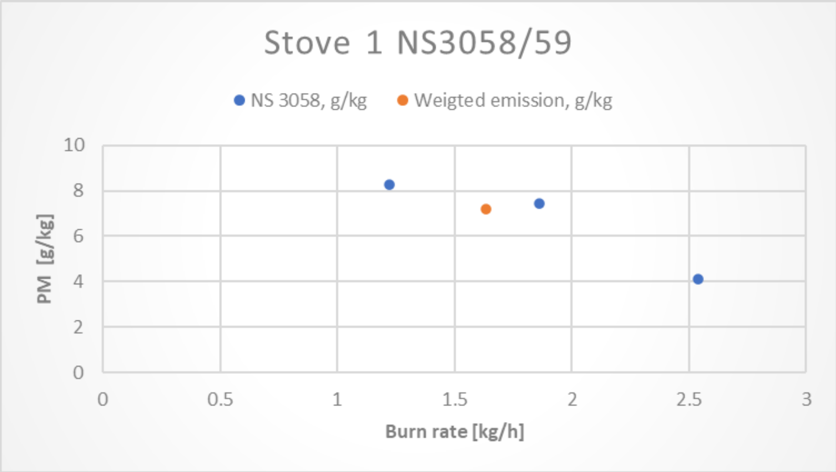

Figure 9: Stove 1 tested in accordance with NS3058/NS3059

This clearly shows that a stove declared with a very good performance at nominal heat output and a small fuel load with EN 16510-1 EN-PME do not guarantee as low emissions when tested with NS 3058/59 to satisfy Norwegian environmental protection level.

6. Discussion

Influence of the fuel size on emissions

In 2018 SINTEF compared the two proposed methods HF (Heated filter) and FFDT (Full flow dilution tunnel) in FprEN 16510-1:2016 with the Norwegian standard NS 3058:1994.[11] One major difference in the test procedure is the amount of wood required for testing. NS 3058 calculates the amount of wood from the combustion chamber volume. FprEN 16510-1:2016 follows the instruction by the manufacturer. This result in major weight differences. The manufacturer declares much less fuel weight compared to calculating it based on the combustion chamber volume. The product design mainly influence the use of a product and it is very unlikely that the user strictly follows the instruction manual and will use very little wood, if this feels unnatural for the size of the combustion chamber.

Figure 10: 3 test fuels EN nom 1/EN part 2 (left), EN nom 2 (middle) and EN part 1 (right)

The results of the earlier study clearly illustrated the influence of the test fuel size on the emission. The fuel amount for the realistic cases in this study was still small compared to the combustion chamber volume, as the pictures in Figure 10 shows. Table 6 gives an overview of the test fuel weight.

Table 6: Overview of the different test fuels and combustion conditions

EN nom 1 Nominal	EN nom 2 Nominal	EN part 1 Part Load	EN part 2 Part load
Optimal	Realistic	Optimal	Realistic
1.1 kg	1.8 kg	0.6 kg	1.1 kg

The results of the comparison tests clearly demonstrated that the mass of the test fuel influenced the amount of particles measured. Little fuel gives significantly less particle emissions both for nominal heat output and part load as Figure 11 presents. Part load testing with a small amount of fuel does not give more emissions with the heated filter method

[11] Seljeskog, M. and Kausch, F. 2018. Sammenlikning av partikkelutslipp målt iht FprEN16510-1:2016, oppvarmet filter (F.2-HF), uttynningstunnel (F.3-FFDT) mot NS 3058:1994 samt anbefalte grenseverdier. SINTEF.

than nominal testing. This a very different result compared to testing in accordance with NS 3058 which uses the same amount of fuel for part load testing and result in clearly more emissions.

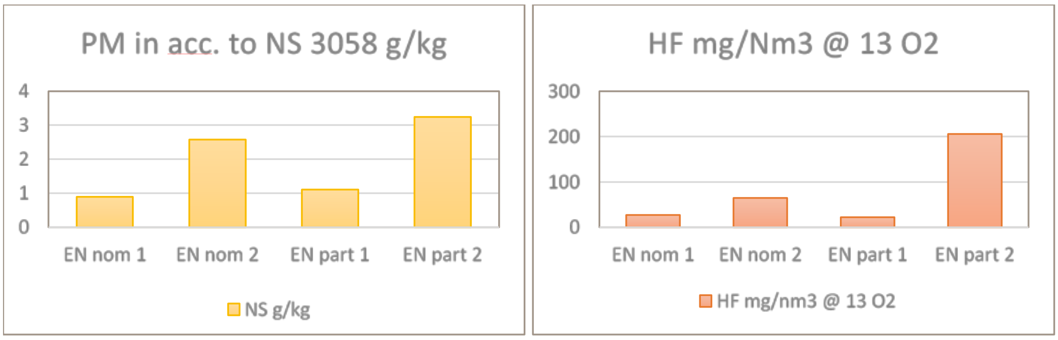

Figure 11: Test results of the comparison of different test fuels for different combustion conditions

Testing with a test fuel size declared by the manufacture produced around 0.5 g/kg particles when measured and calculated in accordance with FprEN 16510-1:2016 FFDT method. NS 3058 uses a different way of calculation and result in up to two times more emissions compared to the FFDT method[11]. The filter in the FFDT procedure was dried at 180 °C explaining in addition the differences between the FFDT method and NS 3058.

The influence of the test fuel size was earlier shown in a study comparing NS 3058 with EN 13240 DINplus.[12] Four different cases were tested, both methods with spruce and birch. EN 13240 let the producer decide the amount of wood which leads to less fuel in the combustion chamber resulting in less emission for both heated filter method and full flow dilution tunnel (Figure 12).

Lower emissions when using a smaller fuel amount can be explained by achieving a more controllable and stable combustion process. In the extreme case, with frequent fuel loading with very small wood pieces, a close to continuous combustion process will occur, if the stove is initially hot, and in or close to thermal equilibrium with its surroundings. When loading a large fuel amount, more moisture will evaporate initially, more volatiles will be released fast thereafter, and the char burnout phase will be longer, all contributing to a less controllable and more unstable combustion process which increase emissions. The wood type and the wood log/piece size will influence the emission levels through the influence on the drying, devolatilisation and char burnout behaviour.

[12] Goile, F, Karlsvik, E and Skreiberg, Ø, 2010. The influence on the emissions due to use of EU standards compared with NS standards. SINTEF.

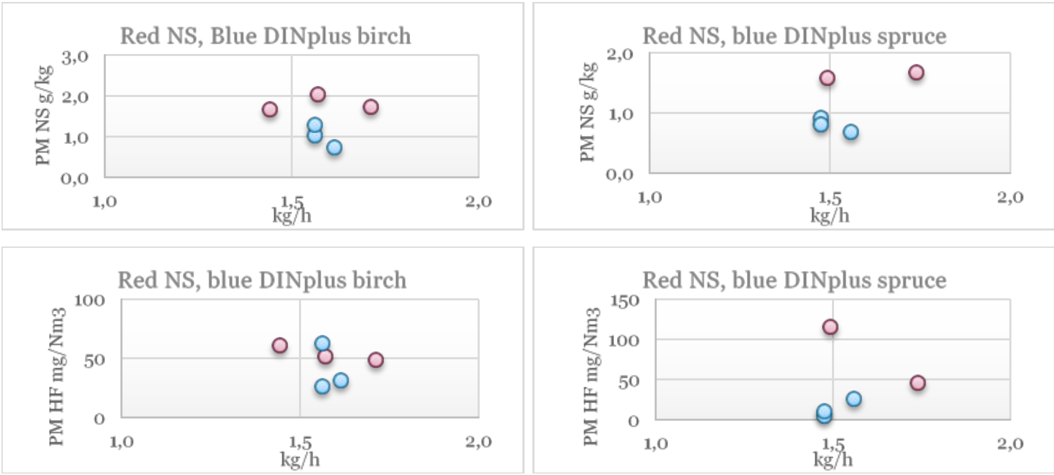

Figure 12: Comparison DINplus [blue] and NS 3058 [red] , 4 different cases were compared (DINplus with 1.1 kg birch, DINplus with 1.1 kg spruce, NS 3058 with 1.7 kg birch and NS 3058 with 1.7 kg spruce)[13]

OGC and condensed particles

Both OGC (organic gasous compounds) and PM (particulate matter) together form secondary aerosols in the atmosphere. The EN-PME project, from a scientific point of view, suggested to measure both emissions in their purest state. This method was suggested as a short term method and not long term. The described long term measurements shall measure secondary organic aerosols which require dilution and exposure in a micro smog chamber simulating atmospheric reactions. At the moment the parameter for correct dilution of flue gas is not known and hence the project suggested to measure both PM and OGC in its purest possible form, as this would be a more correct scientific start. However, the results show that there is no correlation between OGC and particulate matter emission to air.[14]

Wood stoves are operated under different conditions. The type tests only require testing at nominal heat output, a condition where the stove is optimized. However, the operation and the following combustion condition does not only influence the extent of particle formation but also the health effects through the particle size and composition.[15,16]

Modern wood stoves produce in general much lower PM, OGC and CO emissions than stoves produced before 1998. Wood stoves in Norway has improved significantly due to

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[13] Morten Seljeskog, Alexis Sevault, Asbjørn Østnor, Øyvind Skreiberg, Variables Affecting Emission Measurements from Domestic Wood Combustion, Energy Procedia, Volume 105, 2017, Pages 596-603
[14] EN PME TEST Project Position paper, Isaline Fraboulet
[15] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2777846/
[16] http://www.verenum.ch/Publikationen/W1612Berlin2007.pdf

the stricter Nordic Ecolabel requirements of 2 g/kg particulate matter emissions, tested in accordance with NS 3058 and NS 3059.

It is not clear that the EN-PME method can reflect small differences in combustion conditions when sampling PM at 180 °C. OGC also include methane, which will not form particles as it does not condense, meaning that OGC is not a good indicator at all for the PM formed in the atmosphere. Hence this method cannot clearly exclude bad stoves from the state of the art technology.

EN-PME was developed for a future long term method which includes condensation, but did not consider the influence of different operation conditions of a stove and its influence on the sampled emissions.

The data from the EN-PME-TEST experimental campaign shows that there is no direct correlation between OGC and condensed particle when diluted.

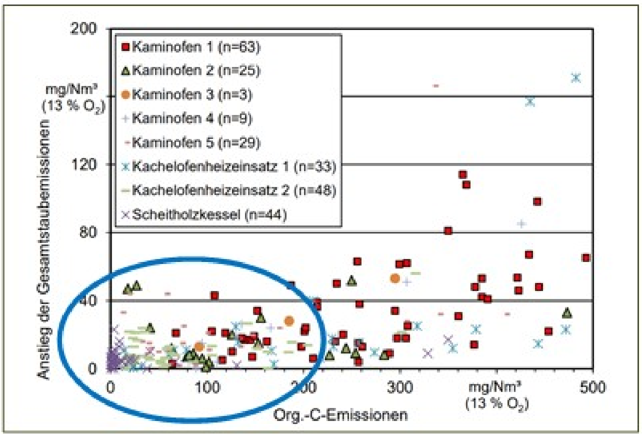

Figure 13: Increase of PM emissions in a dilution tunnel in relation to OGC measurement (filter treated at 120°C)[17]

Figure 13 shows the increase of particle emissions compared to heated filter measurements in dependence to OGC measurements. The study concludes that there is no clear correlation, which means that measuring only OGC and PM with a heated filter gives no information about emissions to air. For higher concentration of OGC there is a trend of more condensed particles. However, for lower concentration below 500 mg/Nm^3 OGC there is none. OGC contain a significant fraction of methane, a gas which do not contribute to particle formation and do not condense when diluted. Very low OGC emission can also result in higher particulate matter emissions when condensed as the figure shows. A large group of measurements show an increase of around 20 mg/Nm^3 but also up to 40 mg/Nm^3 when condensed, which must be caused by condensation of non-OGC compounds.

[17] Entwicklung einer abgestimmten Methode zur Bestimmung der Partikelemissionen von mit fester Biomasse betriebenen Feuerstätten (EN-PME-Test), Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ), 22032411 bzw. 11NR324

CEN argues that type testing is god enough to compare two stoves and that if the emission limits are strict enough to ensure that the stove will be a god stove. However, these results show that measuring the solid and gaseous emissions separately are not sufficient enough to evaluate eventual released condensed emission to air.

It is also important to note that the reported emissions are influenced by the filter treatment even though a dilution tunnel method is used. The same study showed that a major fraction of particles evaporates when the filter is dried at high temperatures, for example 120 °C. A closer investigation of the influence of the filter temperatures showed that around 40% of the mass is evaporated compared to drying at 40 degrees[17].

Real life operation vs type testing

The former European BeReal project[9] illustrates very well the huge difference in measured particle mass between type tests and real-life operation, shown in Figure 14, when using the current EN 13240 DINplus. The results show a significant difference between type testing, testing at research laboratories and field testing (BeReal method).

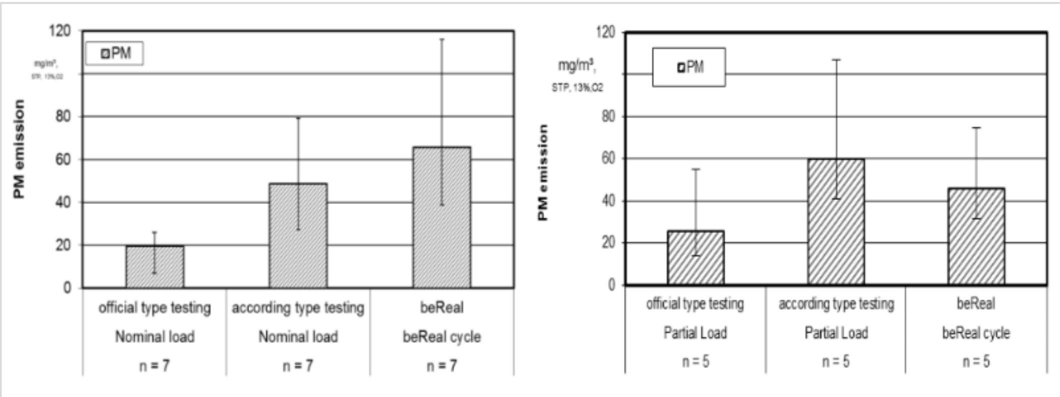

Figure 14: Comparison of type testing and real life use of a stove at nominal load (left) and part load (left)

The major disadvantage of the EN-PME method compared to the Norwegian standard is that it was primarily intended for use in test laboratories and the actual firing procedure and its influence on emission was not investigated.[18] It is known that the combustion condition highly influence the amount of hazardous emission and in addition the toxicity and its health effects. [19,20]

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[18] http://task32.ieabioenergy.com/wp-content/uploads/2017/03/16.00_EN-PME-TEST.pdf
[19] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2777846/
[20] http://www.verenum.ch/Publikationen/W1612Berlin2007.pdf

Evaluation of the combustion quality can only be done by measuring also condensed particles.

Standards outside Europa

Norway is not the only country using a dilution tunnel for sampling condensed particles from wood stoves during type approval. Australia, New Zealand, USA, Canada and UK are all countries that not only uses a dilution tunnel but also calculate the fuel wood in the dependence of the combustion chamber volume and require testing at different heat outputs as Table 7 shows.[21]

Table 7: Overview over test requirements in different countries[21]

	Tested load settings	**Mass of test batch**
International draft/ DIS 13336	low, medium, high	Calculated based on combustion chamber volume (20%)
Australian/ New Zealand Standards	low, medium, high	Calculated based on combustion chamber volume (16%)
British recommendations for testing	low, medium, high	
Canadian Standard	4, from low to high	Calculated based on combustion chamber volume (112±12 kg/m³)
Unites States Standards	4, from low to high	Calculated based on combustion chamber volume (112±12 kg/m³)
European standard	Generally, only nominal load	Defined by the manufacturer based on the thermal heat output (THO)

However, in Europe at the moment, part load testing is new for wood stove testing and the understanding is very different from country to country. EN 16510-1 has included part load testing, however, it is up to the producer to declare part load operation and hence testing. Similar to nominal heat output testing the producer again decide the fuel amount.

Norway however, as mentioned earlier, requires testing with a full fuel amount also for part load output, in the same manner as UK, USA, Canada, New Zealand and Australia. A project in 1998 identified Norwegian firing habits and showed that the Norwegian standard NS 3058 reflect Norwegian firing habits.[22]

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[21] https://www.ieabioenergy.com/wp-content/uploads/2018/11/IEA_Bioenergy_Task32_Test-Methods.pdf

[22] Hansen, F.H et al, Fyringsmønster for vedfyrte Ildsteder, SINTEF rapport, 1998

Part load operation

The European project BeReal (advanced testing methods for better real life performance of biomass heating appliances) however, conclude that part load firing is common in central Europe with little fuel. The test regime includes a part load testing but with two small wood pieces. This do not necessarily result in higher emissions compared to nominal testing and is very different from Norwegian testing and firing habits. Firing habits can be very different from country to country and hence it is difficult to harmonize testing. However, testing must be done in a way that it reflects the actual use of a wood stove in the actual market, to guarantee good performance during real life use.

Alternative dilution method

The dilution tunnel method used in the Norwegian standard has some drawbacks, especially in that the dilution process is not controlled. It is known that formation of particles by condensation depends on many factors like dilution rate, temperature, moisture content in the dilution air and residence time, which might result in some differences from one day to another. Another disadvantage is the size of the dilution tunnel, which requires a large test laboratory.

In Italy the Italian National Agency for New Technologies, Energy and Sustainable Economic Development together with Innovhub Experimental Stations developed a small part flow diluter chamber to overcome the disadvantage with the dilution tunnel.[23] This method is now further developed in the European project IMPRESS 2.[24] This method is a promising alternative to the FFDT for collecting condensables and seems also to be a method for type approval and development of wood stove for producers.

[23] https://www.enea.it/en/news-enea/news/environment-heating-innovative-system-for-measuring-fine-particles
[24] http://empir.npl.co.uk/impress/2018/11/19/a-work-package-2-update-from-enea/

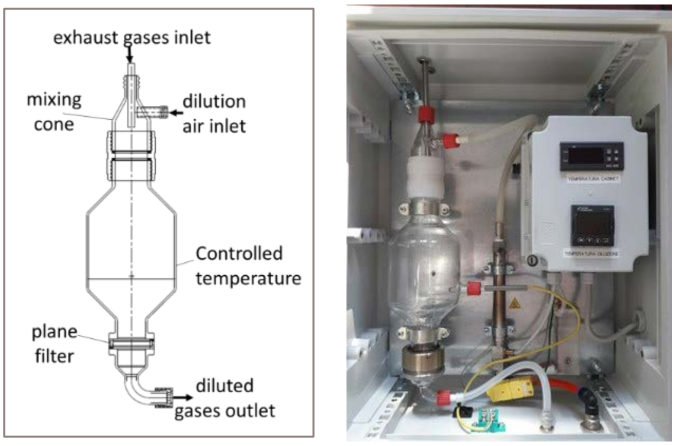

Figure 15: ENEA dilution chamber

The development of the mini dilution chamber shows the increasing awareness that emission from wood combustion do not just contain solid particles but also condensed particles. For example, the EMEP report from 2019 concluded that most European countries underestimates emissions from residential heating because they mainly report only the solid fraction of the particle emission.[25]

[25] EMEP Status Report 2019; https://emep.int/publ/reports/2019/EMEP_Status_Report_1_2019.pdf

Further work

Several factors influence emissions from wood stoves, which makes it difficult to compare emissions from different test studies and explains that there is still a gap of knowledge. This comparison test and earlier comparison test confirms that EN 16510-1:2018 with EN-PME is a very different method compared to the Norwegian standard NS 3058, it tests stoves just under optimized conditions. It can be assumed that the method does not guarantee better stoves in Norway in the future, compared to the best stoves currently available on the marked. The latest measurements showed that a stove that performs very good when measured according to the heated filter method, resulted in as much as 7.2 g/kg when measured with NS 3058/59. This assumption can be further investigated by testing a selection of non-NS 3058 approved stoves with different design, approved for the European market and therefore fulfil the Ecodesign requirements. This would be the actual verification for the Norwegian comments sent earlier to CEN/TC 295/WG 5, CEN/TC 295/WG 6 and to CEN/TC 295. It can be expected significant different results for stoves with large combustion chambers and with large glass surfaces and low declared heat output. Common Norwegian room heaters fired with wood logs, cover stoves with a heat output between 3-10 kW. Fireplace inserts are less common and can typical be found with heat outputs between 3-15 kW. Several appliances should be selected to present typical common products which could appear on the Norwegian market.

Emissions from wood stoves are mainly influenced by the firing patterns of the user. Buildings and wood stoves have changed significantly in Norway over the last two decades since the last heating pattern survey. It is necessary to confirm that the test procedure of the Norwegian standard still reflect Norwegian real-life use of a wood stove, or if the use has changed over the years. There is the need to investigate todays firing patterns for both old and new technologies related to building structures and heating demands. A survey of today's firing habits will help to improve the emission inventories as well.

EN-PME was developed as short-term method to later include a test method that either measured secondary organic aerosols with a smoke chamber or an alternative dilution tunnel method. ENEA developed a dilution chamber and DTI is currently working on a mini dilution tunnel. A near future project could be to gather a consortium and then perform a common project with the mentioned partners.

7. Conclusions/recommendations

Test standards are developed to ensure that products fulfil certain requirements. They are guiding the development of a product. The results of testing five stoves according to NS 3058/59 and EN 16510/EN-PME showed that these stoves will pass type approval requirements if they are developed to meet the specification in the test standard. NS3058/59 includes testing at different heat outputs and calculates the amount of fuel according to the size of the combustion chamber and hence, reflect a more realistic amount of fuel. The European test standard EN16510-1 only requires testing at one nominal heat output with a fuel load decided by the manufacturer, which do not consider real-life use, hence there are major differences between both test methods besides the particle sampling method.

Testing two wood stoves that fulfil the Ecodesign requirements with very low declared emissions when tested according to the European standard with the heated filter method, showed significant higher emissions than when tested with more realistic amounts of wood and at lower and higher heat output (somewhat below and above nominal load). One stove, when tested according to NS3058/59, showed higher emissions than the requirements set by Ecodesign. EN16510-1 with EN-PME do not guarantee better products compared to the ones which exists on the Norwegian market today, especially compared to products which comply with the Nordic Swan label. Most likely will future wood stoves (which are planned to be tested only according to EN 16510-1:2018 with EN-PME) produce more emissions to air.

The direct comparison of the EN-PME sampling method and NS 3058 in parallel from the current experimental campaign showed that emissions from the NS measurements are approximately 7 times higher with 108 mg/MJ compared to EN-PME test with 15 mg/MJ. The differences vary between 2 and 60 times. However, these stoves were already approved for the Norwegian market and the difference can be expected to be much higher in the future, if EN-PME approved stoves reaches the Norwegian market.

OGC measurements are supposed to be sufficient to reflect the appearance of condensed particles. However, as stoves have improved over the recent years there is no longer a correlation between OGC at lower ranges and condensed particles. Therefore, OGC is not good enough for type testing to evaluate the performance of a residential wood heater.

Another major drawback is that EN-PME method cannot be used in its current state for calculating emission factors, or as a way of estimating national PM inventories. This is supported by EMEP estimates, which strongly suggests that PM emissions in Europe are currently underestimated in many countries, and that condensable matter from the residential combustion sector, in particular wood-burning, are a key source for these missing emissions.

A harmonized European test standard for room heaters fired with wood needs to reflect real life operation and measure health and environmental relevant emissions.

Norwegian authorities should inform the European commission and other related European authorities about the disadvantages of the current standard EN 16510-1 :2018 and the new test method, EN-PME. There is a strong need for a harmonized standard that reflect real life use of residential room heaters fired with wood and measure relevant health and environmental emissions. Norwegian authorities can contribute to research and collaboration with other European Research institutions to provide sufficient data and contribute to develop of a long term method measuring health and environmental relevant condensed PM emissions.