

**Assessment of particulate and NO_x
emissions from a range of log and pellet
appliances and boilers by a range of
measurement techniques**

**Report on the effect of method
adjustments**



Prepared by:
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Assessment of particulate and NO_x emissions from a range of log and pellet appliances and boilers by a range of measurement techniques

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Prepared by

Name Mark Lewitt
Position Principal Consultant

Approved by

Name Iain Summerfield
Position Principal Consultant



Date October 2016

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Kiwa Ltd T/A Kiwa GASTEC
Kiwa House
Malvern View Business Park
Bishops Cleeve, Cheltenham
GL52 7DQ
UK

Telephone: +44 (0)1242 677877
Fax: +44 (0)1242 676506
E-mail: enquiries@kiwa.co.uk
Web: www.kiwa.co.uk

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1 Introduction

Particulate air pollution has been a recognised problem in urban centres and many of the countries in the EU have passed a wide variety of local legislation. This has resulted in a number of different approaches to measuring particulate emissions, both qualitative and quantitative. Unfortunately, these approaches can report very different values. This is further complicated as the different methods traditionally report results in different units.

Such differences were not of great consequence when local legislation was written around the local measurement technique, but with the advent of the single market and the rise in interest in biomass, the situation is now changing. There is considerable evidence to indicate that the above measurement techniques can collect and report widely varying quantities of particulate matter and NO_x.

This work programme carried out a series of comparative and round-robin tests to investigate this issue to provide Defra with robust evidence to inform the choice of measurement technique to demonstrate compliance with emission limits. Tests of particulate, total hydrocarbon (THC) and NO_x measurements from representative biomass appliances were carried out.

This report shows the results of tests carried out by Kiwa Gastec in the UK (Kiwa) to assess the influence of modifying the emission test protocol on particulate emission measurement results using the heated filter 'DIN+' measurement technique.

It examines the ranges of results obtained for multiple measurements of particulate emission for individual appliances operated under two generic conditions, i.e. at full (rated output) and at reduced firing rates, which are referred to in this report as 'High' and 'Low' respectively.

On this basis the relationships between DIN+ and other measurement protocols derived from it are assessed and the scope to improve its **accuracy** and its **compatibility** with other particulate measurement protocols is investigated.

2 Description of Appliances

Table 1 presents a summary of the features of the appliance used for this study.

Table 1 Comparison of Appliance B Features

Appliance	B
Type	Insert room-heater
Fuel	logs
Output, kW	8
UK Clean Air Act Exempt?	yes
BImSchV 2?	no
RHI Certificate?	na
MCS Compliant?	na
Nordic Swan Ecolabel?	no
Likely to burn clean / dirty?	Clean

na not applicable

The effects of appliance characteristics and issues affecting the reproducibility of combustion conditions from test to test were discussed in the report on inter-method and inter-laboratory comparisons¹.

One area of uncertainty in measurements of particulate emissions from solid fuel roomheaters is the amount of condensable material in the flue gas and the extent to which such material is collected by different particulate sampling techniques.

The ‘DIN+’ sampling technique samples hot, undiluted flue gases and is thought to miss a significant amount of this condensable material but was chosen for this study as it does provide a more convenient and flexible/adaptable methodology for changes in the protocol.

This test programme aimed to investigate the effect of modifying the DIN+ sampling technique and measurement protocol to determine which elements have greatest impact on the measured levels of particulate emission.

3 Testwork

The test programme for this part of the study included carrying out measurements of particulate emissions from Appliance B using the DIN+ method but with small modifications to the technique and measurement protocol.

3.1 Test Matrix – Comparisons between standard and adjusted methods

Table 2 below shows tests carried out with each of the method adjustments. In addition to adjustments made to probe the question of loss of volatile matter, the variation in the particulates measurements with time during individual appliance operation cycles (i.e. a fuelling to burn out period) were also investigated.

Table 2 Test Matrix for DIN+ method adjustment comparison tests carried out on Appliance B

Output	Method	Replicates	Comment
High	DIN+ 70°C	5	Baseline DIN+ test.
	DIN+ 160°C	5	Filter temperature raised to match EN13284-1 (reference Standard for PM measurement).
	DIN+ +3min	5	Starting measurement when door closed after refuelling – DIN+ starts up to 3 minutes after refuelling.
	DIN+ full	5	Extending test period from 30 minutes to cover full (EN) burn cycle.
	DIN+ prefilt	3	Recovery of prefilter deposits (acetone and water rinse) to match EN 13284-1.
	DIN+ 10min	3 X 4	Short-term measurements to assess variability in PM emission over a burn cycle.
Low	DIN+ 70°C	5	Applying DIN+ test to a low output.
	DIN+ 160°C	5	Filter temperature raised to match EN13284-1.
	DIN+ prefilt	3	Recovery of prefilter deposits (acetone and water rinse) to match EN 13284-1.

Part of the test programme was to assess whether agreement between measurement techniques and protocols might be improved if they are based on comparable sampling periods.

3.2 Test Equipment

3.2.1 DIN+ method

Smoke emissions were measured using the DIN+ equipment, described in CEN/TS 15883^{II}.

3.3 Test Fuel

The test fuel used was test wood logs conforming to the specification given in BS EN 13240:2001^{III} for thermal performance testwork on roomheaters burning wood logs. Fuel analyses are provided in **Table 3**.

The fuel selection method statement is reproduced in Appendix 1. In addition, for this work efforts were made to select similar logs for each test within the constraints of a batch of commercial logs. The logs used were all of a similar length as supplied.

Table 3 Test fuel analyses

Parameter	Units	Beech Wood Logs	
		ar	db
Total moisture	%	32.4	-
Free moisture	%	4.51(aa)	-
Ash content	%	0.1	0.2
Volatile matter	%	57.6	85.2
Fixed Carbon	%	9.9	14.6
Total Sulphur	%	<0.01	<0.01
Carbon	%	45.2	66.9
Hydrogen	%	6.06	8.96
Nitrogen	%	3.80	5.62
Oxygen by difference	%	12.4	18.3
Gross Calorific Value	MJ/kg	13.079	19.347
Net Calorific Value	MJ/kg	10.989	16.497

Notes:

ar as received
aa as analysed
db dry basis
nd not determined

3.4 Test Procedures and adjustments

Smoke emissions from the appliances were measured for two conditions, High Output and Low Output, which were attained through adjusting the air control settings

For High Output the primary and secondary air settings were those used for the nominal output tests. For Low Output a low setting for the secondary air that maintained clean combustion was determined and then used. The low setting used was not the minimum setting for the secondary air control.

The mass of fuel used as the refuel charge for each test was according to the appliance capacity. The standard method was to use four evenly sized logs, three laid side-by-side on the fuel bed and the fourth rested diagonally on top. However, this was adapted to meet the manufacturers' guidance for the appliance. The information provided in the appliance manual is summarised in Table 4 below.

Table 4 Appliance fuel specifications

Appliance	Manufacturer specified wood length, cm	Manufacturer specified wood diameter, cm	Standard fuelling	Maximum firing rate, kg/h
B	Up to 45	Not specified	Open stacking	2.6

The refuelling procedure adopted was to allow the newly charged fuel to burn with the primary and secondary air controls set at maximum for a maximum period of 2 minutes. After this period, with flames from the logs fully established, the primary air and secondary air supplies were adjusted to provide the required operating level i.e. High Output or Low Output. Setting the air flow accurately and repeatably was constrained by the appliance controls.

Following the ignition period a pre-test period was used to establish a suitable firebed.

The test durations were not predefined. The fire was allowed to burn back to the initial level of embers established at the start of the test.

Close attention was paid to the manufacturer's recommended operating procedures with regard to use of the appliance.

The appliance operation method for each of the replicate tests was in as far as possible identical including efforts to select similar logs for each test. However, other factors also may affect particle emission.

The progression of combustion will be different for every log, being affected by such factors as:

- The characteristics of the individual log including the presence of knots and the presence/thickness of bark.
- The preparation of the logs as the split surface of logs inevitably varies and can affect the way the logs lie in the appliance e.g. producing areas where one log shades another from the effect of full radiation, affecting the way that volatiles are released and ignited.

Individual log characteristics determine when events occur which are likely to cause short term fluctuations in particle pick up in the flue gas (such as the collapse of the partially burned logs).

3.4.1 Smoke measurements – DIN+ 70°C method

The smoke emission in all tests was measured using the DIN+ method described in CEN/TS 15883^{IV}. The method statement is given in Appendix 2.

Ten tests were carried out, five each at high and low output. The operational profiles for the appliance for each test are presented in Appendix 3 (Figures A3.1a to A3.1e). Baseline measurements for DIN+ were also undertaken by two other test laboratories.

This base method is the one against which the results of variations upon it are considered in this report.

3.4.2 Smoke measurements – DIN+ 160°C method

This method mirrors the DIN+ technique and protocol except that the filter assembly is held at 160°C. The objective of this method adjustment was to investigate the impact of elevated temperature on the amount of material captured during sampling.

The particulate matter that comprises wood smoke is a combination of char and ash particles with varying amounts of condensed volatile matter. The char and ash provide nucleation points for condensation.

The temperature of the sample filter is likely to be an important controlling parameter which influences the amount of volatile matter condenses or remains condensed during sample collection and measurement.

Ten tests were carried out, five each at high and low output. The operational profiles for the appliance for each test are presented in Appendix 3 (Figures A3.2a to A3.2e).

3.4.3 Smoke measurements – DIN+ 70°C method including first 3 minutes

The standard DIN+ test commences sampling up to 3 minutes after refuelling. As demonstrated in the previous reports on the ESP method **Error! Bookmark not defined.**, and on method and laboratory comparisons¹ the trends for gaseous products of incomplete combustion and optical density indicate that the highest emission concentrations generally occur within five minutes of fuel addition.

For these measurements the sampling period was commenced at refuelling (this is the practise for the other particulate sampling techniques and protocols used for residential solid fuel heating appliances) and so the emissions during the initial 3 minutes were included in the samples.

Five tests were carried out at high output. The operational profiles for the appliance for each test are presented in Appendix 3 (Figures A3.3a to A3.3c).

3.4.4 Smoke measurements – DIN+ 70°C method full cycle

The DIN+ standard method specifies a 30minute sample extraction period commencing 3 minutes after fuel addition.

Measurements according to other particulate sampling techniques and protocols (including BS 3841^V, BS PD 6434^{VI}, NS3058 and USEPA) use sampling periods based on the actual heat release cycle for an appliance from fuelling to burnout and are typically longer than 30 minutes.

These tests involved applying the DIN+ method to sampling periods comparable with those for the other methods used and reported previously¹**Error! Bookmark not defined..**

Five tests were carried out at high output. The operational profiles for the appliance for each test are presented in Appendix 3 (Figures A3.4a to A3.4c).

3.4.5 Smoke measurements – DIN+ 70°C method – prefilter deposit recovery

For these tests the material deposited in the sampling train upstream of the filter was removed (and recovered) prior to each measurement. This is in contrast with the usual practice of cleaning the system after a set of measurements (in the case of this study typically 5 at an output condition) have been completed. The cleaning / recovery procedure described in the method statement in Appendix 2 was used.

Six tests were carried out, three each at high and low output. The operational profiles for the appliance for each test are presented in Appendix 3 (Figures A3.5a to A3.5c).

3.4.6 Particulate measurements – DIN+ 70°C method – 10 minute sub-sampling

Sequential sampling periods of 10 minutes each were carried out during individual appliance operation cycles.

Four periods were sampled across consecutive tests for timing reasons:

Period	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
0 to 10 minutes	X		X		X	
11 to 20 minutes		X		X		X
21 to 30 minutes	X		X		X	
31 to 40 minutes		X		X		X

Six tests were carried out, each at high output. The operational profiles for the appliance for each test are presented in Appendix 3 (Figures A3.6a to A3.6c).

4 Results and Discussion

Summary and exemplary tables and plots are included within the main text.

Individual results from particulate emission tests listed in the matrix in Table 2 above are shown in Appendix 3. Also presented in these appendices are results from CO₂, CO, hydrocarbon, and NO_x emission measurements plotted as profiles (as identified in Section 3.4 above) and summarised in Tables A3.1a to A3.2d.

4.1 Inter-laboratory comparison results of ‘baseline’ DIN+ method

DIN+ measurements carried out on appliance B at the three laboratories were discussed in a previous report¹. This current report does not consider inter-laboratory reproducibility and the results are reproduced here solely to provide context for the results of the DIN+ method adjustment studies reported here. For reference the results are summarised in Table 5 below.

Table 5 Particulate measurements by standard DIN+ method, on Appliance B, made at three laboratories, mg/m³

Output	High				Low			
	Lab2	Lab1		Lab3	Lab2	Lab1		Lab3
Sample system washings included?*	NO	NO	YES	NO	NO	NO	YES	NO
Test 1**	139	38	53	127	131	46	48	173***
Test 2**	114	91	107	164***	97	34	35	131
Test 3**	121	95	111	145	108	13	14	197***
Test 4**	82	49	66	86	39****	38	39	160
Test 5**	109	133	150	104***	104	48	49	220***
Average	113	81	97	125	110	36	37	176
SD	20.7	38.3	38.9	31.2	14.7	13.9	14.0	34.2
RSD (%)	18	47	40	25	13	39	38	19
Ratio highest :lowest result	1.7	3.5	2.8	1.9	1.4	3.7	3.4	1.7
Ratio highest : lowest average result	1.5				5.0			

NOTES:

* The sample system washings are not included in the particulate measurement in the standard DIN+ method

** The results are presented in the sequence they were executed/reported. The Test number must not be taken to imply any relationship between tests of the same number.

*** The laboratory reported that high particle loadings affected sample volume

**** The laboratory reported that a sample timing error invalidated this result and it has not been used

For the two appliances tested (Appliance B and Appliance C) in the three laboratories, the differences in the results between laboratories were considered significant. The results from Appliance B from the three laboratories do not fit a simple relationship. For the High Output tests, the ranges of results from the three testhouses overlap but for the Low Output results

there is no overlap in the ranges. The magnitude of the PM emission concentrations data reported for each laboratory for both outputs were Lab1<Lab2<Lab3.

For all laboratories, the variation in measured PM concentrations between tests appears high (as indicated by the standard deviations and the ratios between highest and lowest emission test results) and illustrates the difficulty in obtaining reproducible test conditions between tests for manually-controlled, wood log, appliances.

The DIN+ protocol adopted by Lab1 included a section of heated sample line to connect the sample probe to the heated sample filter holder. The other laboratories included a close-couple sampling probe and heated filter. The PM collected in the Lab1 heated sampling line were recovered quantitatively and the effect of their inclusion on the particulate measurements calculated. The results are included in Table 5. Around 17% (for High Output tests) and 5% (for Low Output tests) of particulate material extracted from the flue was deposited in the sampling line. However, the inclusion of a sample line between the probe and filter housing appears insufficient to account for the differences in average PM concentrations determined by Lab1 and those by Lab2 and Lab3.

4.2 Repeatability of all the variants of the DIN+ method

The relatively wide variation in PM emissions determined at the rated output baseline measurements may indicate the unpredictability of the combustion conditions from test to test, even for this single appliance (B) in the same laboratory and hence, limits the repeatability of PM measurement data that can be expected.

Results of individual tests are given in Appendix 3 (Tables A3.3 and A3.4). The results are summarised in **Table 6** below.

Table 6 Repeatability of Appliance B results when measured by DIN+ and DIN+ based methods, mg/m³ @ 13% O₂

Method		DIN+	DIN+	DIN+	DIN+	DIN+
Output level	Statistic	70°C	160°C	3 mins	full cycle	pre-filter
High	Average	81	77	94	62	59
	SD	38	20	28	16	5
	RSD	47%	26%	30%	26%	9%
Low	Average	36	105			12
	SD	14	55			1
	RSD	39%	42%			10%

Although the repeatability of measurements (as indicated by the relative standard deviation) was generally better than for the baseline measurements, the variability in the measured

particulate emission concentrations during the baseline tests limit the observations and conclusions regarding the method adjustment.

High filter temperature - The average particulate concentrations at 'high' filter temperature at rated output are essentially the same as found during the lower temperature baseline measurements. Higher particulate concentrations were found for the lower output test condition.

Measurement including period immediately after refuel - Although the inclusion of the initial 3 minutes after refuelling seems to show a significant increase in the amount of particulate collected on average over these tests which would be expected, the reported higher emissions are likely within the uncertainty of the baseline measurements.

Measurement over full test cycle - Although the average PM concentration was lower than the average concentration during the baseline and this might be expected if the full cycle included periods of lower PM emission, reported emissions are likely within the uncertainty of the baseline measurements. However, see Section 4.3 for more detailed analysis of PM emissions during different periods of the burn cycle.

Prefilter PM recovery – The average PM concentration was lower than during the baseline whereas this test should have included both material collected in the filter and material deposited upstream of the filter.

Overall the measurements by the different method variants gave fairly similar results on average to those from the baseline High Output conditions. The measurements at the Low Output conditions suggest a greater variability in the particulate emissions under these conditions.

4.3 Variation in particulate emission with time

Six tests carried out consecutively, with two 10 minute DIN+ 70°C samples collected at defined time intervals in each, provided limited time series of particulate concentrations. The results are presented in Table 7 and Figures A3.6a to A3.6c.

Table 7 Results for the standard and DIN+ method applied to a standard sample period and to multiple sample periods in a single test for Appliance B, High Output – Particulate emissions, mg/m³ at 13% O₂

Test	1	2	3	4	5	6	Average	Standard DIN+ method
0-10 mins	47		75		95		72	
11-20 mins		72		33		55	53	
21-30 mins	17		15		14		15	
31-40 mins		41		27		57	42	
Average	46							81
SD	26							38
RSD	57%							47%

As noted previously, the variability of emissions between burn cycles makes comparison difficult however, the following was found:

1. The highest measured particulate concentration was found during the initial ten minutes of a burn cycle, this period also had the highest average particulate concentration of the burn cycle.
2. The lowest particulate concentrations were found during the third interval (21-30 minutes into the burn cycle).
3. Measured particulate concentrations in the final interval sampled (31-40 minutes of the burn cycle) were higher than for the third interval.
4. The particulate concentration measured when CO / THC levels are elevated is higher than when these levels are low. Even when CO / THC levels have dropped to a relatively low level the levels of particulate measured remain significant.

5 Conclusions

The repeatability of the measurements, using the DIN+ method variants, reported here (as indicated by the relative standard deviation) was generally better than for the baseline DIN+ measurements. However, the variability in the measured particulate emission concentrations during the baseline tests limit comparisons with the baseline.

The average particulate concentrations at 'high' filter temperature at rated output are essentially the same as found during the lower filter temperature baseline measurements. However, higher particulate concentrations were found for the lower output test condition.

Although the inclusion of the initial 3 minutes after refuelling seems to show a significant increase in the amount of particulate collected on average over these tests, the reported higher emissions are likely within the uncertainty of the baseline measurements.

The highest measured particulate concentration was found during the initial ten minutes of a burn cycle, this period also had the highest average particulate concentration of the burn cycle.

The lowest particulate concentrations were found during the third interval (21-30 minutes into the burn cycle).

Measured particulate concentrations in the final interval sampled (31-40 minutes of the burn cycle) were higher than for the third interval.

The particulate concentration measured when CO / THC levels are elevated are higher than when these levels are low. However, even when CO / THC levels have dropped to a relatively low level the levels of particulate measured remained significant.

6 Recommendations for future testing

The results of the adjustments to testing have been difficult to assess because of the variability in the measured particulate emission concentrations during the baseline tests which has limited comparisons.

The information which was assessed in this test programme is relevant to development of an improved solid fuel appliance test procedures (and in particular the 'ideal' start and duration of testing).

It is recommended that further testing to investigate the relationship between testing measurement methods always undertakes **parallel** (simultaneous) measurements so that comparison is always with the same burn cycle – i.e. removing the uncertainties associated with the variability between burn cycles.

To assess whether the uncertainty due to the variability found between individual burn cycles may be reduced by extending emission tests to cover several burn cycles it is recommended that the impact of measuring particulate emissions from multiple refuels in a single test is investigated.

7 References

^I Assessment of particulate and NO_x emissions from a range of log and pellet appliances and boilers by a range of measurement techniques. Report on inter-method and inter-laboratory comparisons. Kiwa GASTEC at CRE, Report 60097-3, December 2013.

^{II} CEN/TS 15883:2009 Residential solid fuel burning appliances - Emission test methods

^{III} BS EN 13240:2001 Roomheaters fired by solid fuel - Requirements and test methods.

^{IV} CEN/TS 15883:2009 Residential solid fuel burning appliances - Emission test methods

^V BS 3841-2 1994 Determination of smoke emission from manufactured solid fuels for domestic use – Part 2: Methods for measuring the smoke emission rate

^{VI} PD 6434:1969 Recommendations for The design and testing of smoke reducing solid fuel burning domestic appliances

Appendix 1 Log fuel selection method statement

Date: 08 May 2006	BS EN Standards 12815, 12809, 13229 & 13240,	
	Tests with wood	Page: All/02

Issue

SIZE OF WOOD LOGS

The test fuel specifications state that all fuels, including wood logs, should be "of commercial size in accordance with manufacturer's instructions". Potentially, this gives the manufacturer considerable leeway in describing the fuel size in its operating instructions.

Interpretation

The standards are not really ambiguous. Whilst they can be of the size in accordance with the manufacturer's instructions they also have to be "logs" and of "commercial size".

Thus the sizes allowable for wood logs are limited in range to the smallest (~300 mm) and largest (0.5 metre) available in the European market

Policy

Gastec at CRE will purchase logs on the commercial market. Whilst some selection can be made of these logs to suit the physical size of the appliance and the manufacturer's instructions no further size reduction of the logs will be permitted, eg to produce slivers, to generate wood pieces which could not sensibly be sold as "wood logs"

Author John Tucker		Initials:
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Appendix 2 DIN+ method statement

TEST EQUIPMENT USED

	Equipment Number	Calibration Status	
Test Rig	FAT		
Data logger (PC)	FAT		
Squirrel logger	FAT		
Flue gas analyser (NO ₂)	FAT	Span before test	
Flue gas analyser (C _x H _y)	FAT		
Heated filter box (set to 70°C)	FAT		
Pumped gas flow temp	FAT		
Heated filter box temp	FAT		
Gas meter	FAT		
Stop watch	FAT		
Scales for filters	FAT		

Note: Ensure that equipment has valid calibration status before starting test.

1. METHOD

- 1 The DINplus testing for particulates, NO_x and hydrocarbons is carried out concurrent to the efficiency and nominal heat output test conducted as described in BS EN12809, 12815, 13229, 13240, 14785 and 303-5. The DINplus methodology follows that outlined in DD CEN/TS 15883:2009 and a DIN CERTCO document available from TÜV Rheinland, dated June 2008. (There will be an accompanying test sheet – with the same test number – for the efficiency and nominal heat output test).
- 2 Span the NO_x and hydrocarbon analysers and connect NO_x and hydrocarbon to the Channels 11 and 12, respectively, of the Squirrel logger. Ensure that the ranges for the analysers are set to 10000 ppm for hydrocarbons and 400 ppm for NO_x, and that the Squirrel ranges are set to 20 volts.
- 3 On lighting the appliance, ensure that the heaters for the line and filter housing are switched on.
- 4 Ensure that the thermocouple measuring the suction flow temperature is connected to a channel of the Pico logger
- 5 Prior to conducting first test in the series, take reading of gas meter, turn on suction pump and operate for 15 minutes exactly. Record gas meter reading at the end of this pre-test period and determine total gas volume used. Check if volume is between 0.140 and 0.150 m³ (as measured). If readings are outside range, then pump speed should be adjusted as necessary and the procedure repeated for as many times as necessary. Use table below to record information.

Gas meter reading – end	m ³						
Gas meter reading – start	m ³						
Total gas volume	m ³						

- 6 Weigh at least three filters (having been dried at 105°C for at least an hour and then stored in a desiccator for at least 4 hours).
- 7 Check that the filter housing is 70°C and heated line is 150°C. Then insert first filter.
- 8 Immediately prior to the first test in the series, insert dust sample probe (ensuring that it is correctly positioned) and connect heated line.
- 9 Three minutes after refuelling from the start of the test, switch on pump and simultaneously record the reading on the gas meter.
- 10 After 30 minutes, immediately turn off pump and record the reading on the gas meter. Determine total volume flow and approximate temperature of the suction gas. Calculate total flow corrected to NTP. If total flow is 270 +/- 5% litres, ie 256.5 – 283.5 litres, then test is valid.
- 11 Carefully remove filter and place in labelled petri dish. Put in drying oven at 105°C for at least one hour and store for at least 4 hours in a desiccator.
- 12 Weigh filter and dish
- 13 Repeat steps 9 – 12 for each test.
- 14 During a test make note of a spot sample of the analyser and Squirrel readings

	Analyser (ppm)	Squirrel (V)
NOx Channel 11		
HCs Channel 12		

- 15 At the end of the series of tests, remove/disconnect the dust sample probe and heated line. Rinse with acetone, collecting the washings in a tared aluminium tray. Allow the washings to evaporate at ambient temperature and record the weight of the tray and residue.

5. **TEST PERIOD** Ensure logger is on before starting the test.

		Test 1	Test 2	Test 3	Test 4
Filter number					
Mass filter, with support (before test)	g				
Mass filter, with support (after test)	g				
Mass gain (A)	g				
Washings	Mass tray + washings	g			
	Mass tray	g			
	Mass washings	g			
	Mass washings per test (B)	g			
Total mass gain (A + B)		g			
Clock time - Start					
Clock time - End					
Gas meter reading – end	m ³				
Gas meter reading – start	m ³				
Total gas volume	m ³				
Temperature flow gas (approx.)	°C				
Total flow (to 0°C) (approx.)#	litres				
Valid test? (Between 256.5 & 283.5 litres)					
Actual temp of flow gas*	°C				
Av.CO ₂ or O ₂ in flow gas (during sampling period)*	%				
Delete as appropriate					

Corrected total flow = Total flow x (273)/(273+Temp flow)

* from prn files

6. TEST RESULTS

The NO_x and CxHy logger data for each refuelling / efficiency period shall be copied to the Excel spreadsheet at N/SFAP/DINplusdatacollate.xls. For the purposes of reporting the NO_x and CxHy and emissions, the final test results must also be processed using the spreadsheet at N/SFAP/DINplusdatacollate.xls.

For the purposes of reporting the particulate emissions, the final test results must be processed using the spreadsheet at N/SFAP/DINplus.xls. Note that the average oxygen or CO₂ contents used in the calculations are obtained from the separate spreadsheet used to determine the output and efficiency. A separate spreadsheet also applies for the temperature of the flow gas for the particulates.

For the particulate measurements, the thirty minute period of each particulate test should be highlighted in the oxygen (or CO₂) and flow gas temperature columns and the average values noted (from the bottom right of the screen)

Obtain printouts of test results. All printouts must be retained and filed with this document.

7. SUMMARISED TEST RESULTS

Parameter		Test 1	Test 2	Test 3	Test 4	Mean
Mean CxHy emission	ppm					
Mean NO _x emission	ppm					
Particulate emission	mg/Nm ³					

COMMENTS

Appendix 3 DIN+ method variants test results

TABLES

Table A3.1a Averages of operating parameters for each test - CO, %, as measured

Output	High					Low				
Method	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter
Test 1	0.30	0.42	0.20	0.22	0.19	0.32	0.48			0.42
Test 2	0.27	0.50	0.25	0.14	0.23	0.24	0.67			0.37
Test 3	0.28	0.27	0.33	0.22	0.22	0.65	0.95			0.29
Test 4	0.18	0.43	0.32	0.20		0.71	0.97			
Test 5	0.14	0.54	0.31	0.28		0.50	0.72			
Maximum	0.30	0.54	0.33	0.28	0.23	0.71	0.97			0.42
Minimum	0.14	0.27	0.20	0.14	0.19	0.24	0.48			0.29
Average	0.23	0.43	0.28	0.21	0.21	0.48	0.76			0.36
SD	0.07	0.10	0.06	0.05	0.02	0.20	0.20			0.07
RSD	54%	39%	20%	23%	9%	42%	27%			18%

Table A3.1b Averages of operating parameters for each test – NO_x as NO₂ mg/m³ @ 13% O₂

Output	High					Low				
Method	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter
Test 1	143	-	81	77	85	89	74			55
Test 2	124	-	69	99	92	104	64			51
Test 3	125	-	69	95	98	98	63			62
Test 4	130	120	41	84		81	74			
Test 5	142	115	69	68		87	82			
Maximum	143	120	81	99	98	104	82			62
Minimum	124	115	41	68	85	81	63			51
Average	133	118	66	85	92	92	71			56
SD	9	4	15	13	6	9	8			6
RSD	7%	3%	22%	15%	7%	10%	11%			10%

Table A3.1c Averages of operating parameters for each test – OGC mg C/m³ @ 13% O₂

Output	High					Low				
	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter
Test 1	529		144	91	45	373	910			173
Test 2	397		128	35	89	207	1244			211
Test 3	393		173	88	69	878	1409			154
Test 4	215	528	190	81		850	1498			
Test 5	130	570	318	88		516	903			
Maximum	529	570	318	91	89	878	1498			211
Minimum	130	528	128	35	45	207	903			154
Average	333	549	190	77	68	565	1193			179
SD	159	30	75	23	22	294	277			29
RSD	48%	5%	40%	31%	33%	52%	23%			16%

Note: Organic Gaseous Carbon (OGC) is calculated from the Total Hydrocarbon (THC) according to the method in DD CEN/TS 15883:2009. This is the standard basis on which these emissions should be reported.

Table A3.1d Averages of operating parameters for each test – CO₂, %, as measured

Output	High					Low				
	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter
Test 1	9.6		12.0	8.6	8.7	10.2	9.2			5.7
Test 2	10.5		10.3	10.4	9.3	9.6	6.8			6.8
Test 3	9.8		9.4	9.7	9.6	7.7	6.7			8.3
Test 4	11.0	9.9	9.2	8.5		6.4	6.7			
Test 5	10.6	9.8	10.0	9.1		8.1	8.4			
Maximum	11.0	9.9	12.0	10.4	9.6	10.2	9.2			8.3
Minimum	9.6	9.8	9.2	8.5	8.7	6.4	6.7			5.7
Average	10.3	9.9	10.2	9.3	9.2	8.4	7.5			6.9
SD	0.6	0.1	1.1	0.8	0.5	1.5	1.2			1.3
RSD	7%	8%	10%	7%	4%	11%	9%			9%

Table A3.2a Average operating parameters for tests where 10 minute samples were collected using the standard DIN+ method – CO, % as measured

	Sample period from start of test				
	0 to 10	11 to 20	21 to 30	31 to 40	All
Test 1	0.75	0.34	0.06	0.08	0.30
Test 2	0.44	0.32	0.11	0.13	0.25
Test 3	0.32	0.08	0.07	0.14	0.17
Test 4	0.25	0.16	0.11	0.11	0.16
Test 5	0.75	0.22	0.03	0.12	0.29
Test 6	0.24	0.15	0.15	0.23	0.22

Table A3.2b Average operating parameters for tests where 10 minute samples were collected using the standard DIN+ method – OGC mg C/m³ @ 13% O₂

	Sample period from start of test				
	0 to 10	11 to 20	21 to 30	31 to 40	All
Test 1	519	160	0	0	158
Test 2	176	77	10	0	58
Test 3	216	11	0	5	74
Test 4	87	42	5	0	31
Test 5	725	231	2	0	214
Test 6	144	42	14	31	96

Table A3.2c Average operating parameters for tests where 10 minute samples were collected using the standard DIN+ method – NO_x, mg/m³ @ 13% O₂

	Sample period from start of test				
	0 to 10	11 to 20	21 to 30	31 to 40	All
Test 1	75	79	76	79	73
Test 2	69	76	74	70	68
Test 3	83	97	86	72	76
Test 4	84	97	94	86	82
Test 5	85	83	83	79	73
Test 6	99	96	87	79	81

Table A3.2d Average operating parameters for tests where 10 minute samples were collected using the standard DIN+ method – CO₂, %, as measured

	Sample period from start of test				
	0 to 10	11 to 20	21 to 30	31 to 40	All
Test 1	17.0	13.6	11.2	9.5	12.9
Test 2	15.8	13.2	10.4	7.7	11.6
Test 3	14.4	11.1	8.8	7.6	10.2
Test 4	14.3	12.0	10.1	7.9	10.8
Test 5	15.5	12.1	9.9	6.5	11.4
Test 6	13.4	10.6	9.2	6.5	10.0

Table A3.3 Results for the standard and adjusted DIN+ methods applied for Appliance B – Particulate emissions over up to five repeats, mg/m³ at 13% O₂

Output	High					Low				
Method	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter	70°C	160°C	Inc. init. 3 mins	Full cycle	Pre-filter
Test 1	38	107	105	83	64	46	97			11
Test 2	91	67	56	60	61	34	61			12
Test 3	95	52	83	58	54	13	84			13
Test 4	49	80	92	40		38	201			
Test 5	133	79	131	71		48	85			
Maximum	133	107	131	83	64	48	201			13
Minimum	38	52	56	40	54	13	61			11
Average	81	77	94	62	59	36	105			12
SD	38	20	28	16	5	14	55			1
RSD	47%	26%	30%	26%	9%	39%	52%			10%

FIGURES

Figure A3.1a DIN+ 70°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test1 (left) and Test 2 (right)

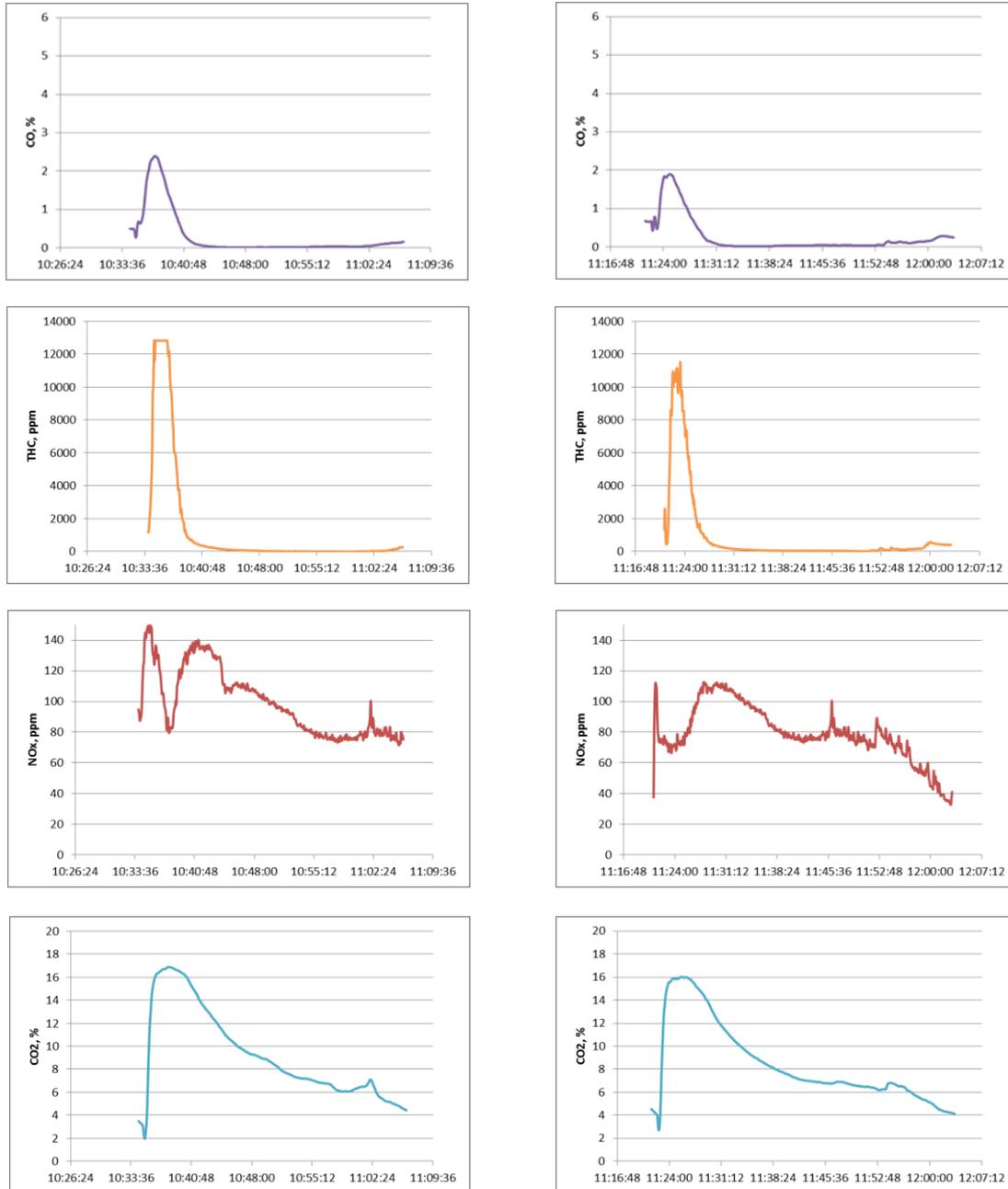


Figure A3.1b DIN+ 70°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 3 (left) and Test 4 (right)

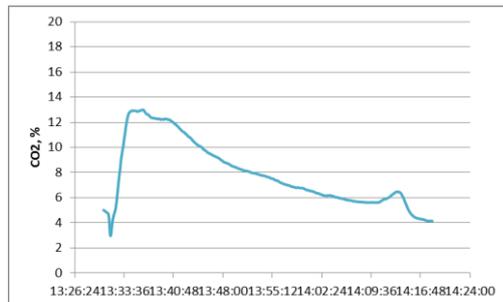
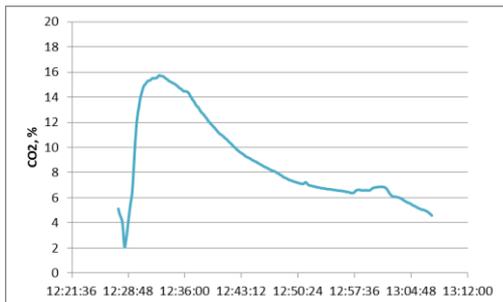
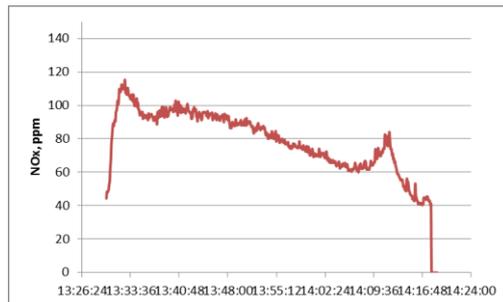
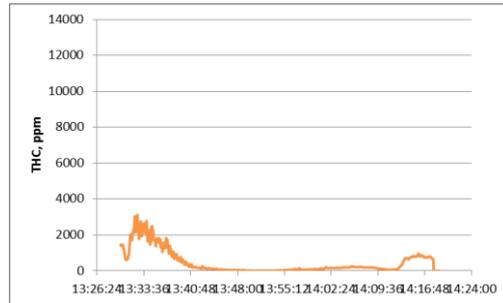
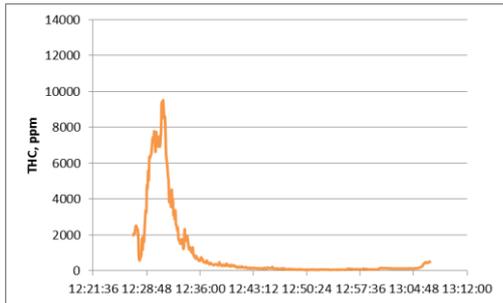
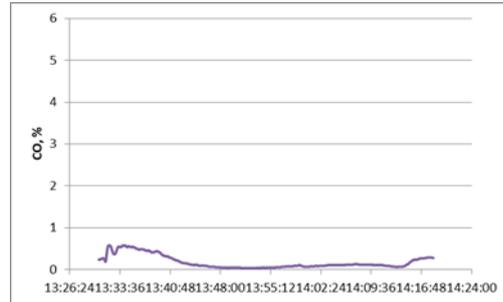
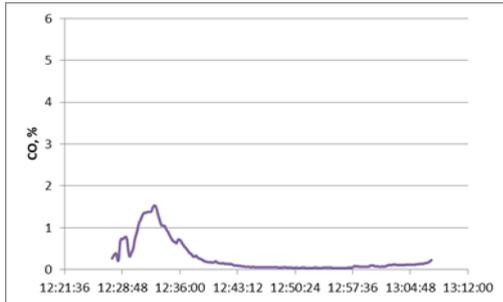


Figure A3.1c DIN+ 70°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 5 (left) and Low Output Test 1 (right)

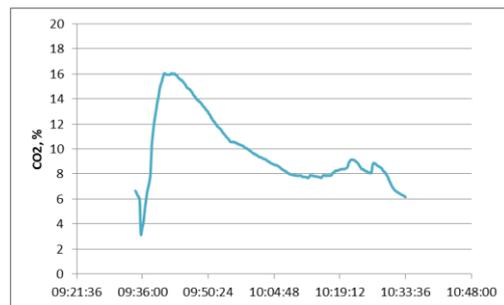
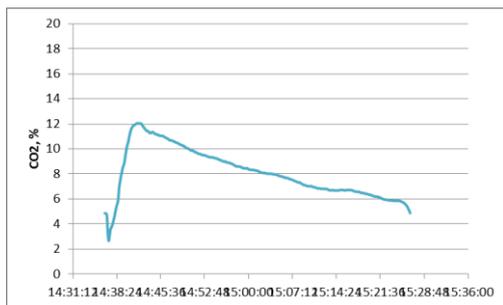
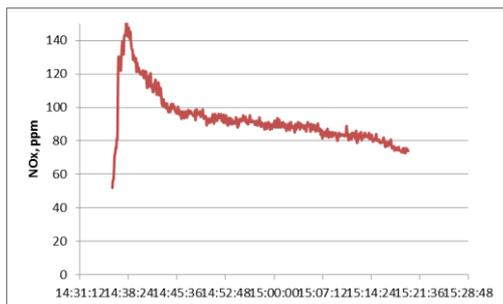
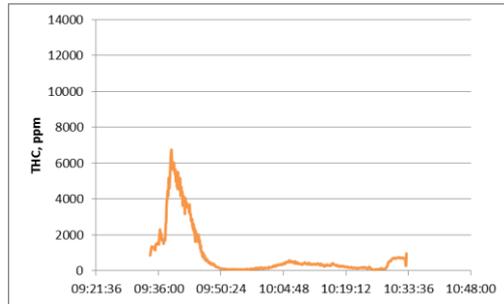
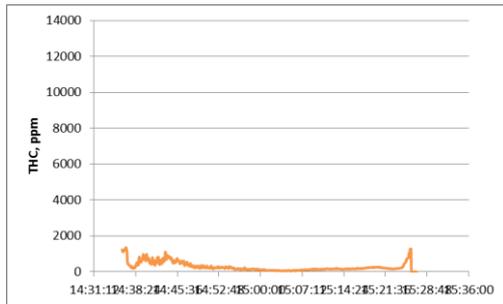
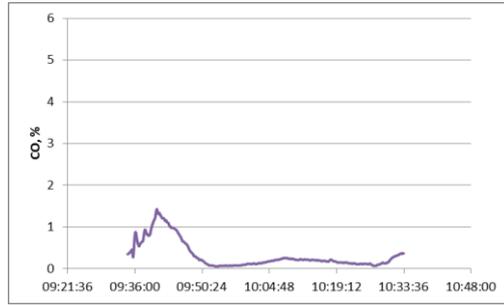
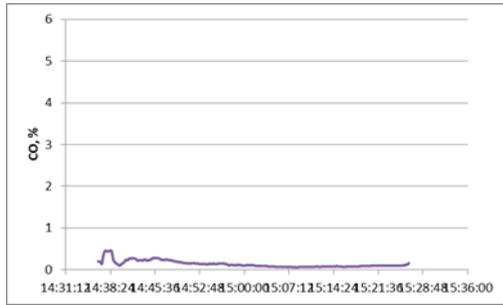


Figure A3.1d DIN+ 70°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, Low Output, Test 2 (left) and Test 3 (right)

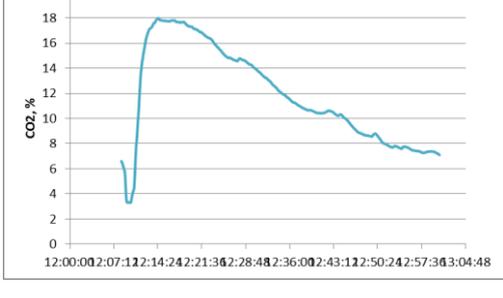
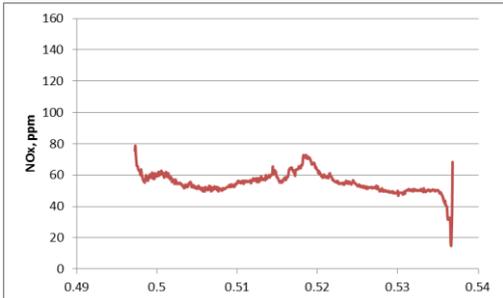
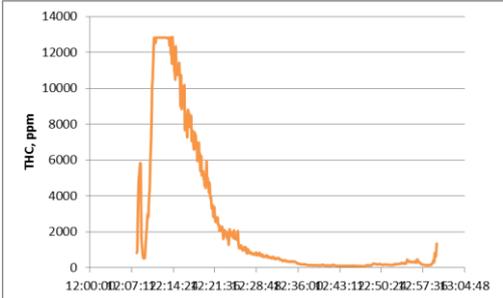
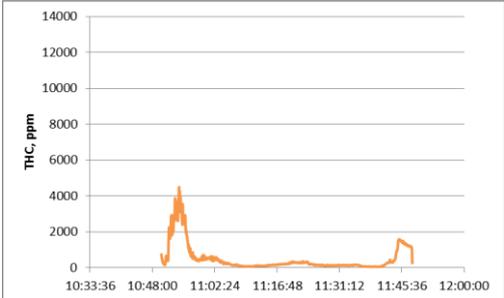
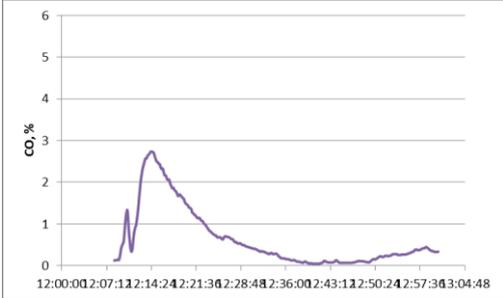
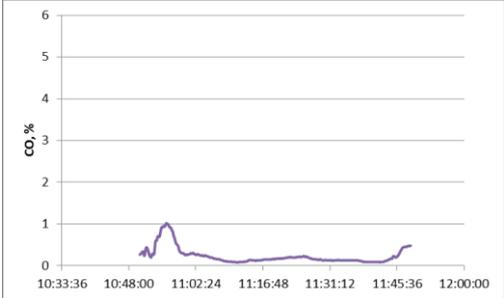


Figure A3.1e DIN+ 70°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, Low Output, Test 4 (left) and Test 5 (right)

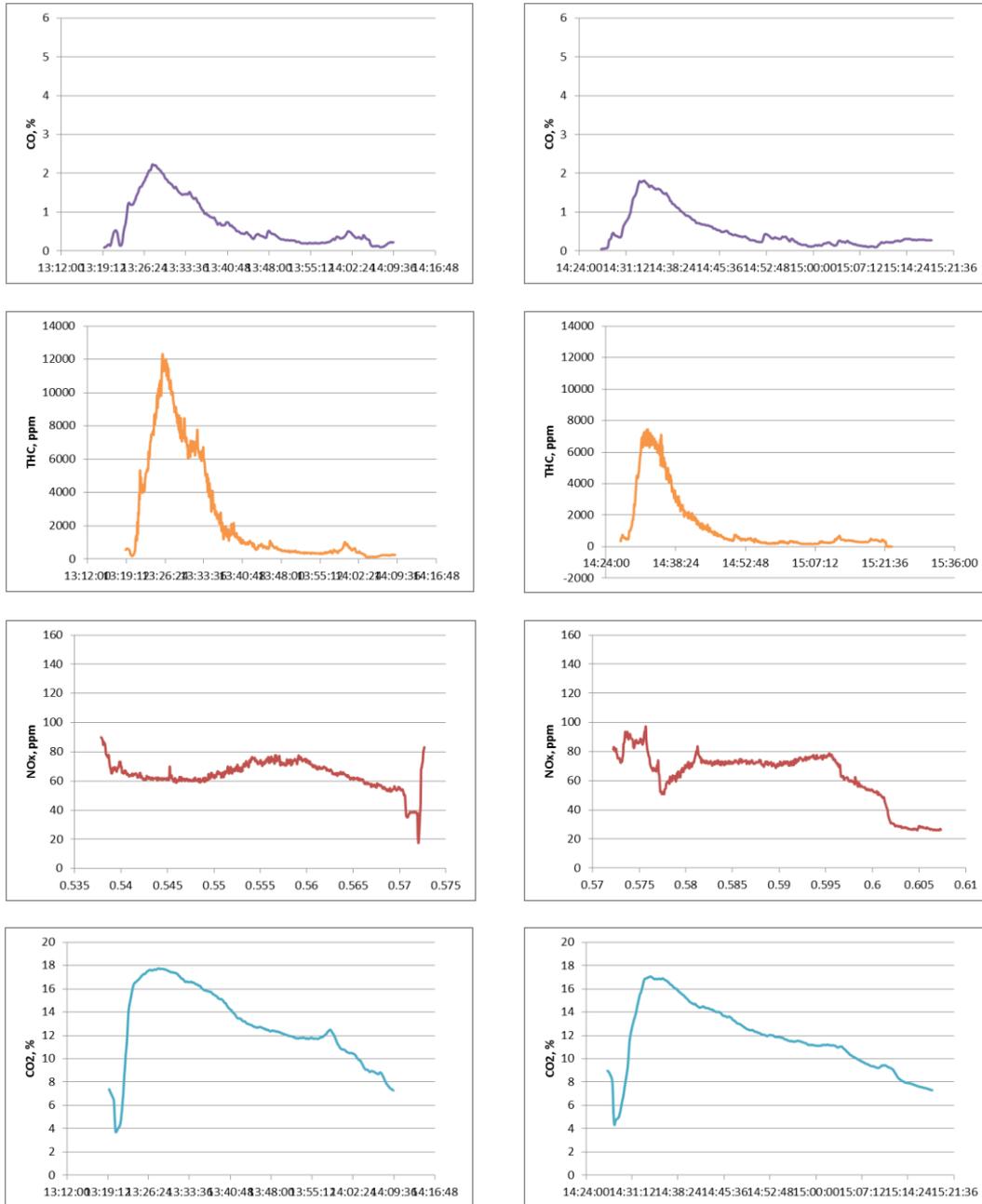


Figure A3.2a DIN+ 160°C method: Flue gas measurement traces of CO and CO₂ for Appliance B, High Output, Test1 (left) and Test 2 (right)

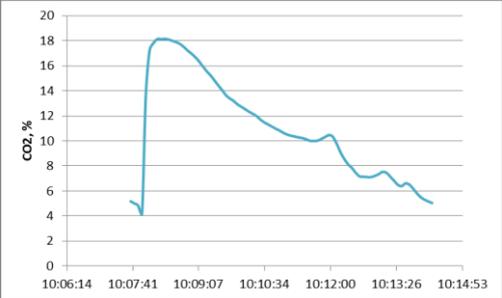
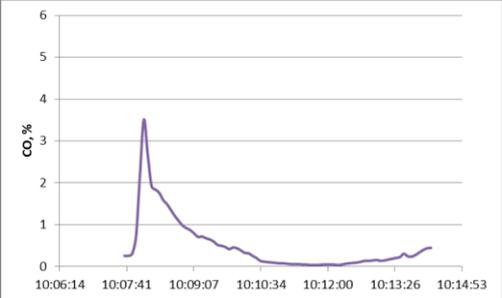
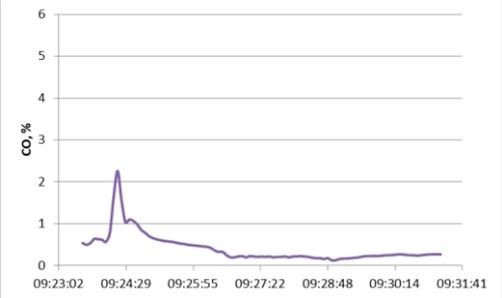


Figure A3.2b DIN+ 160°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 3 (left) and Test 4 (right)

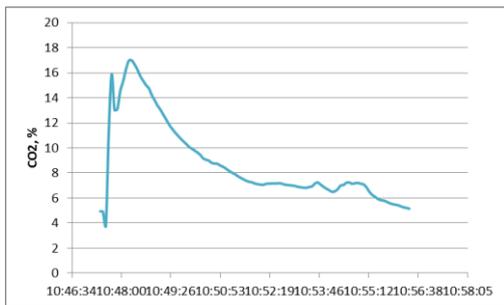
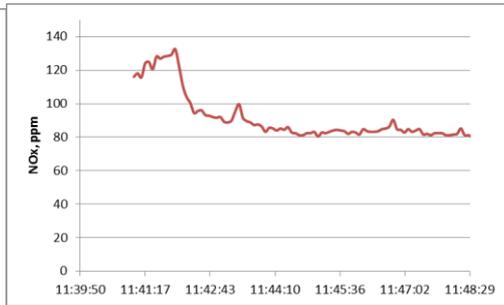
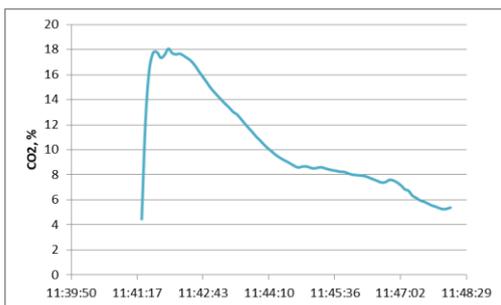
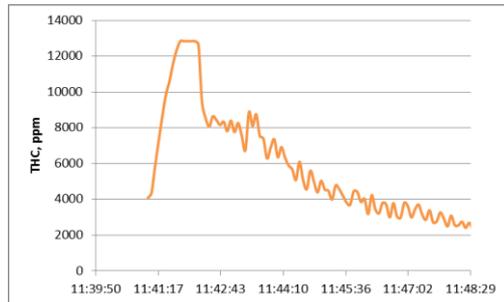
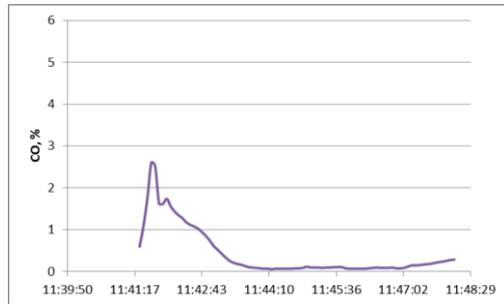
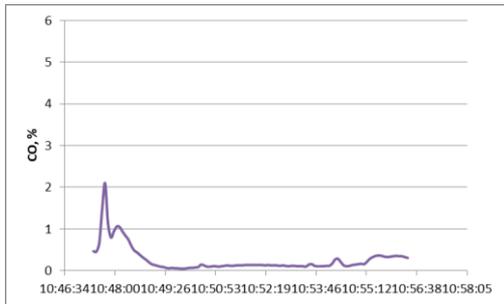


Figure A3.2c DIN+ 160°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 5 (left) and Low Output Test 1 (right)

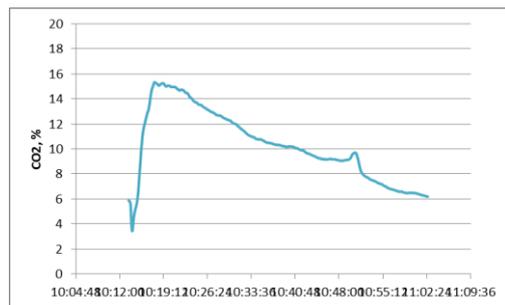
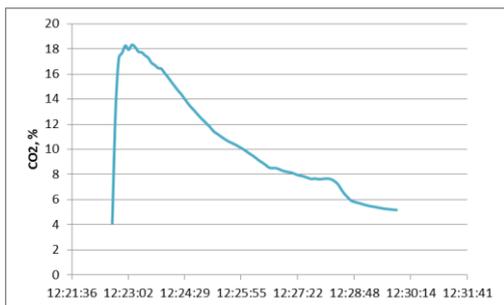
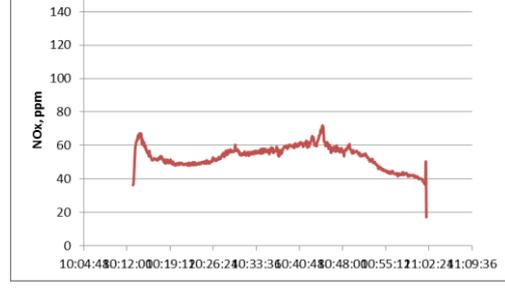
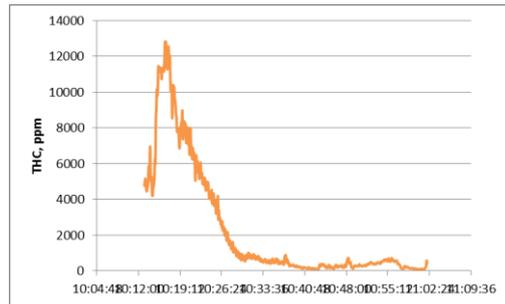
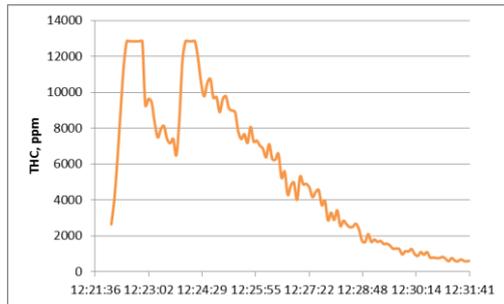
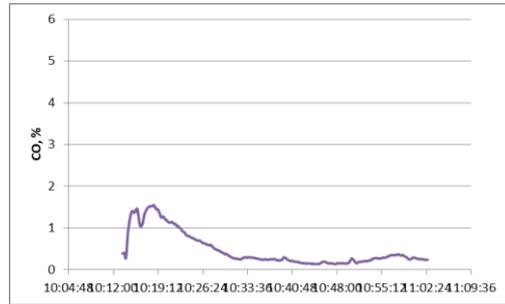
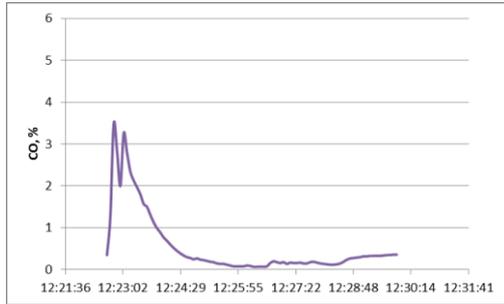


Figure A3.2d DIN+ 160°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, Low Output, Test 2 (left) and Test 3 (right)

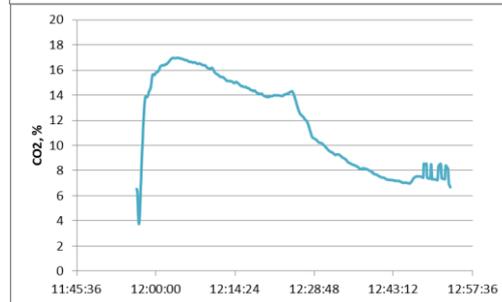
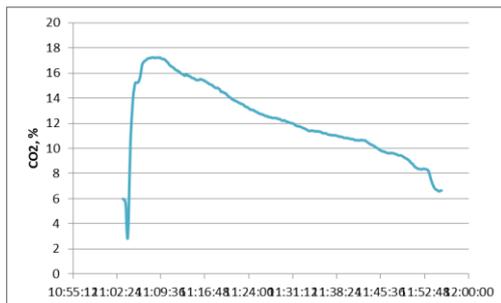
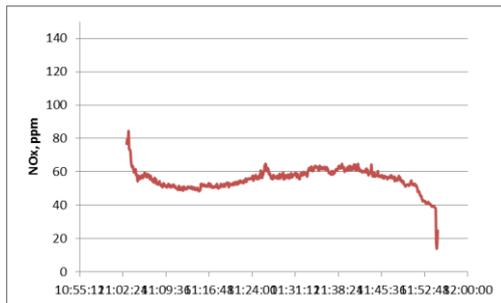
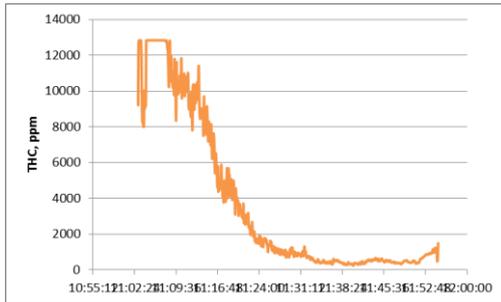
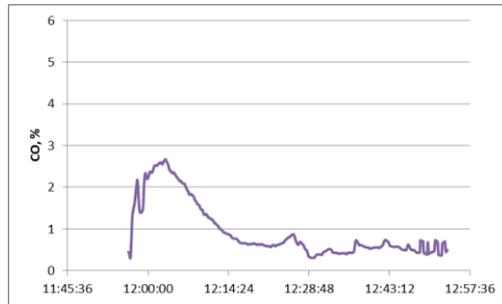
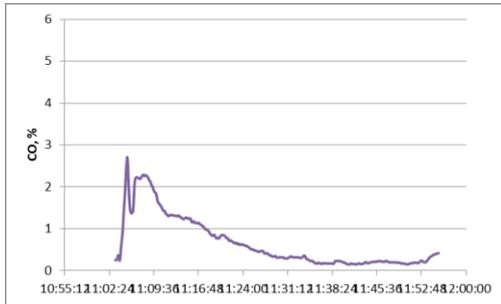


Figure A3.2e DIN+ 160°C method: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, Low Output, Test 4 (left) and Test 5 (right)

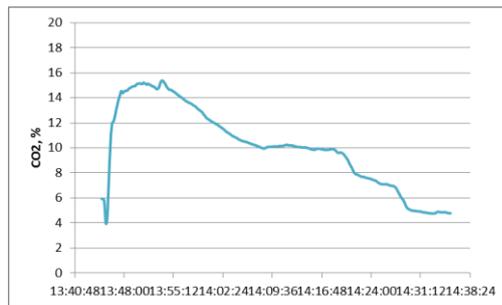
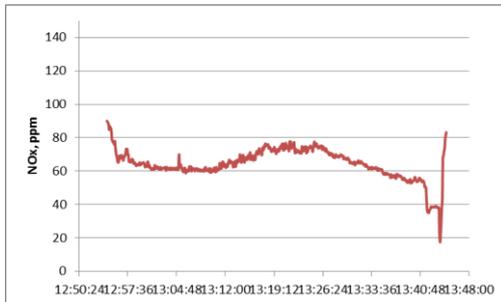
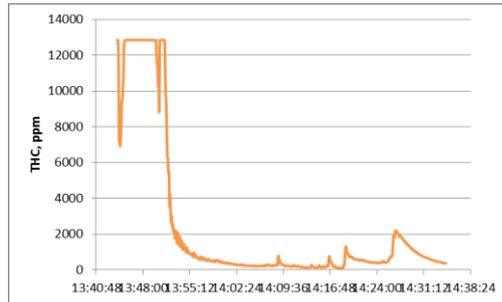
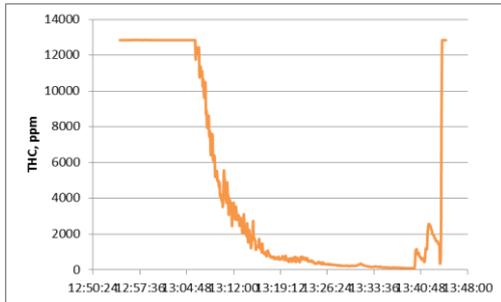
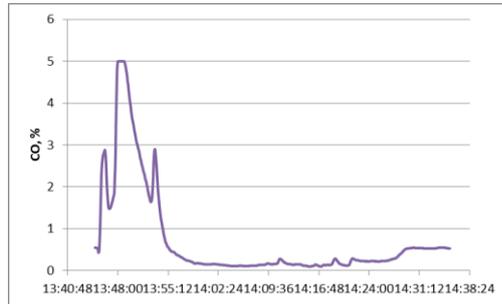
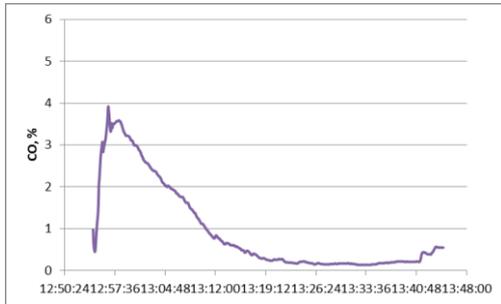


Figure A3.3a DIN+ 70°C method +3 mins at start: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test1 (left) and Test 2 (right)

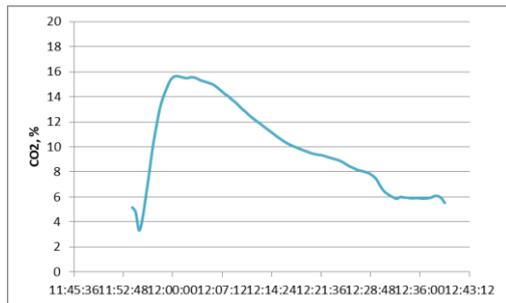
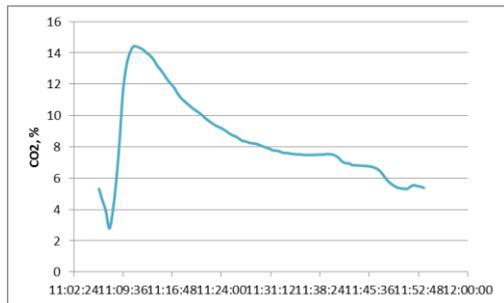
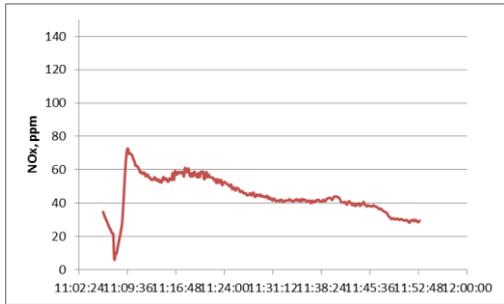
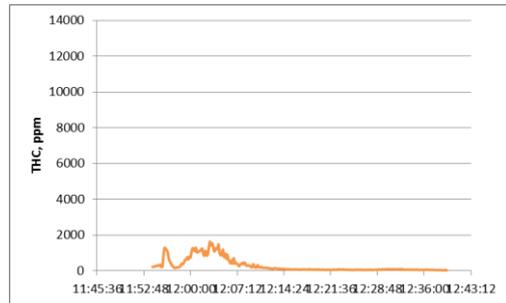
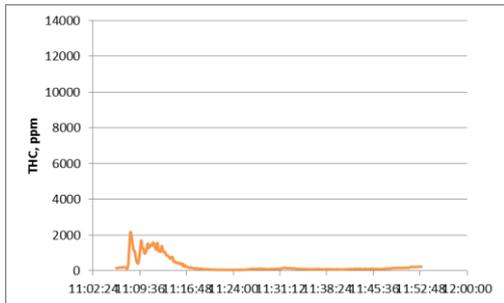
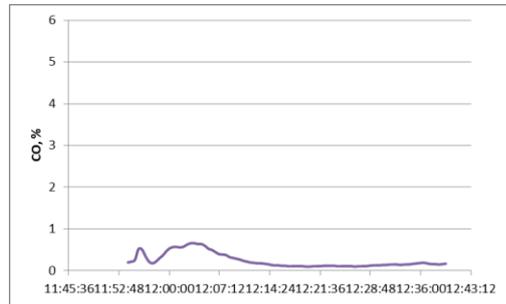
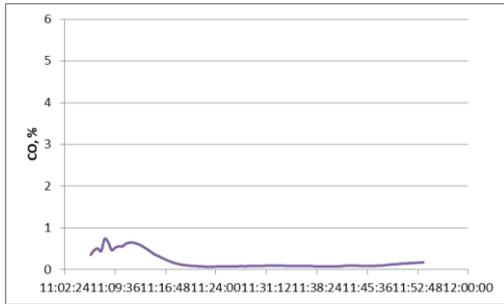


Figure A3.3b DIN+ 70°C method+3 mins at start: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 3 (left) and Test 4 (right)

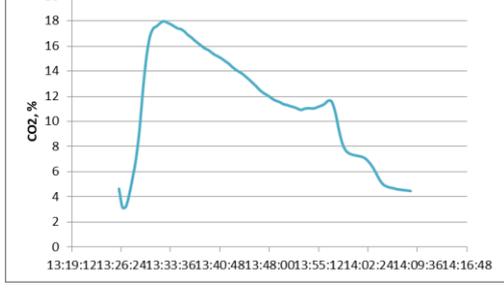
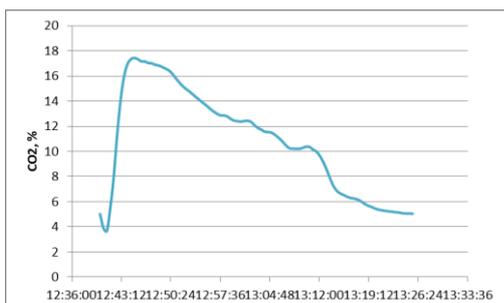
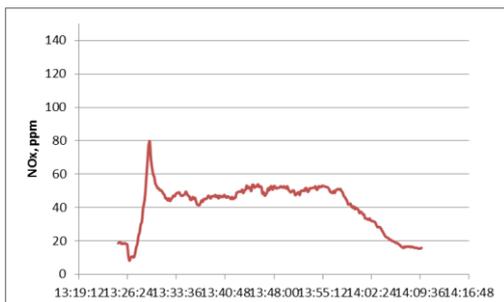
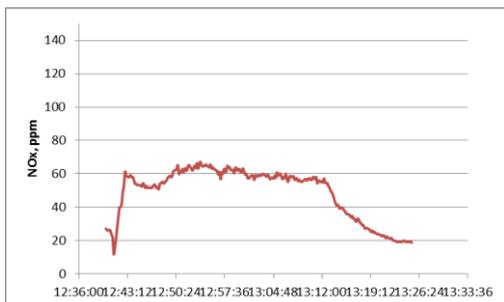
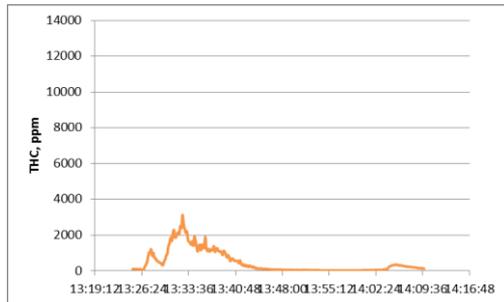
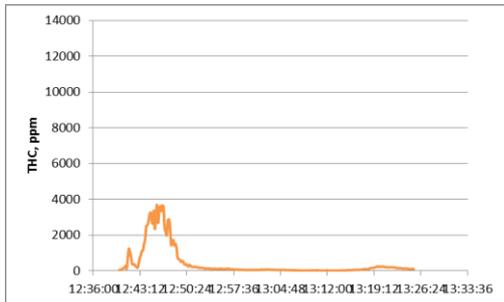
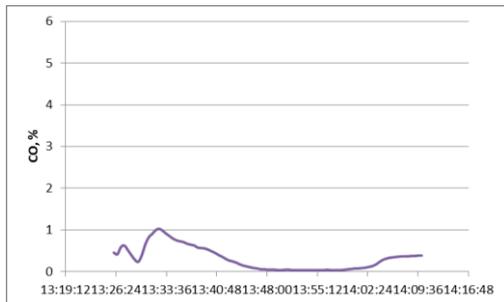
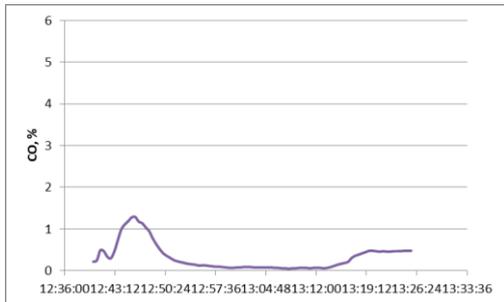


Figure A3.3c DIN+ 70°C method+3 mins at start: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 5

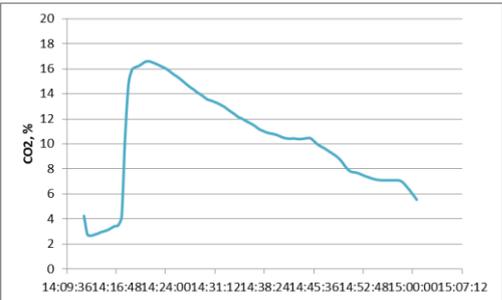
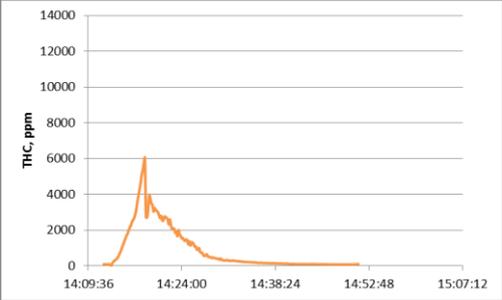
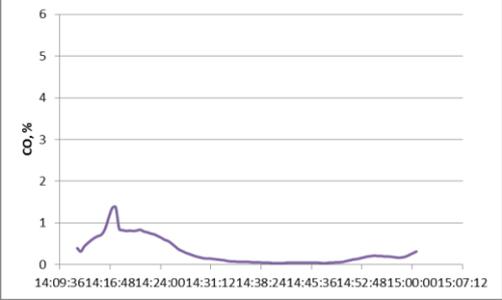


Figure A3.4a DIN+ 70°C method – full cycle: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test1 (left) and Test 2 (right)

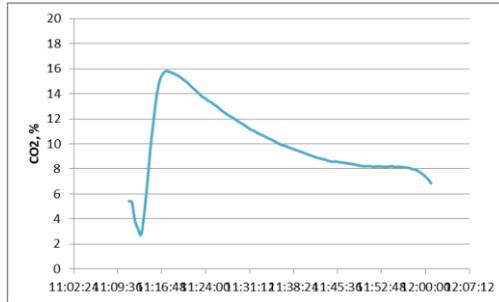
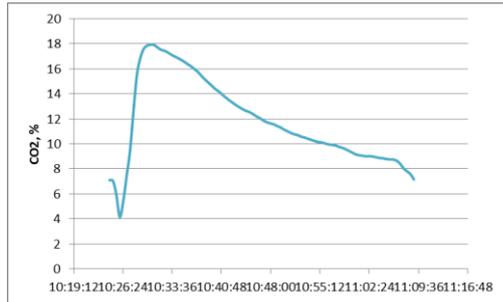
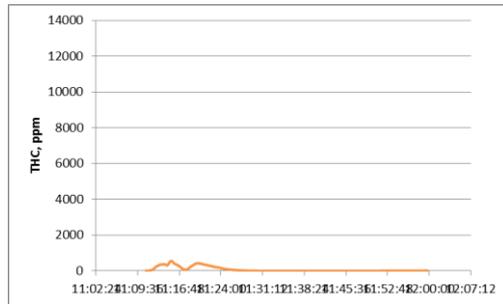
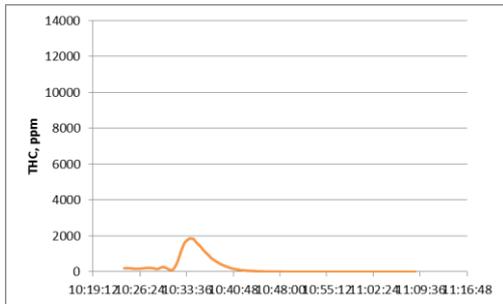
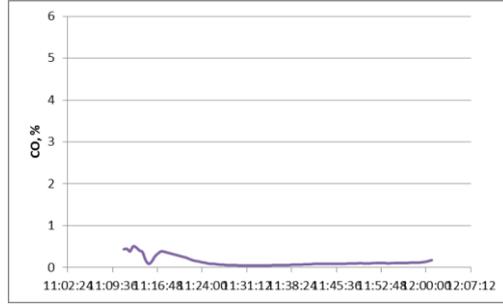
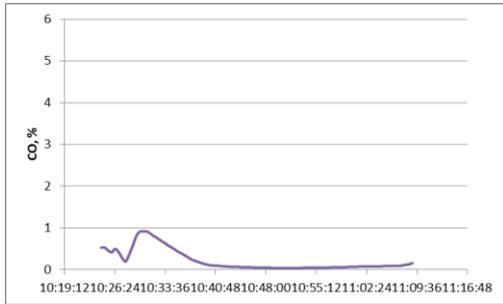


Figure A3.4b DIN+ 70°C method – full cycle: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 3 (left) and Test 4 (right)

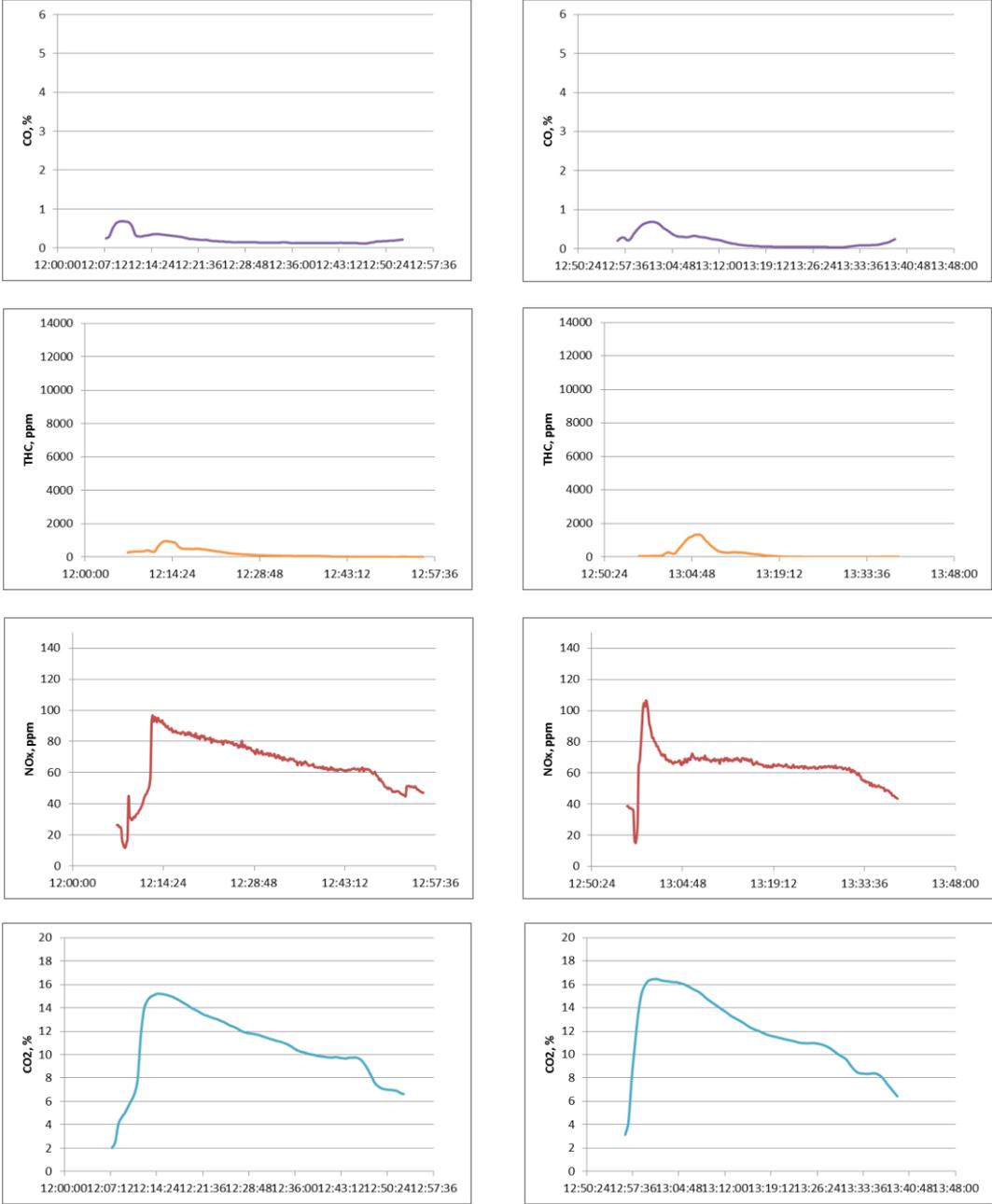


Figure A3.4c DIN+ 70°C method – full cycle: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 5

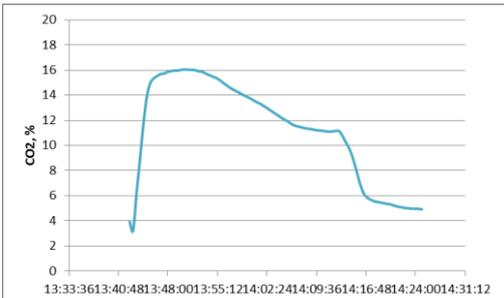
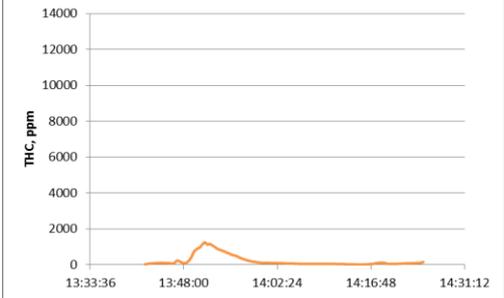
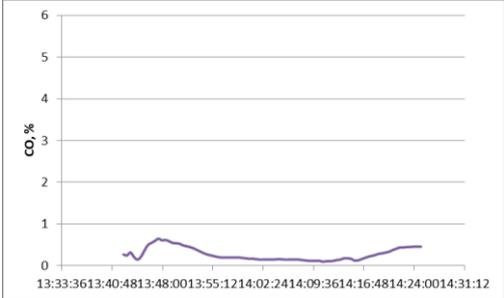


Figure A3.5a DIN+ 70°C method with individual pre-filter washings: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test1 (left) and Test 2 (right)

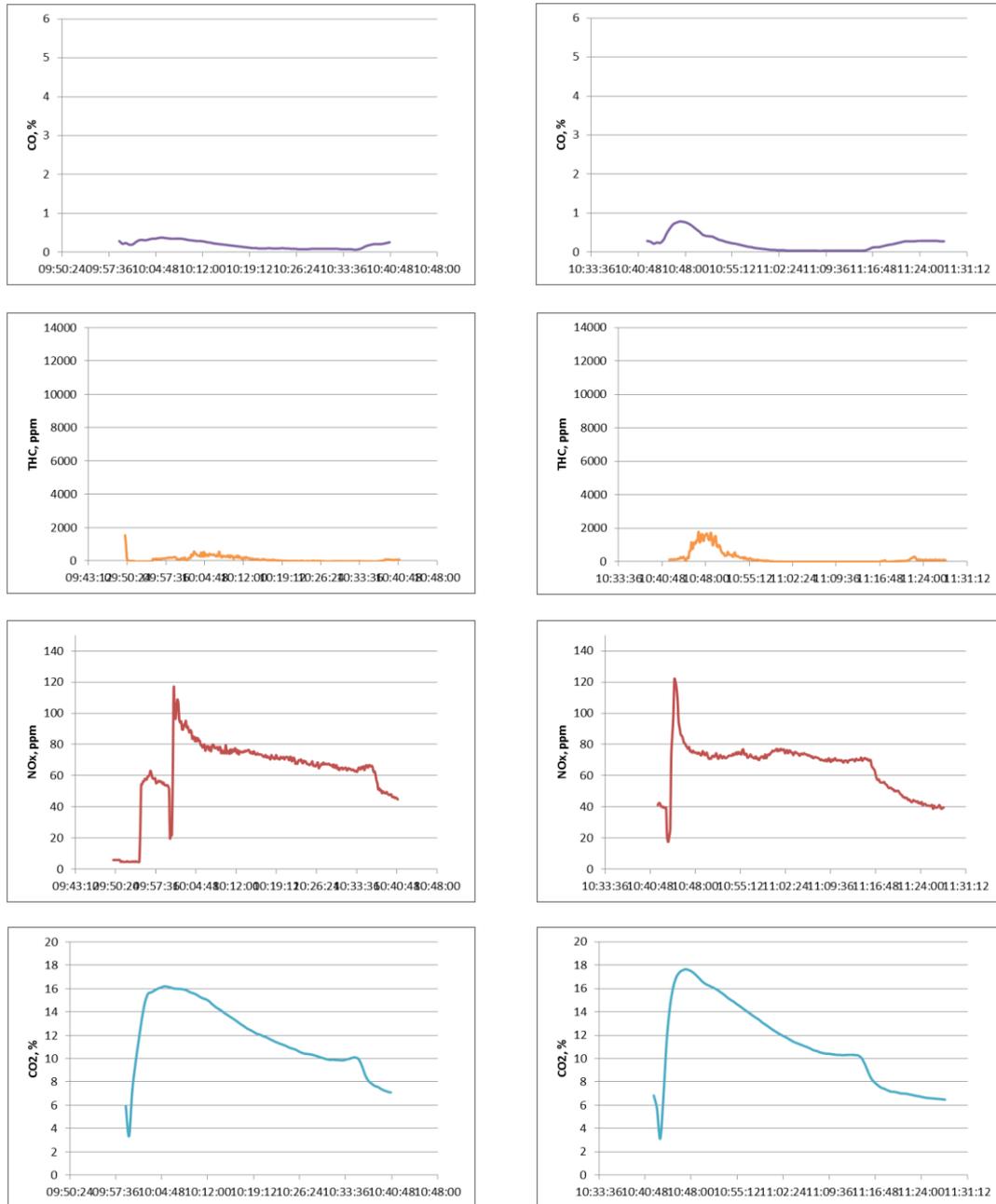


Figure A3.5b DIN+ 70°C method with individual pre-filter washings: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 3 (left) and Low Output Test 1 (right)

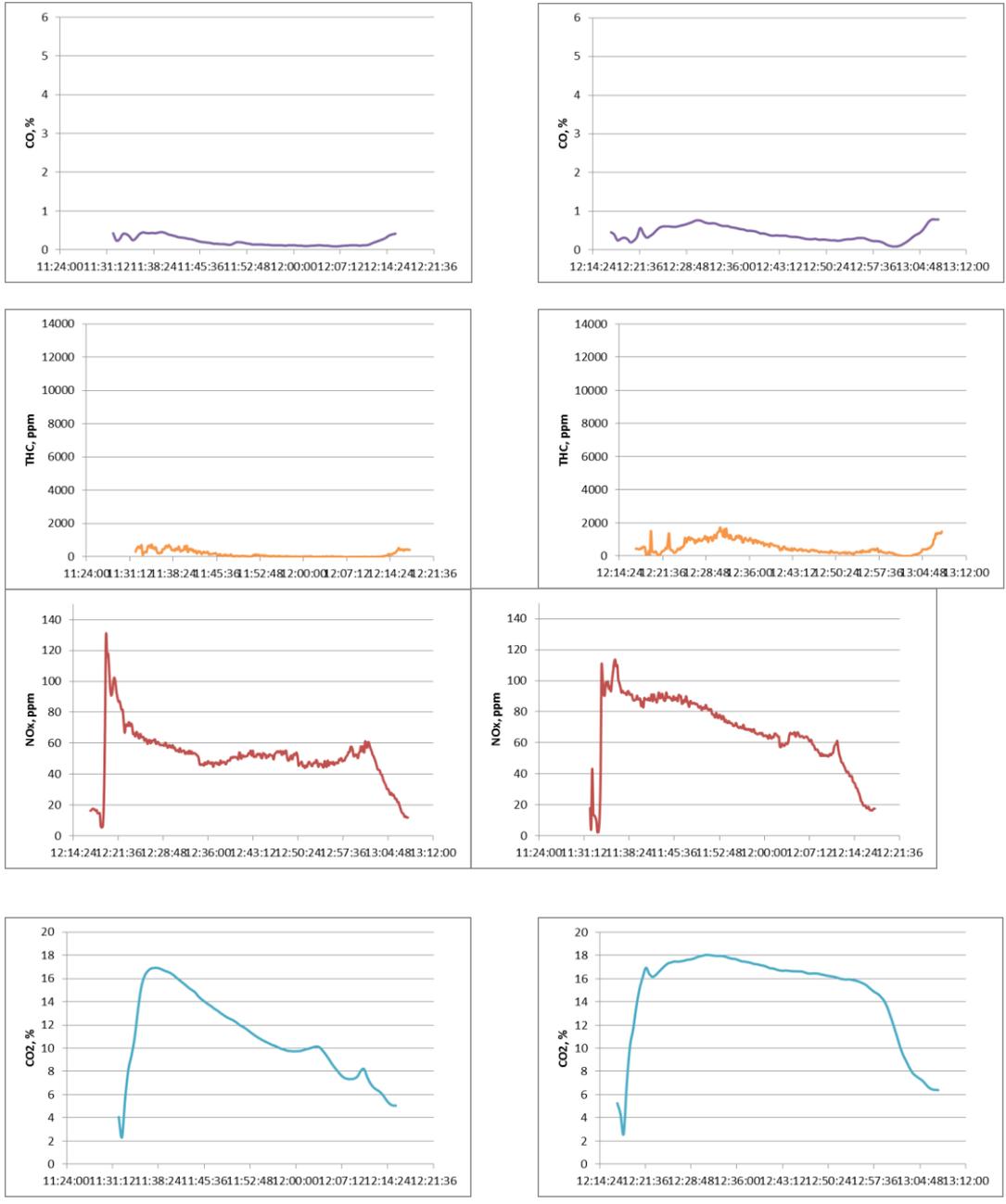


Figure A3.5c DIN+ 70°C method with individual pre-filter washings: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, Low Output, Test 2 (left) and Test 3 (right)

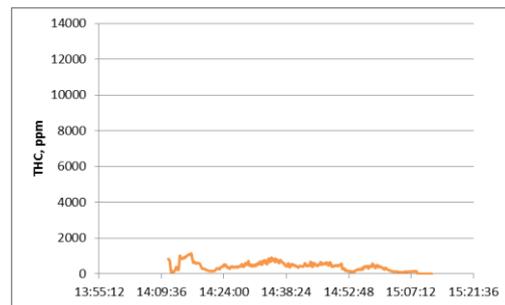
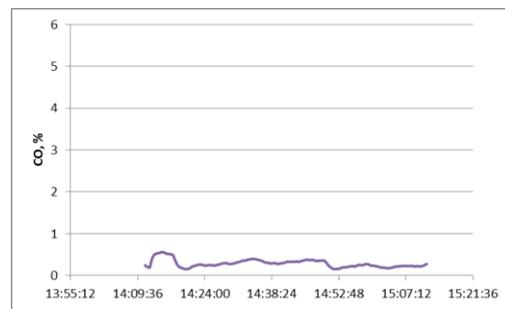
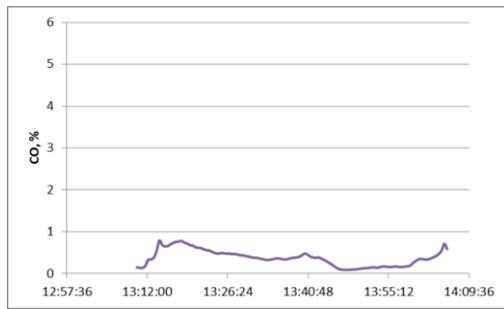


Figure A3.6a DIN+ 70°C method with 10minute samples: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 1 (left) and Test 2 (right) with particulate measurements for comparison

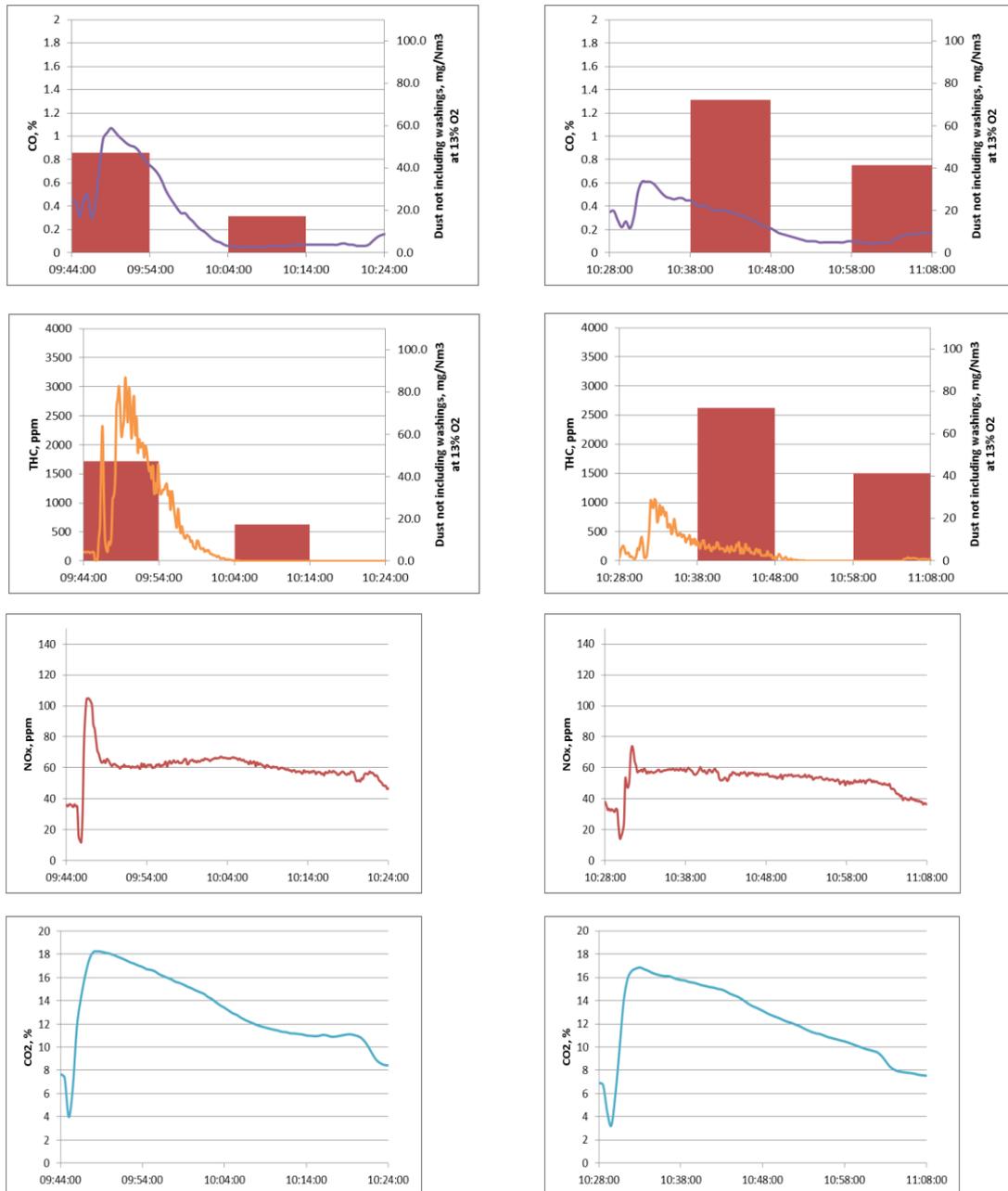


Figure A3.6b DIN+ 70°C method with 10minute samples: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 3 (left) and Test 4 (right) with particulate measurements for comparison

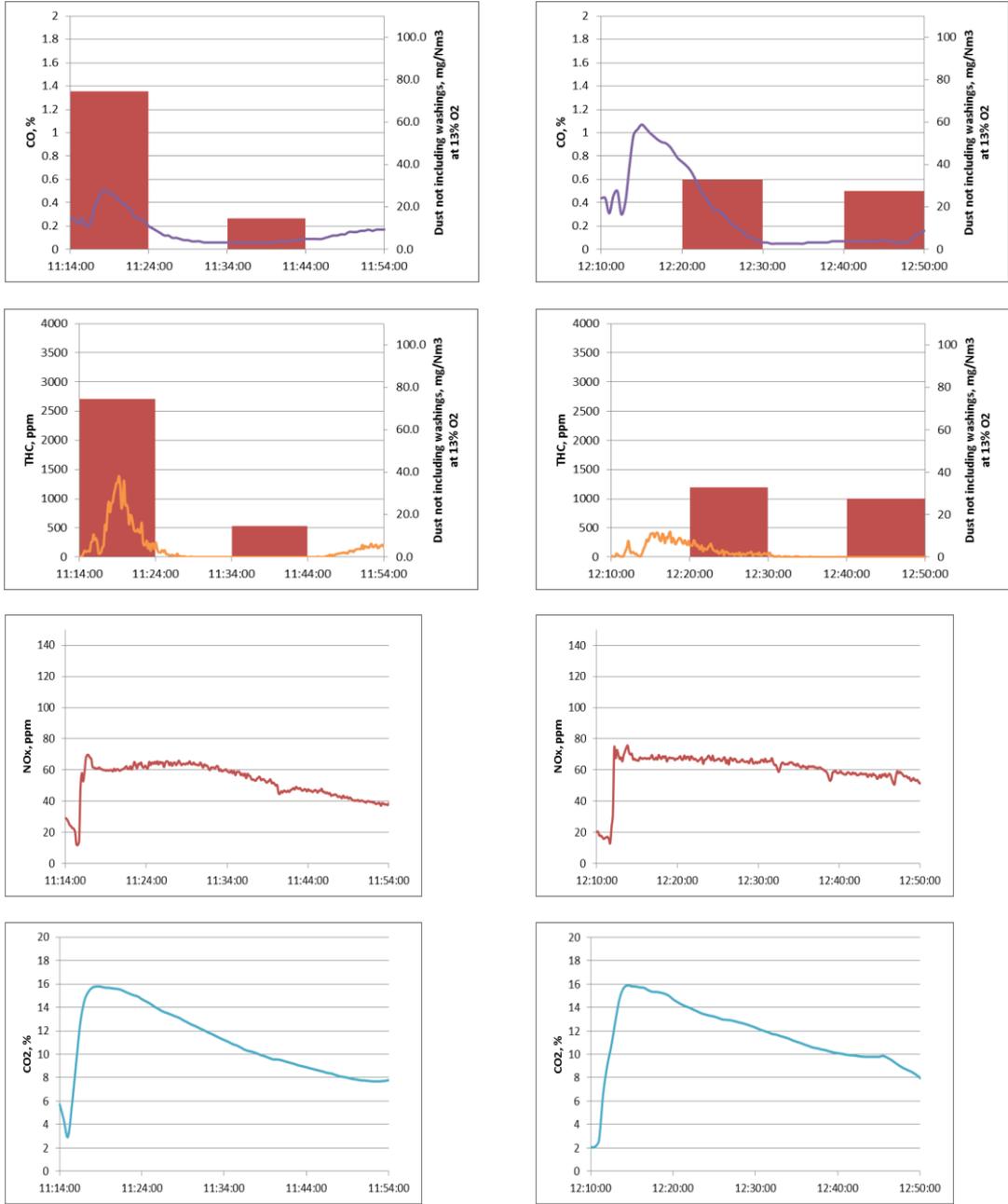


Figure A3.6c DIN+ 70°C method with 10minute samples: Flue gas measurement traces of CO, THC, NOx and CO₂ for Appliance B, High Output, Test 5 (left) and Test 6 (right) with particulate measurements for comparison

