



Department for
Business, Energy
& Industrial Strategy

Measurement of the in-situ performance of solid biomass boilers



Annex C: Laboratory trials results

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Measurement of the in-situ performance of solid biomass boilers

Annex C: Laboratory trials results

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Commercial in confidence

Preface

This document is the laboratory trials results annex to “Measurement of the in-situ performance of solid biomass boilers”, a report prepared for BEIS which details work carried out from 2015 to 2018 where the real-life efficiencies and pollutant emissions of a range of biomass boilers were measured.

The work was carried out by a consortium of Kiwa Gastec, Ricardo Energy and Environment, Energy Saving Trust, HETAS, and Optimum Consultancy.

Table of contents

1	Laboratory trials – small boiler	4
1.1	Test schedule	4
1.2	Summary of results	6
1.3	Small boiler laboratory test graphs.....	8
2	Laboratory trials – large boiler.....	36
2.1	Large boiler test graphs	37
3	Heavy metal test results.....	44

1 Laboratory trials – small boiler

1.1 Test schedule

Test no	Load (%)	Water Vol (l/kW)	Modulation	Fuel	Pattern
1	DHLTR Standing Losses				
2	Boiler Standing Losses				
3	100%	10	No	A1	Continuous
4	30%	10	No	A1	Continuous
5	30%	10	No	A1	Uni-modal
5.1	30%	10	No	A1	Uni-modal
5.2	30%	10	No	A1	Uni-modal
6	40°C return	10	No	A1	Continuous
7	10%	10	No	A1	Continuous
8	10%	10	No	A1	Uni-modal
8.1	10%	10	No	A1	Uni-modal
8.2	10%	10	No	A1	Uni-modal
9	7.5%	10	No	A1	Continuous
10	5%	10	No	A1	Continuous
11	5%	10	No	A1	Uni-modal
11.1	5%	10	No	A1	Uni-modal
11.2	5%	10	No	A1	Uni-modal
12	30%	10	No	A1	Continuous
13	30%	10	50%	A1	Continuous
14	30%	10	50%	A1	Uni-modal
14.1	30%	10	50%	A1	Uni-modal
14.2	30%	10	50%	A1	Uni-modal
15	30%	10	20%	A1	Uni-modal
15.1	30%	10	20%	A1	Uni-modal
15.2	30%	10	20%	A1	Uni-modal
16	30%	10	20%	A1	Continuous
17	10%	10	50%	A1	Uni-modal
17.1	10%	10	50%	A1	Uni-modal
17.2	10%	10	50%	A1	Uni-modal
18	10%	10	20%	A1	Uni-modal
18.1	10%	10	20%	A1	Uni-modal
18.2	10%	10	20%	A1	Uni-modal
19	5%	10	50%	A1	Uni-modal
19.1	5%	10	50%	A1	Uni-modal
19.2	5%	10	50%	A1	Uni-modal

Test no	Load (%)	Water Vol (l/kW)	Modulation	Fuel	Pattern
20	5%	10	20%	A1	Uni-modal
20.1	5%	10	20%	A1	Uni-modal
20.2	5%	10	20%	A1	Uni-modal
21	100%	10	No	A1 (degraded)	Continuous
22(a)	100%	10	No	B	Continuous
22(b)	100%	10	No	B	Continuous
23	30%	30	20%	A1	Uni-modal
23.1	30%	30	20%	A1	Uni-modal
24.1	10%	30	20%	A1	Uni-modal
24.2	10%	30	20%	A1	Uni-modal
25.1	5%	30	20%	A1	Uni-modal
25.2	5%	30	20%	A1	Uni-modal
26	30%	10	20%	A1	Bi-modal
27	5%	10	No	A1	Continuous
28	30%	10	No	A1	Continuous

1.2 Summary of results

Test No.	Actual Load	Modulation and Operating Mode		Fuel used (kg)	Fuel Energy in (kJ)	Elec Energy in (kJ)	Total Energy in (kJ)	Heat out (kJ)	Flue Losses EN (kJ)	Ash Losses EN (kJ)	Case Losses (kJ)	Total Energy Out EN (kJ)	Dust emission (g/GJ)	NOx emission (g/GJ)	HC emission (g/GJ)	CO emission (g/GJ)	Direct Efficiency
3	99%	none	Continuous	140.66	2,394,853	12,747	2,407,600	2,137,416	156,304	76,270	60,105	2,430,094	14	81		200	89%
4	30%	none	Continuous	53.65	913,472	56,777	970,249	654,442	98,897	81,879	64,371	899,589	102	57	22	1118	67%
5 (a)	30%	none	Uni-modal	50.21	854,920	30,177	885,096	640,136	112,733	57,386	39,701	849,956	56	106	51	860	72%
5 (b)	29%	none	Uni-modal	48.78	830,528	32,789	863,317	636,490	147,090	48,722	40,877	873,179	49	100	33	1460	74%
6	108%	none	Continuous	151.83	2,585,018	8,475	2,593,493	2,333,964	149,221	46,800	55,023	2,585,007	10	96	7	275	90%
7	10%	none	Continuous	23.53	400,567	27,016	427,583	207,087	51,846	50,238	68,039	377,210	88	74	28	651	48%
8	11%	none	Uni-modal	22.48	382,753	21,587	404,340	243,880	57,650	19,552	44,285	365,367	76	110	25	655	60%
9	7%	none	Continuous	17.42	296,631	20,949	317,580	150,204	41,555	11,503	67,293	270,555	78	103	27	458	47%
10	2%	none	Continuous	5.62	95,603	7,008	102,610	38,913	12,902	12,380	28,211	92,405		99	23	438	38%
11	6%	none	Uni-modal	14.63	249,136	15,177	264,312	121,911	28,786	25,282	45,178	221,157	48	86	20	394	46%
12	25%	none	Continuous	52.30	890,519	45,420	935,939	544,525	131,628	57,061	63,066	796,279	84	95	17	595	58%
13	29%	50%	Continuous	50.97	867,874	46,524	914,398	616,791	142,656	50,345	69,851	879,643	63	108	25	652	67%
14	30%	50%	Uni-modal	50.64	862,170	36,465	898,635	653,636	187,011	58,437	44,535	943,620	51	109	21	1572	73%
15	29%	20%	Uni-modal	44.08	750,515	5,668	756,183	624,190	70,922	9,183	41,496	745,792	60	126	1	35	83%
16	29%	20%	Continuous	51.89	883,406	48,159	931,565	625,182	150,304	57,030	70,167	902,683	45	116	29	703	67%
17	8%	50%	Uni-modal	18.21	310,113	18,277	328,390	169,334	39,684	32,434	44,764	286,216	74	81	24	644	52%



Test No.	Actual Load	Modulation and Operating Mode		Fuel used (kg)	Fuel Energy in (kJ)	Elec Energy in (kJ)	Total Energy in (kJ)	Heat out (kJ)	Flue Losses EN (kJ)	Ash Losses EN (kJ)	Case Losses (kJ)	Total Energy Out EN (kJ)	Dust emission (g/GJ)	NOx emission (g/GJ)	HC emission (g/GJ)	CO emission (g/GJ)	Direct Efficiency
18	11%	20%	Uni-modal	22.47	382,608	20,604	403,212	241,529	57,649	16,965	44,762	360,905	54	112	32	702	60%
19	5%	50%	Uni-modal	12.03	204,839	12,631	217,470	100,688	30,809	9,356	42,027	182,881	72	94	33	643	46%
20	5%	20%	Uni-modal	12.12	206,294	12,265	218,559	103,389	29,594	9,008	42,449	184,440	76	92	39	541	47%
21	104%	none	Continuous	146.23	2,489,645	11,950	2,501,595	2,247,725	204,933	48,358	48,779	2,549,794	16	88	3		90%
22(a)	95%	none	Continuous	137.20	2,310,277	8,412	2,318,689	2,045,914	238,512	29,170	56,487	2,370,082	45	103	3	358	88%
22(b)	100%	none	Continuous	146.37	2,464,676	13,476	2,478,152	2,153,497	281,387	45,425	61,293	2,541,601	50	100	4	666	87%
23	31%	20%	Uni-modal	46.54	792,390	5,526	797,916	662,418	75,439	33,782	40,700	812,339		134	0	11	83%
24	10%	20%	Uni-modal	20.79	354,021	16,819	370,840	215,293	46,175	23,810	44,394	329,672	60	82	23	611	58%
25	6%	20%	Uni-modal	13.77	234,368	11,597	245,965	134,452	36,052	9,246	38,317	218,068	82	79	17	863	55%
26	29%	20%	Bi-modal	39.14	666,398	4,894	671,292	623,342	58,098	11,338	25,247	718,025	14	124	4	51	93%
27	5%	none	Continuous	14.22	242,122	17,604	259,727	106,544	36,990	11,680	63,217	218,431	77	91	32	565	41%
28	19%	none	Continuous	34.32	584,363	29,127	613,490	410,745	147,422	34,838	39,312	632,317	63	102	34	1762	67%

Test number: 3

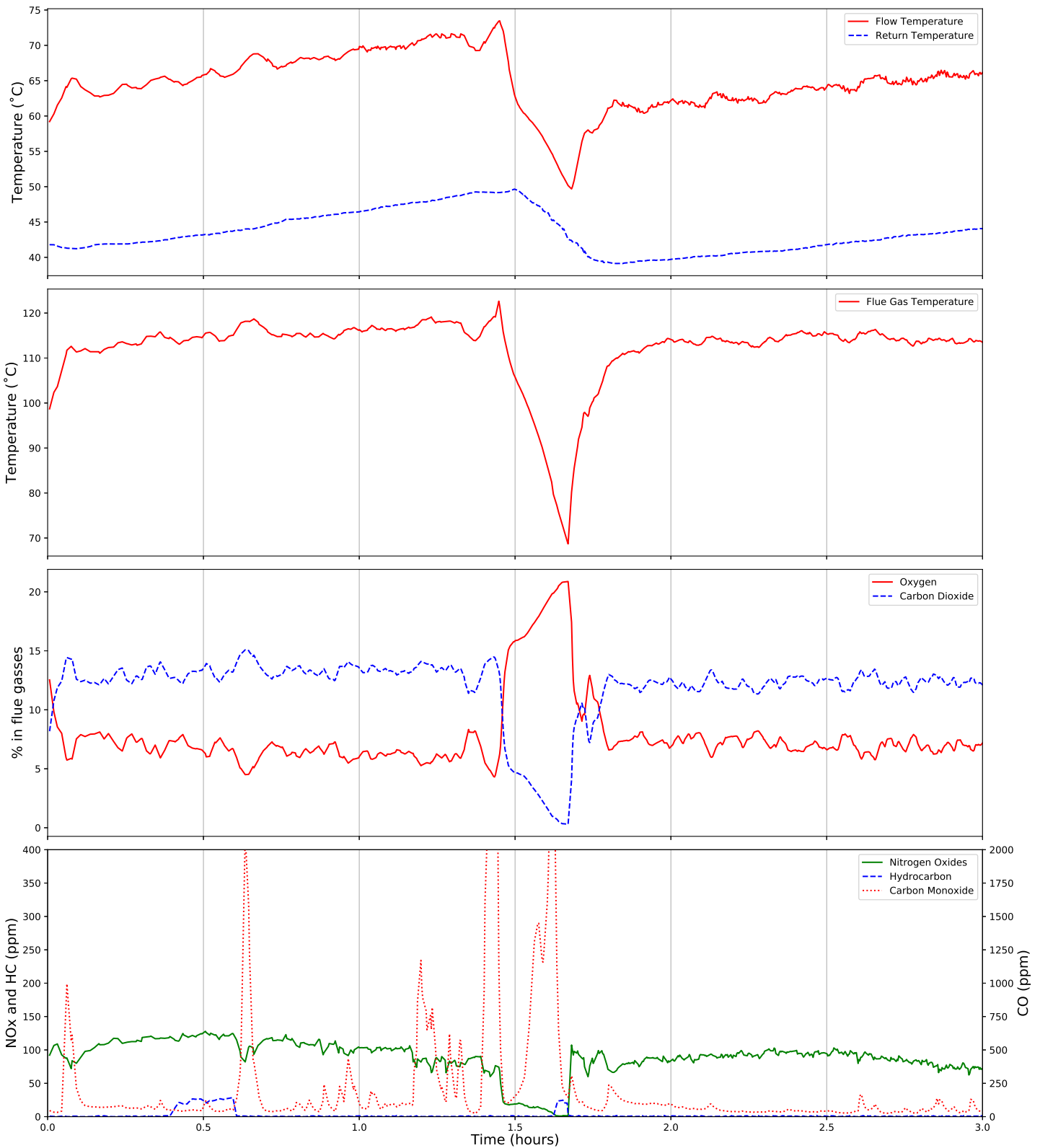
Operating pattern: Continuous

Load Factor: 100 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 140.66 kg
 Electrical energy used: 12,747 kJ
 Total energy used: 2,407,600 kJ

Dust emission: 13.6 g/GJ
 NOx emission: 81.2 g/GJ
 HC emission: N/A

Test duration: 24 hours
 Useful heat output: 2,137,416 kJ
 Direct efficiency: 89 %

Test number: 4

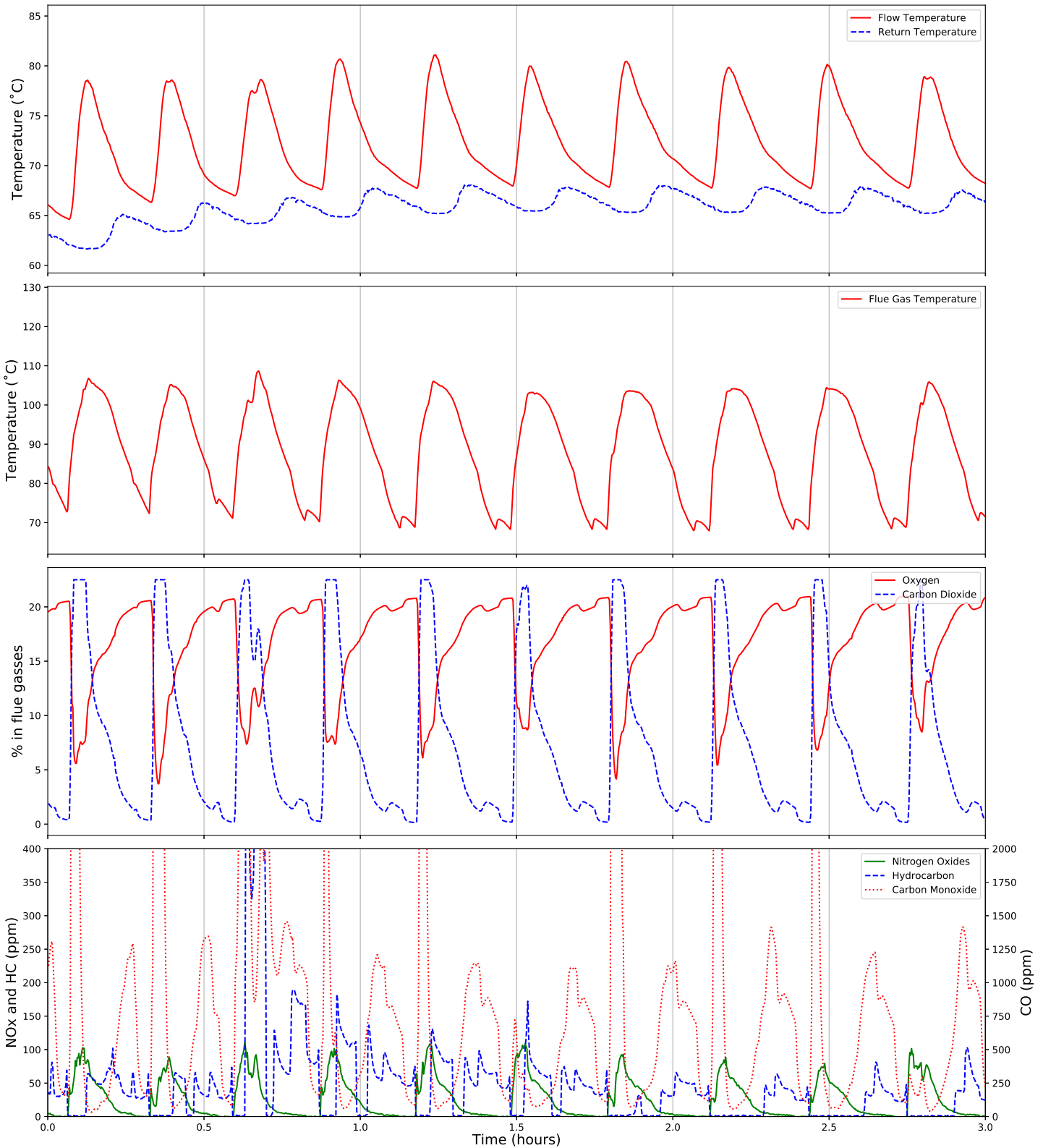
Operating pattern: Continuous

Load Factor: 30 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 53.65 kg
 Electrical energy used: 56,777 kJ
 Total energy used: 970,249 kJ

Dust emission: 101.7 g/GJ
 NOx emission: 56.9 g/GJ
 HC emission: 22.1 g/GJ

Test duration: 24 hours
 Useful heat output: 654,442 kJ
 Direct efficiency: 67 %

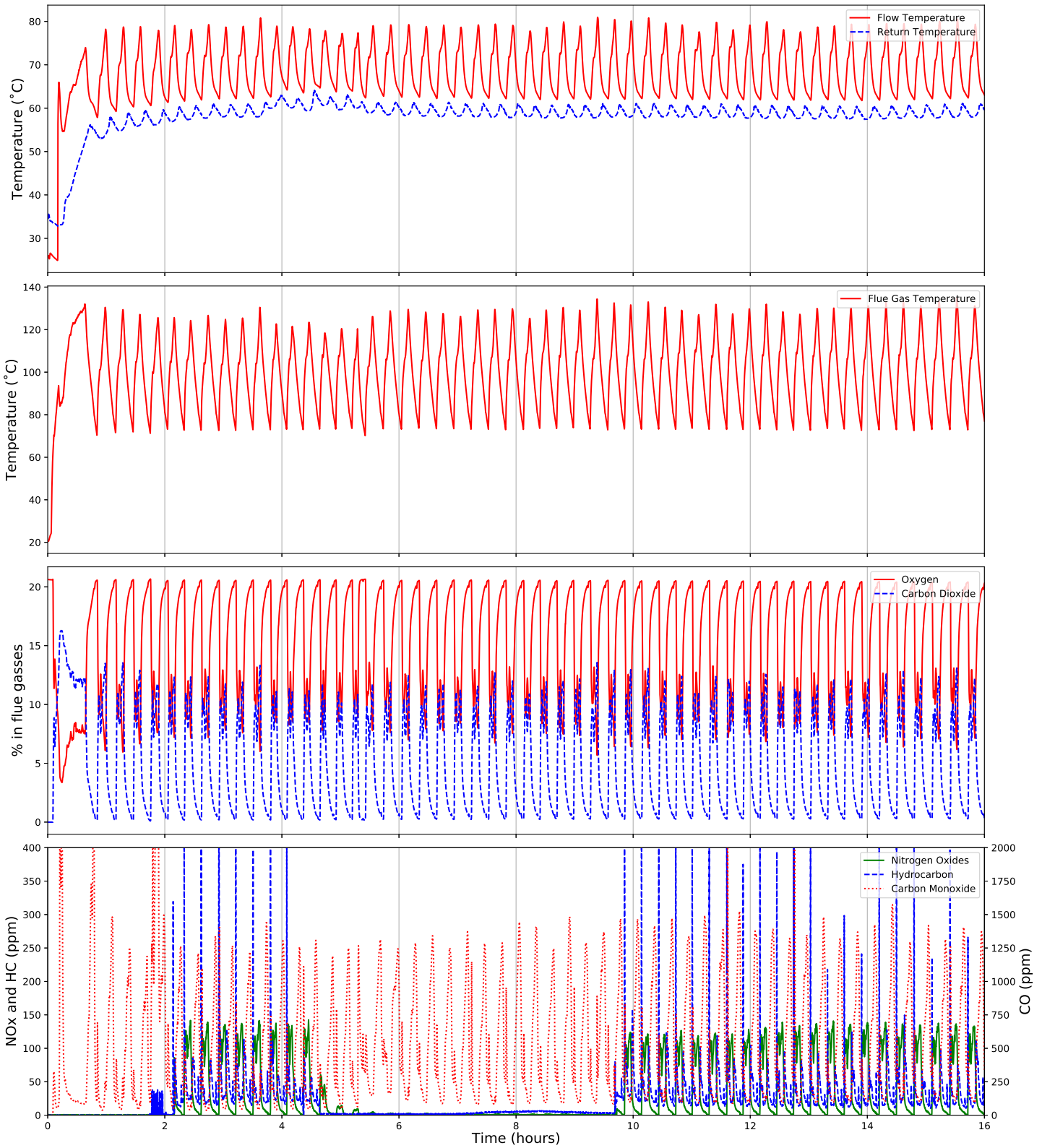
Test number: 5a

Operating pattern: Unimodal
Modulation: No

Load Factor: 30 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 48.78 kg
Electrical energy used: 32,789 kJ
Total energy used: 863,317 kJ

Dust emission: 49.3 g/GJ
NOx emission: 100.0 g/GJ
HC emission: 33.0 g/GJ

Test duration: 16 hours
Useful heat output: 636,490 kJ
Direct efficiency: 74 %

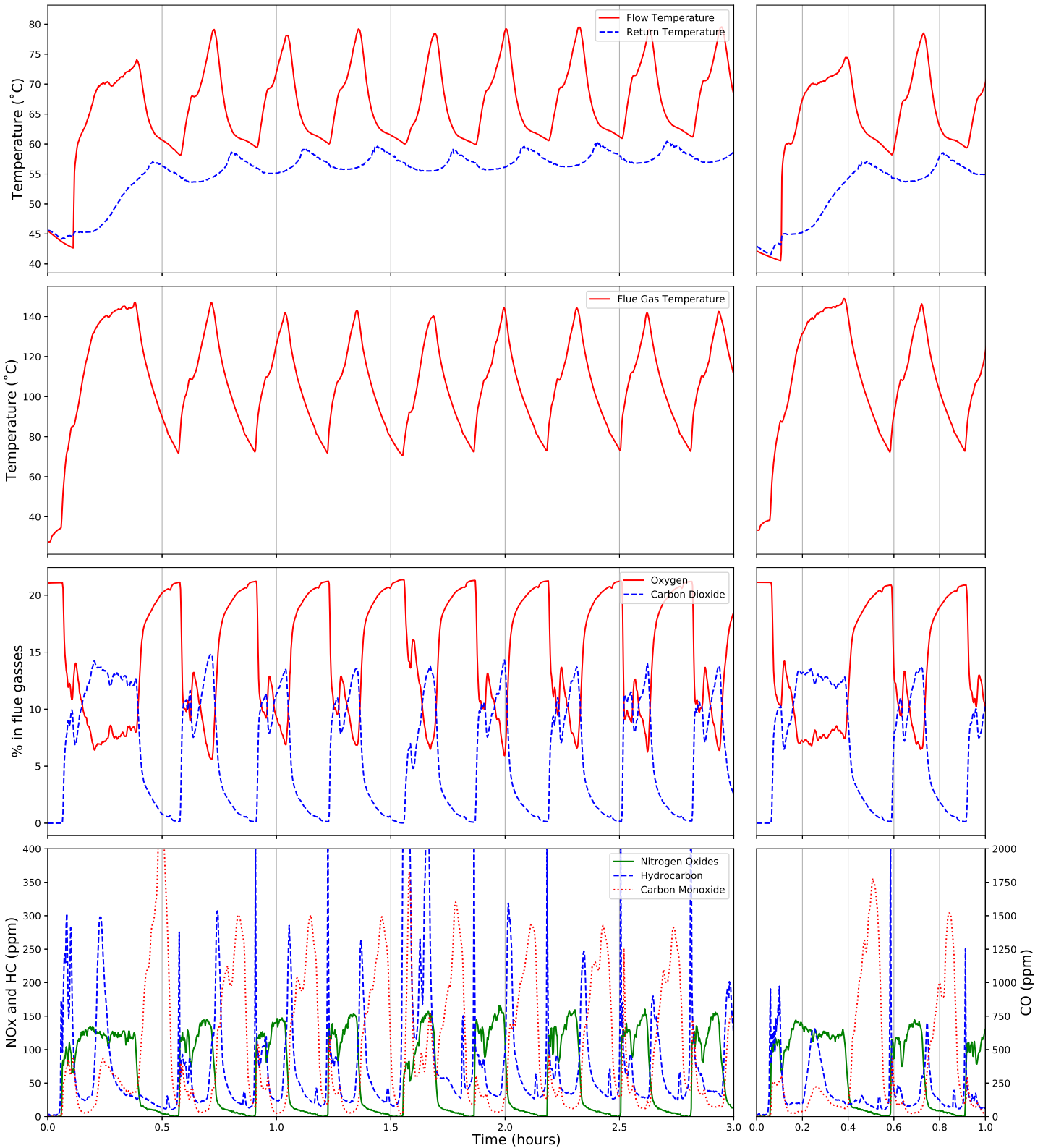
Test number: 5b

Operating pattern: Unimodal
Modulation: No

Load Factor: 30 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 50.21 kg
Electrical energy used: 30,177 kJ
Total energy used: 885,096 kJ

Dust emission: 55.8 g/GJ
NOx emission: 105.6 g/GJ
HC emission: 50.8 g/GJ

Test duration: 16 hours
Useful heat output: 640,136 kJ
Direct efficiency: 72 %

Test number: 6

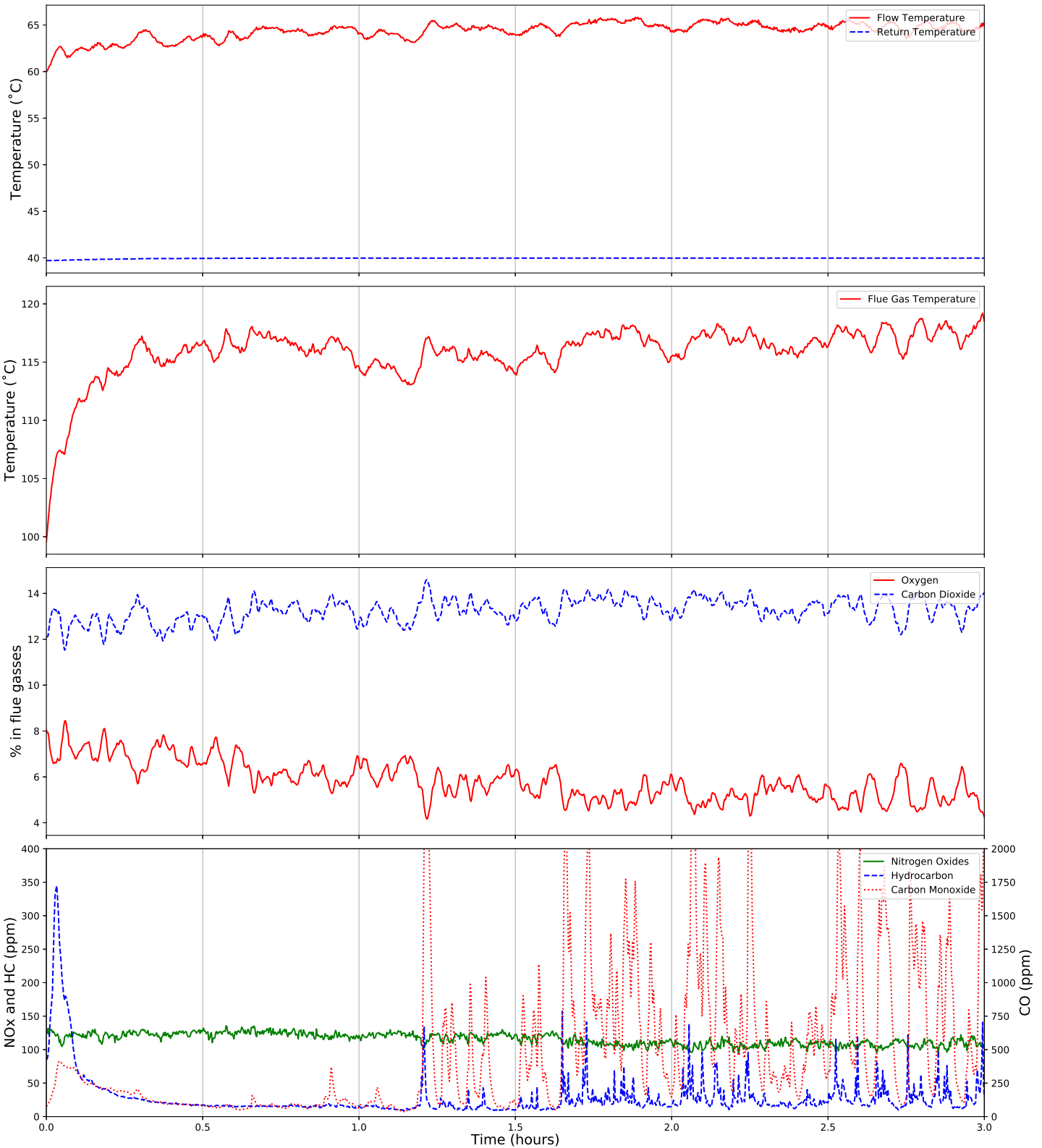
Operating pattern: Continuous

Load Factor: 100 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 151.83 kg
 Electrical energy used: 8,475 kJ
 Total energy used: 2,593,493 kJ

Dust emission: 10.3 g/GJ
 NOx emission: 95.9 g/GJ
 HC emission: 6.6 g/GJ

Test duration: 24 hours
 Useful heat output: 2,333,964 kJ
 Direct efficiency: 90 %

Test number: 7

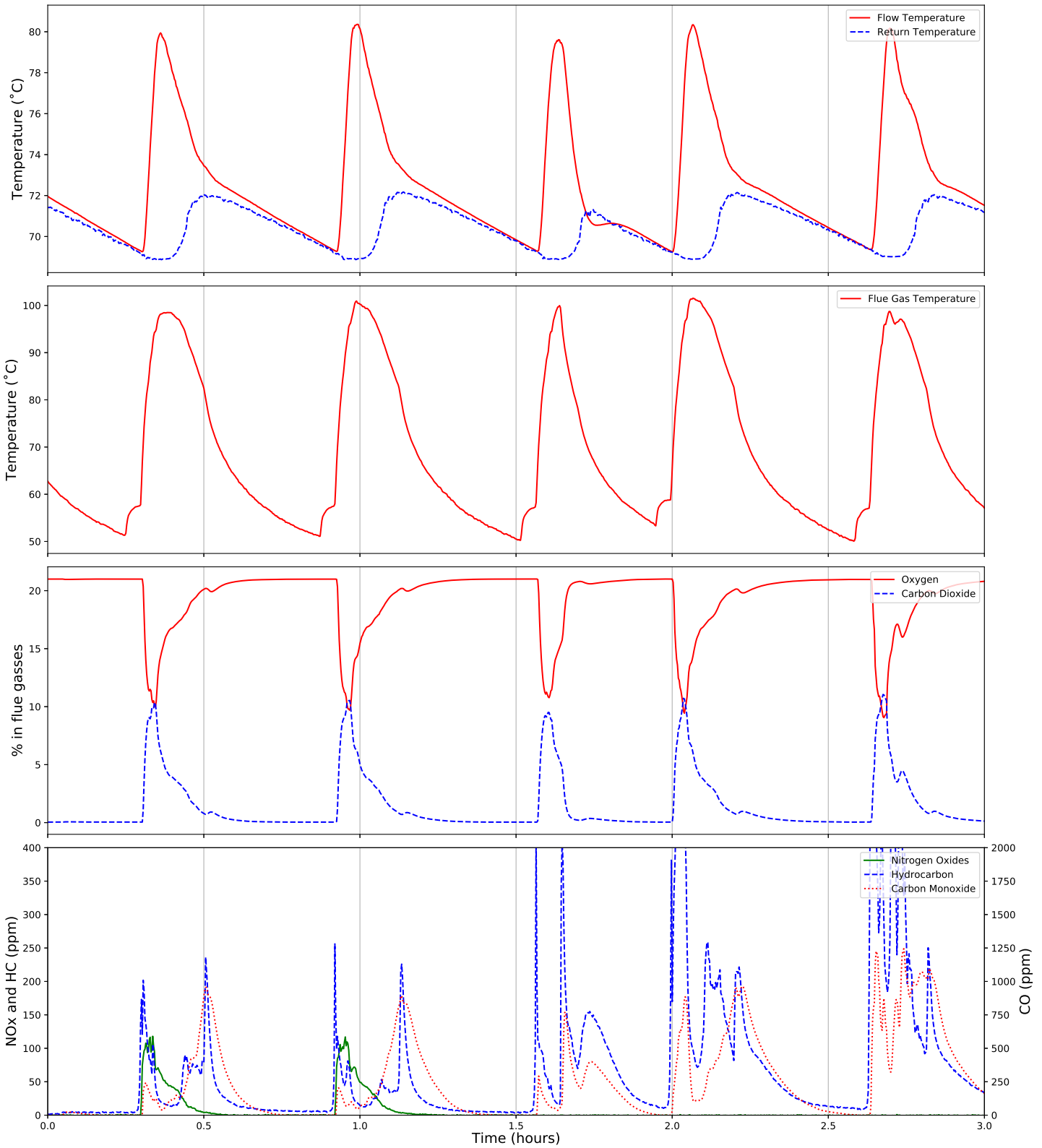
Operating pattern: Continuous

Load Factor: 10 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 23.53 kg
 Electrical energy used: 27,016 kJ
 Total energy used: 427,583 kJ

Dust emission: 87.8 g/GJ
 NOx emission: 73.6 g/GJ
 HC emission: 28.4 g/GJ

Test duration: 24 hours
 Useful heat output: 207,087 kJ
 Direct efficiency: 48 %

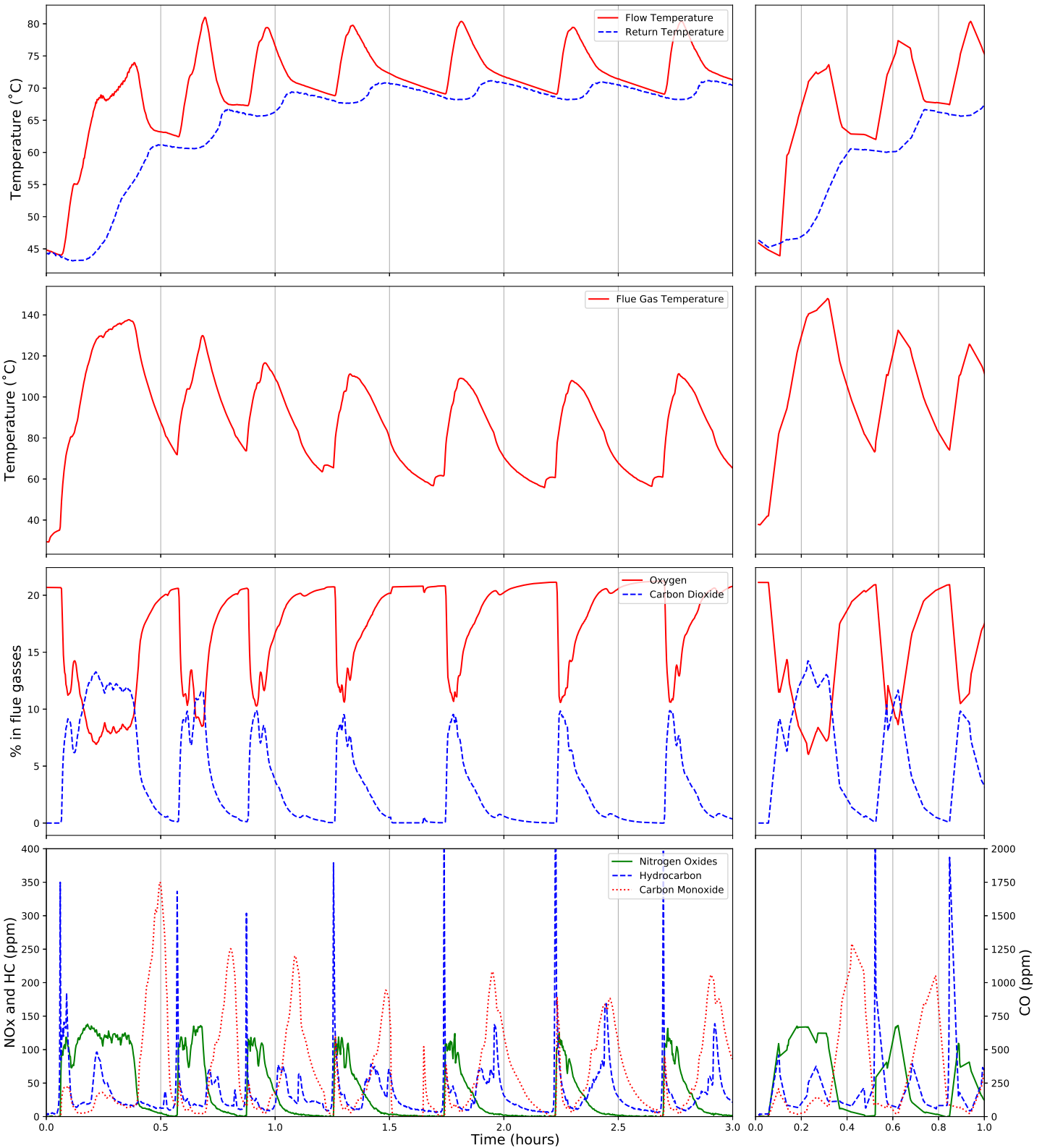
Test number: 8

Operating pattern: Unimodal
Modulation: No

Load Factor: 10 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 22.48 kg
Electrical energy used: 21,587 kJ
Total energy used: 404,340 kJ

Dust emission: 76.4 g/GJ
NOx emission: 109.8 g/GJ
HC emission: 25.4 g/GJ

Test duration: 16 hours
Useful heat output: 243,880 kJ
Direct efficiency: 60 %

Test number: 9

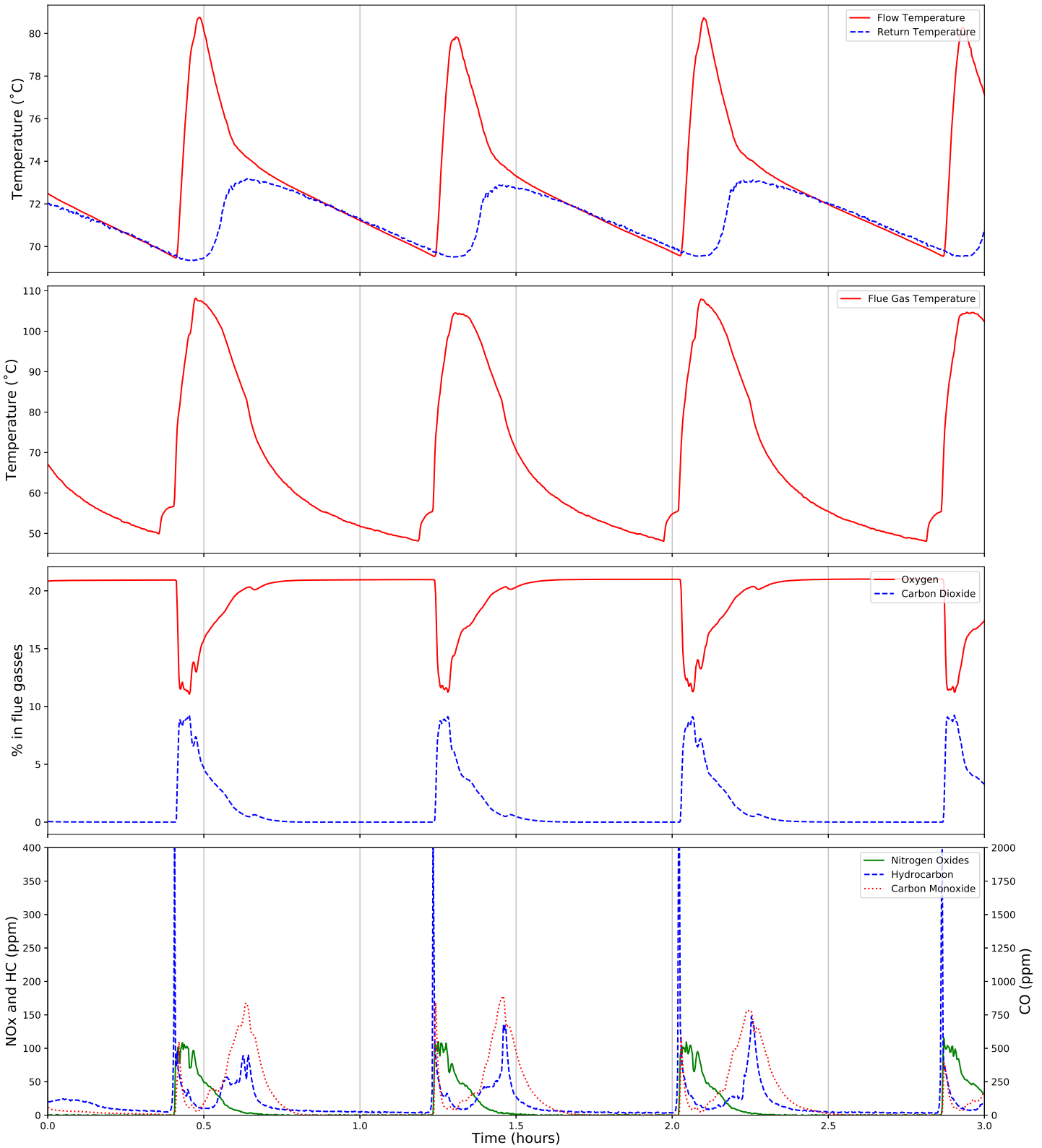
Operating pattern: Continuous

Load Factor: 8 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 17.42 kg
 Electrical energy used: 20,949 kJ
 Total energy used: 317,580 kJ

Dust emission: 77.9 g/GJ
 NOx emission: 102.6 g/GJ
 HC emission: 27.0 g/GJ

Test duration: 24 hours
 Useful heat output: 150,204 kJ
 Direct efficiency: 47 %

Test number: 10

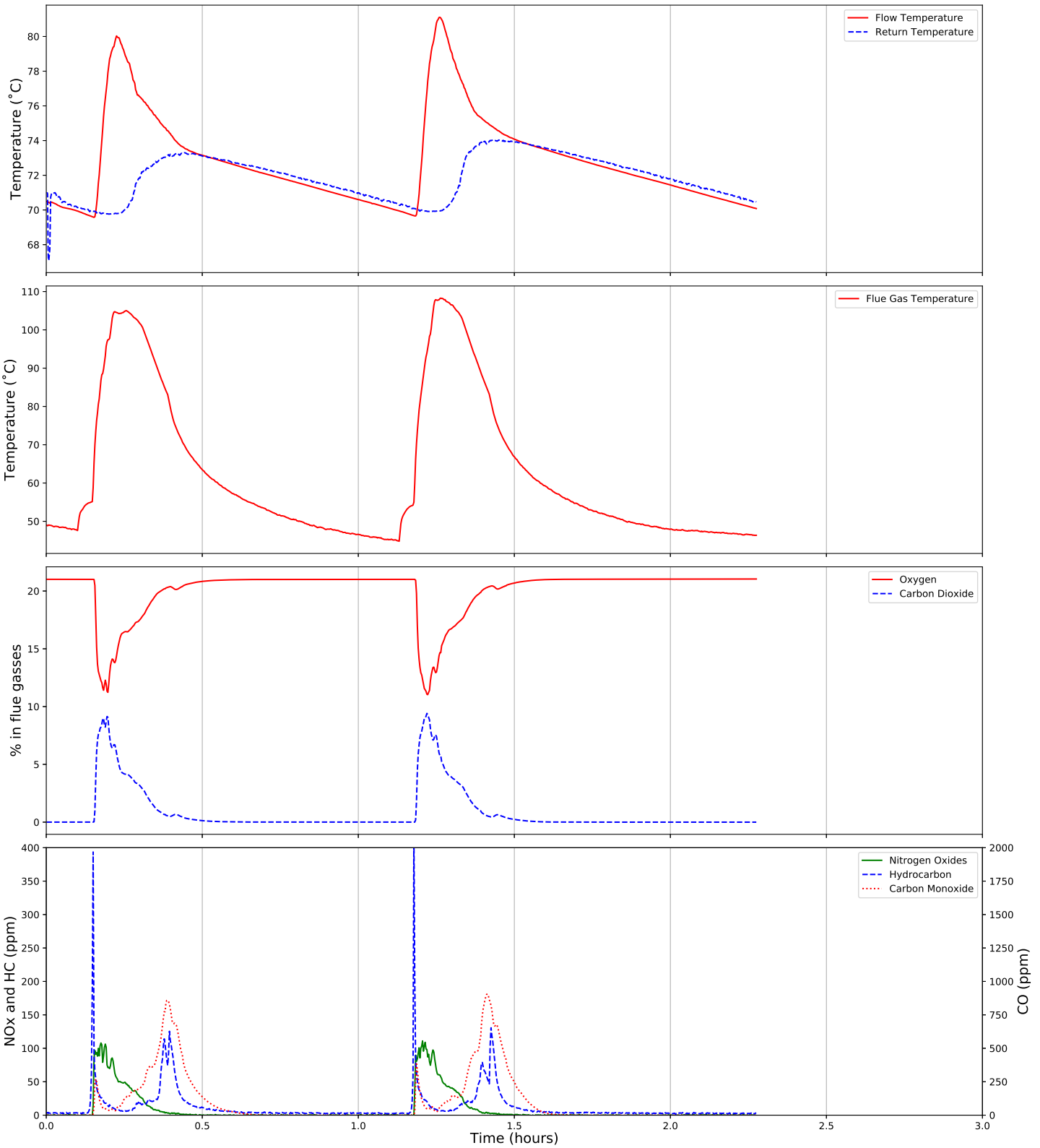
Operating pattern: Continuous

Load Factor: 5 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 5.62 kg
 Electrical energy used: 7,008 kJ
 Total energy used: 102,610 kJ

Dust emission: nan g/GJ
 NOx emission: 98.7 g/GJ
 HC emission: 23.3 g/GJ

Test duration: 24 hours
 Useful heat output: 38,913 kJ
 Direct efficiency: 38 %

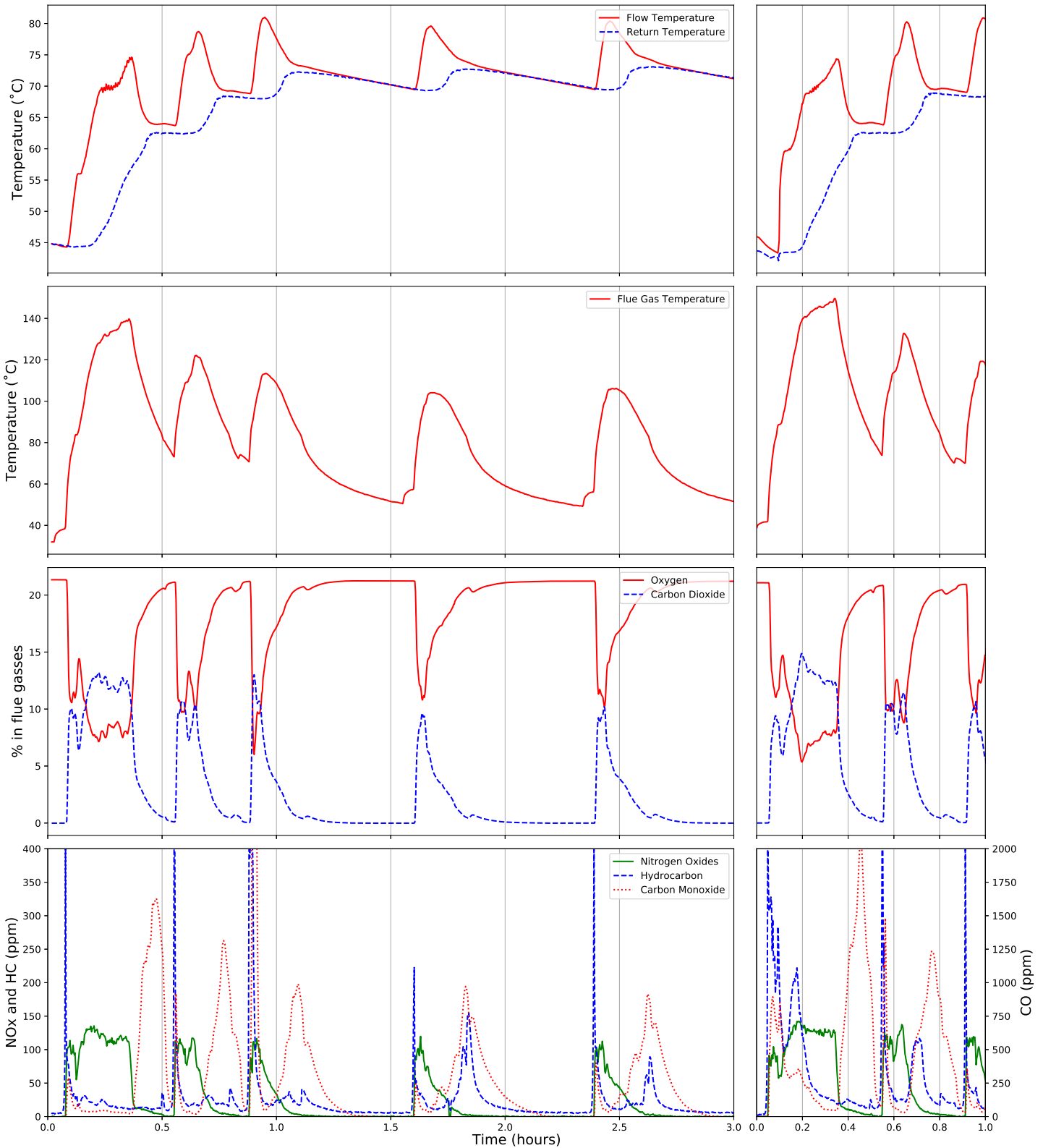
Test number: 11

Operating pattern: Unimodal
Modulation: No

Load Factor: 5 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 14.63 kg
Electrical energy used: 15,177 kJ
Total energy used: 264,312 kJ

Dust emission: 48.1 g/GJ
NOx emission: 85.7 g/GJ
HC emission: 19.9 g/GJ

Test duration: 16 hours
Useful heat output: 121,911 kJ
Direct efficiency: 46 %

Test number: 12

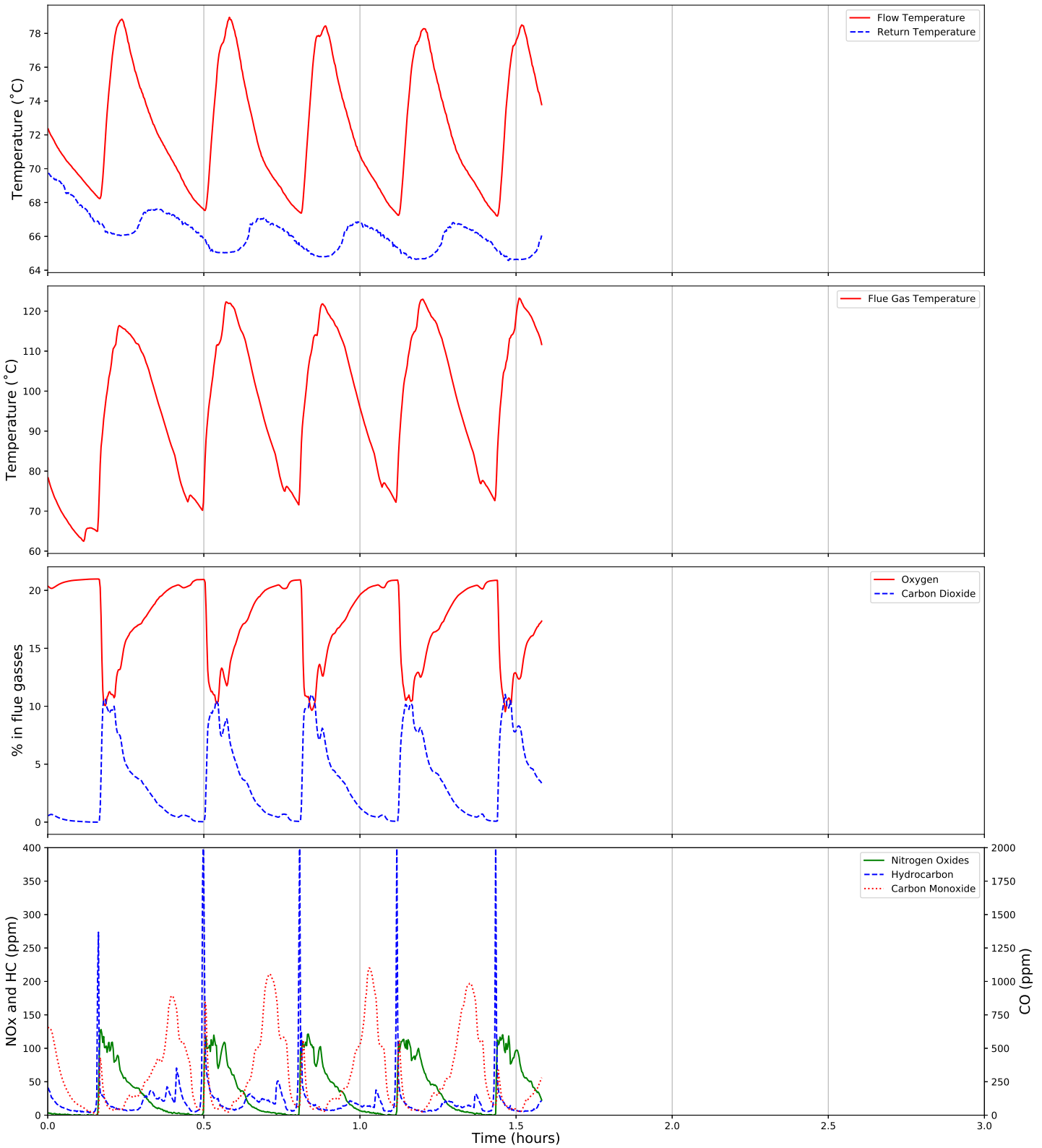
Operating pattern: Continuous

Load Factor: 30 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 52.30 kg
 Electrical energy used: 45,420 kJ
 Total energy used: 935,939 kJ

Dust emission: 83.6 g/GJ
 NOx emission: 95.4 g/GJ
 HC emission: 17.5 g/GJ

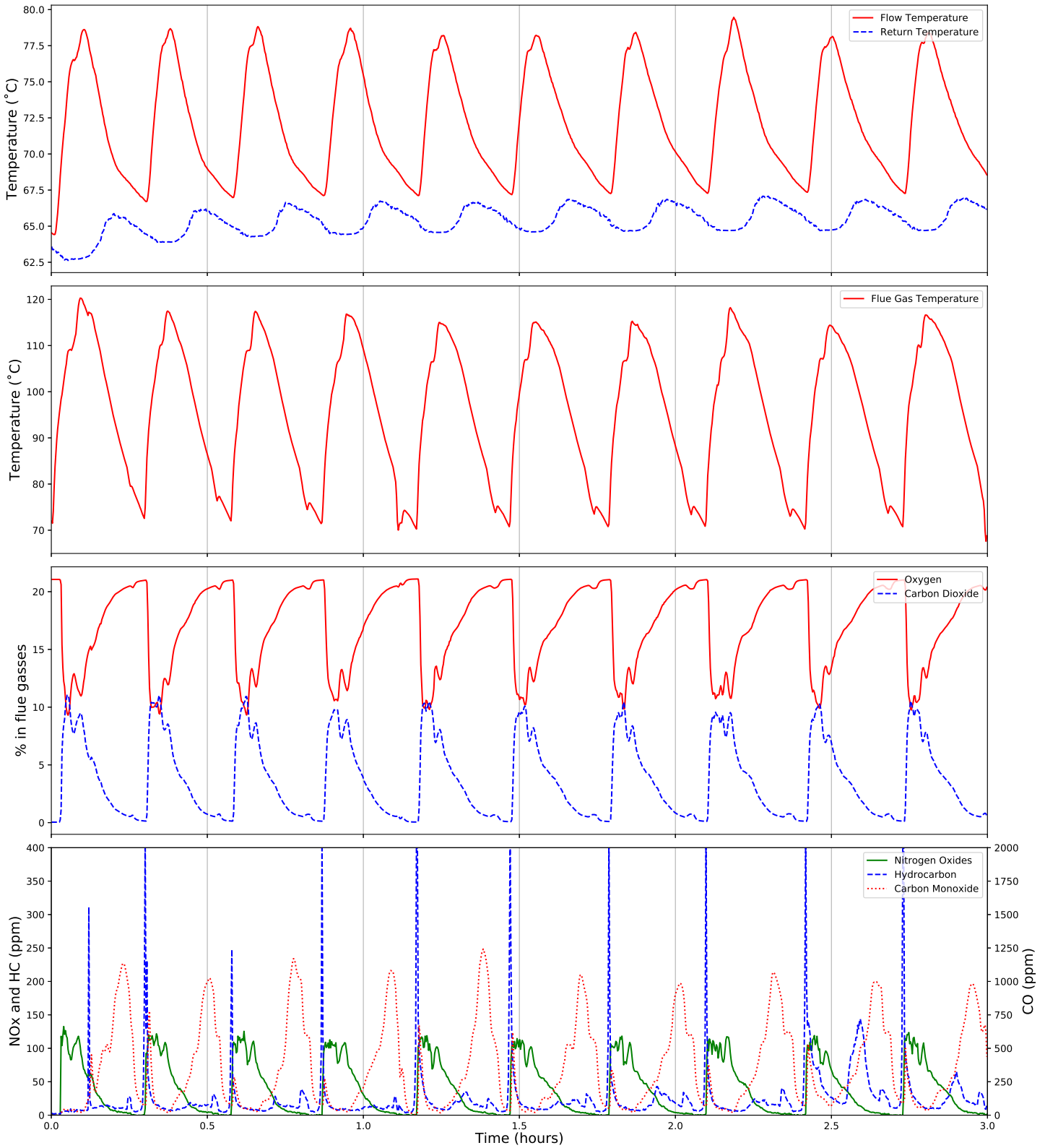
Test duration: 24 hours
 Useful heat output: 544,525 kJ
 Direct efficiency: 58 %

Test number: 13

Operating pattern: Continuous
Modulation: 50 %

Load Factor: 30 %

Water Volume: 10.0 l/kW
Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 50.97 kg
Electrical energy used: 46,524 kJ
Total energy used: 914,398 kJ

Dust emission: 63.1 g/GJ
NOx emission: 108.3 g/GJ
HC emission: 25.1 g/GJ

Test duration: 24 hours
Useful heat output: 616,791 kJ
Direct efficiency: 67 %

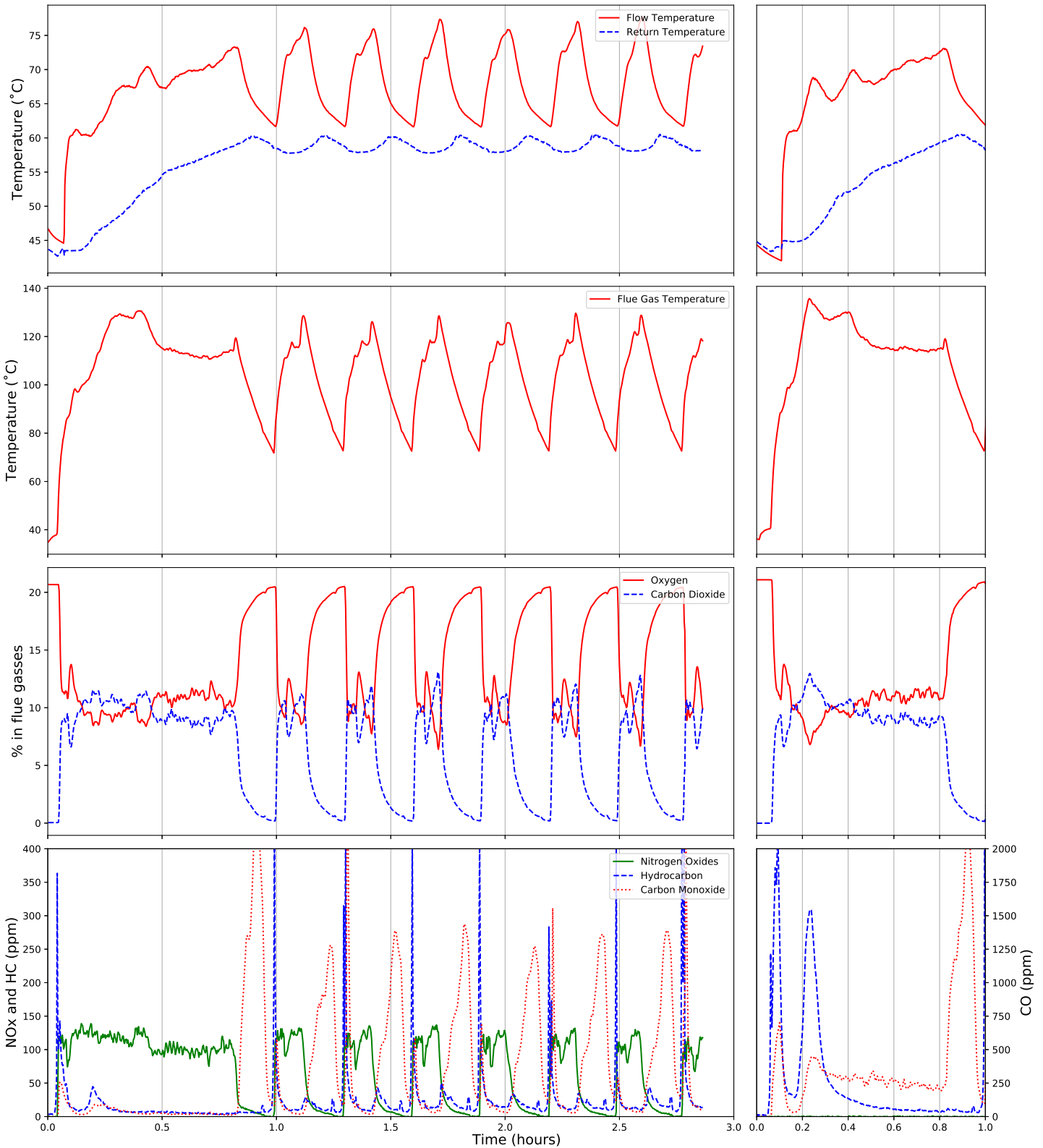
Test number: 14

Operating pattern: Unimodal
Modulation: 50 %

Load Factor: 30 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 50.64 kg
Electrical energy used: 36,465 kJ
Total energy used: 898,635 kJ

Dust emission: 51.0 g/GJ
NOx emission: 108.9 g/GJ
HC emission: 21.7 g/GJ

Test duration: 16 hours
Useful heat output: 653,636 kJ
Direct efficiency: 73 %

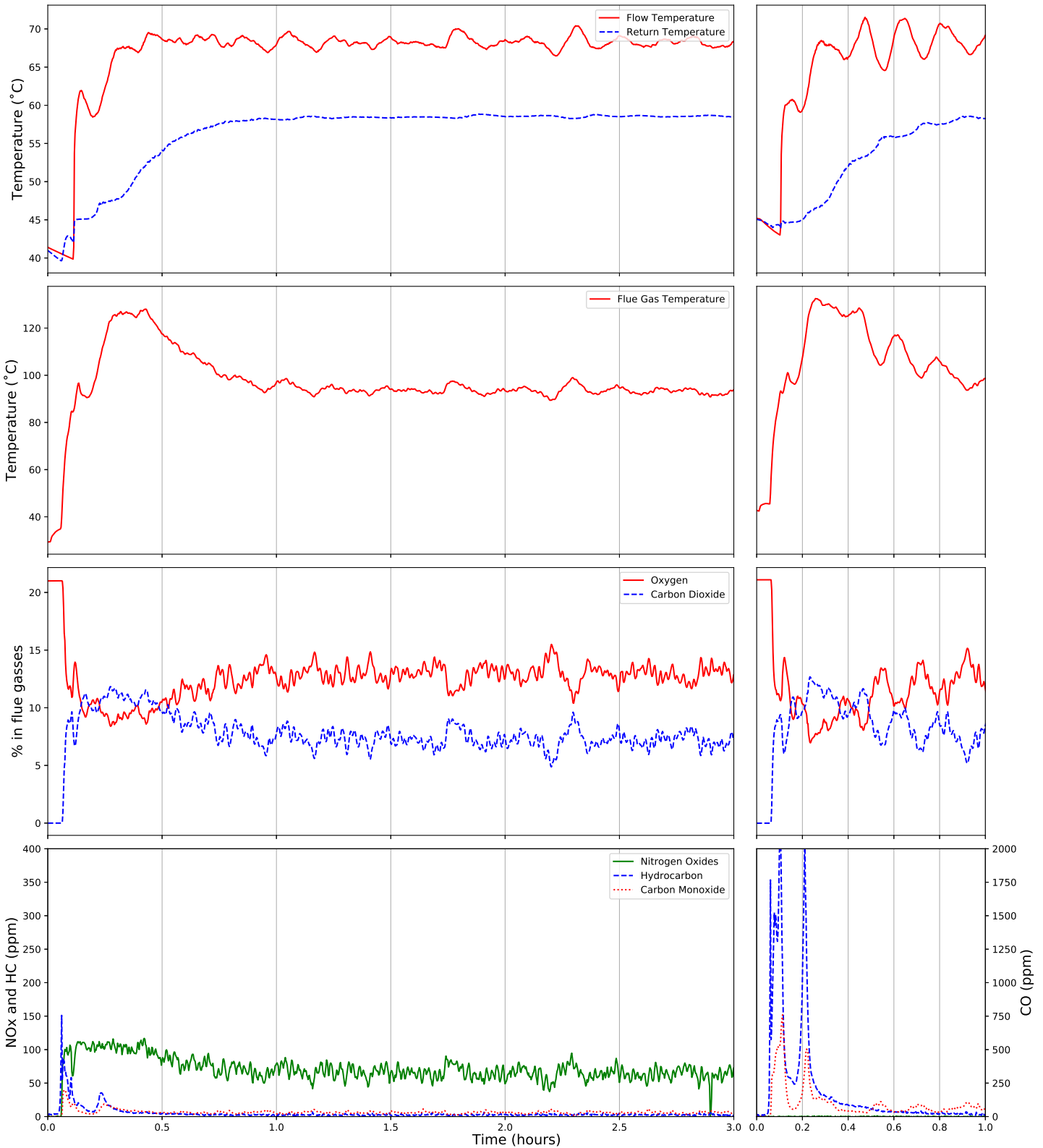
Test number: 15

Operating pattern: Unimodal
Modulation: 20 %

Load Factor: 30 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 44.08 kg
Electrical energy used: 5,668 kJ
Total energy used: 756,183 kJ

Dust emission: 60.3 g/GJ
NOx emission: 125.8 g/GJ
HC emission: 1.3 g/GJ

Test duration: 16 hours
Useful heat output: 624,190 kJ
Direct efficiency: 83 %

Test number: 16

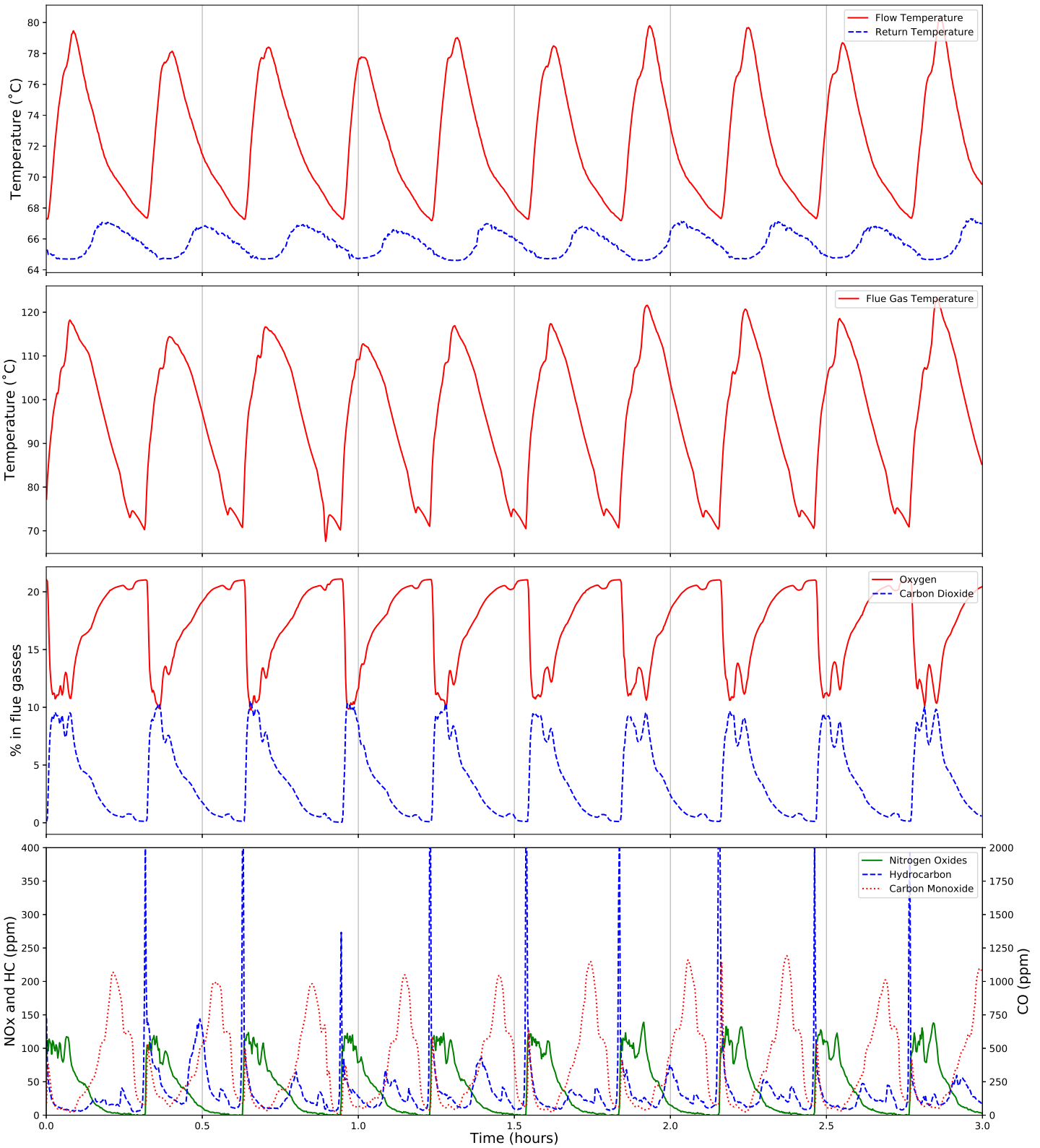
Operating pattern: Continuous

Load Factor: 30 %

Water Volume: 10.0 l/kW

Modulation: 20 %

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 51.89 kg
 Electrical energy used: 48,159 kJ
 Total energy used: 931,565 kJ

Dust emission: 45.3 g/GJ
 NOx emission: 116.3 g/GJ
 HC emission: 29.5 g/GJ

Test duration: 24 hours
 Useful heat output: 625,182 kJ
 Direct efficiency: 67 %

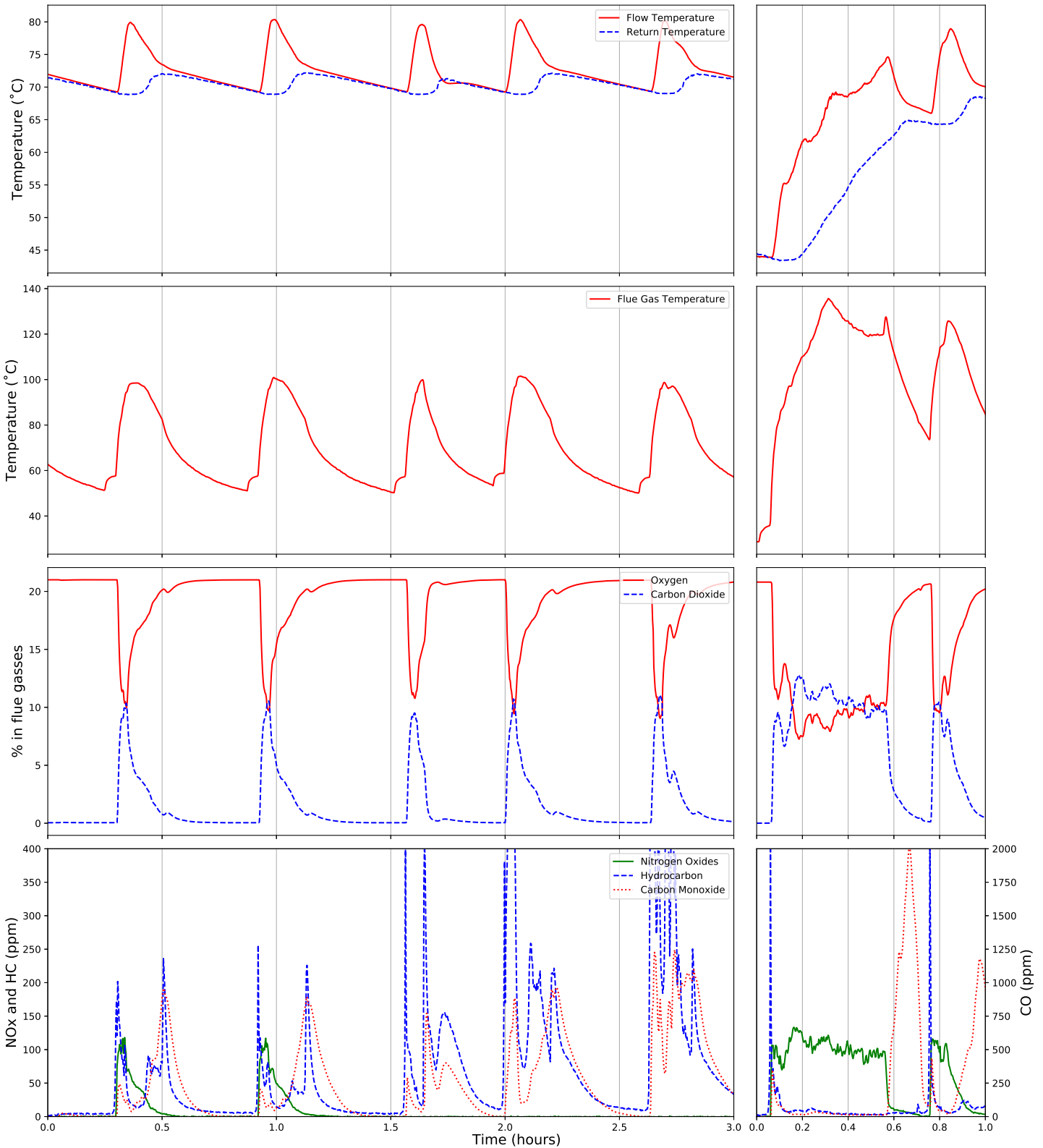
Test number: 17

Operating pattern: Unimodal
Modulation: No

Load Factor: 10 %

Water Volume: 10.0 l/kWh

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 18.21 kg
Electrical energy used: 18,277 kJ
Total energy used: 328,390 kJ

Dust emission: 73.6 g/GJ
NOx emission: 80.7 g/GJ
HC emission: 24.1 g/GJ

Test duration: 16 hours
Useful heat output: 169,334 kJ
Direct efficiency: 52 %

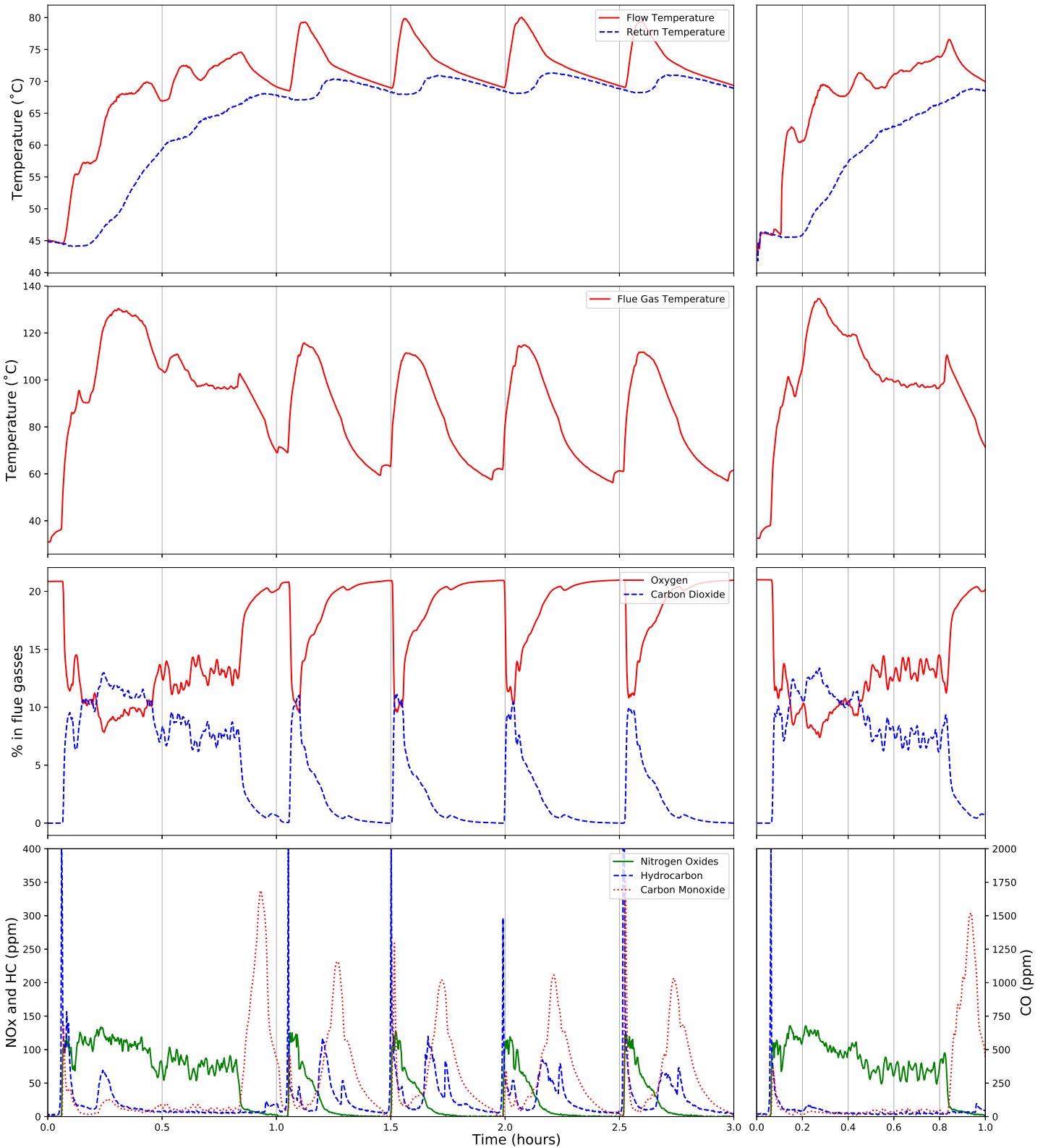
Test number: 18

Operating pattern: Unimodal
Modulation: 20 %

Load Factor: 10 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 22.47 kg
Electrical energy used: 20,604 kJ
Total energy used: 403,212 kJ

Dust emission: 53.6 g/GJ
NOx emission: 111.8 g/GJ
HC emission: 32.4 g/GJ

Test duration: 16 hours
Useful heat output: 241,529 kJ
Direct efficiency: 60 %

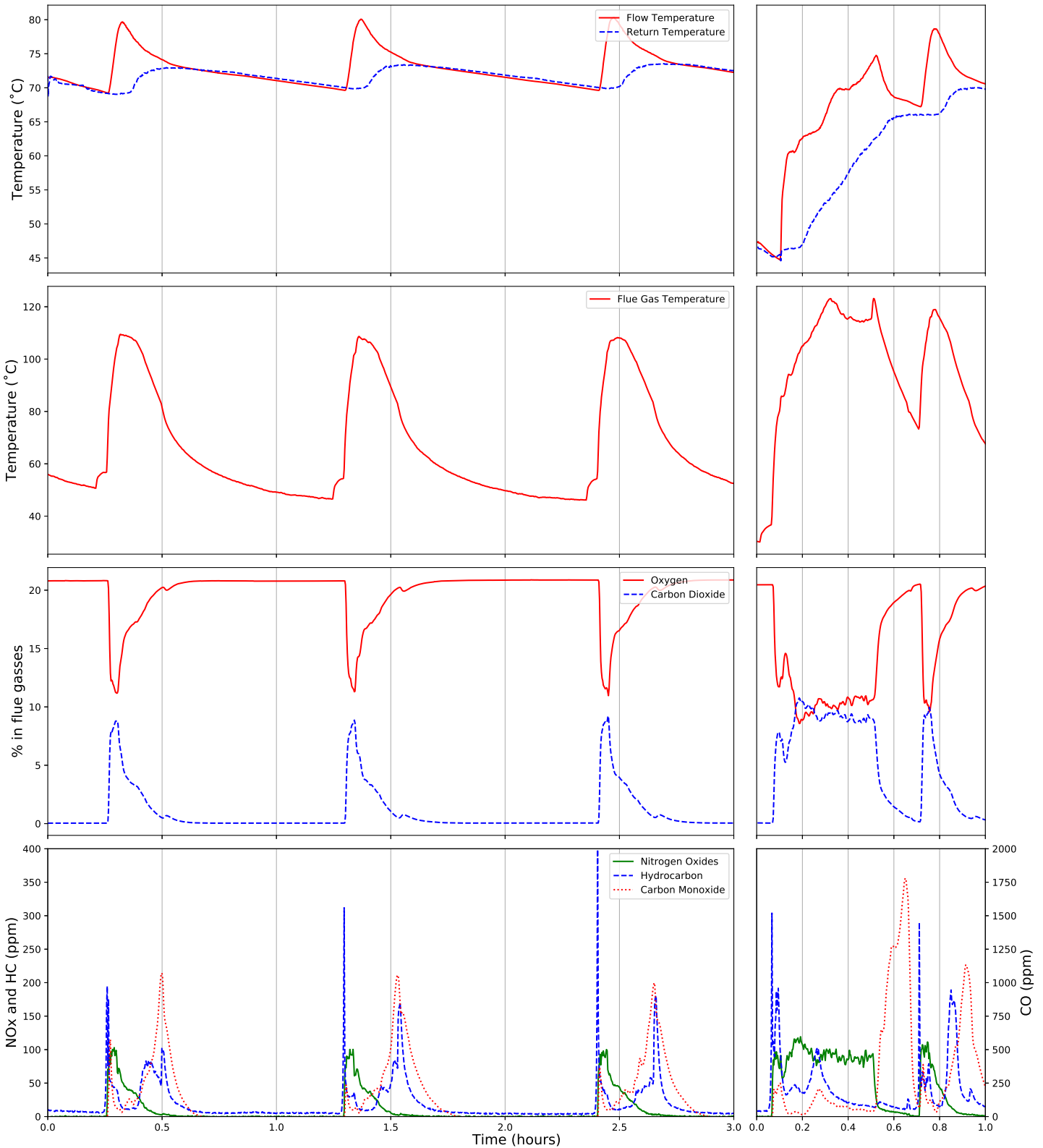
Test number: 19

Operating pattern: Unimodal
Modulation: No

Load Factor: 5 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 12.03 kg
Electrical energy used: 12,631 kJ
Total energy used: 217,470 kJ

Dust emission: 71.6 g/GJ
NOx emission: 94.3 g/GJ
HC emission: 33.0 g/GJ

Test duration: 16 hours
Useful heat output: 100,688 kJ
Direct efficiency: 46 %

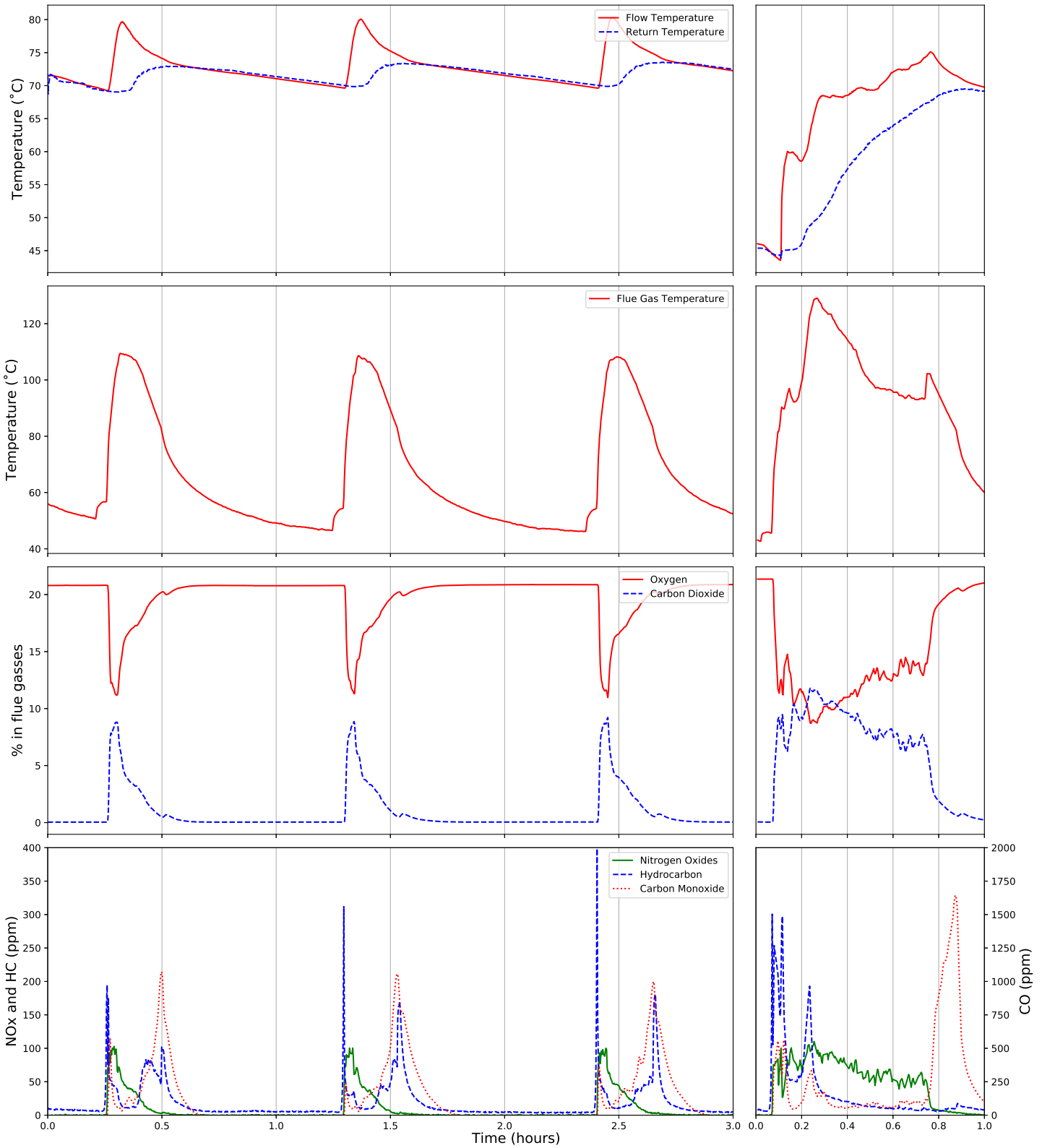
Test number: 20

Operating pattern: Unimodal
Modulation: No

Load Factor: 5 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 12.12 kg
Electrical energy used: 12,265 kJ
Total energy used: 218,559 kJ

Dust emission: 76.1 g/GJ
NOx emission: 91.6 g/GJ
HC emission: 39.1 g/GJ

Test duration: 16 hours
Useful heat output: 103,389 kJ
Direct efficiency: 47 %

Test number: 21

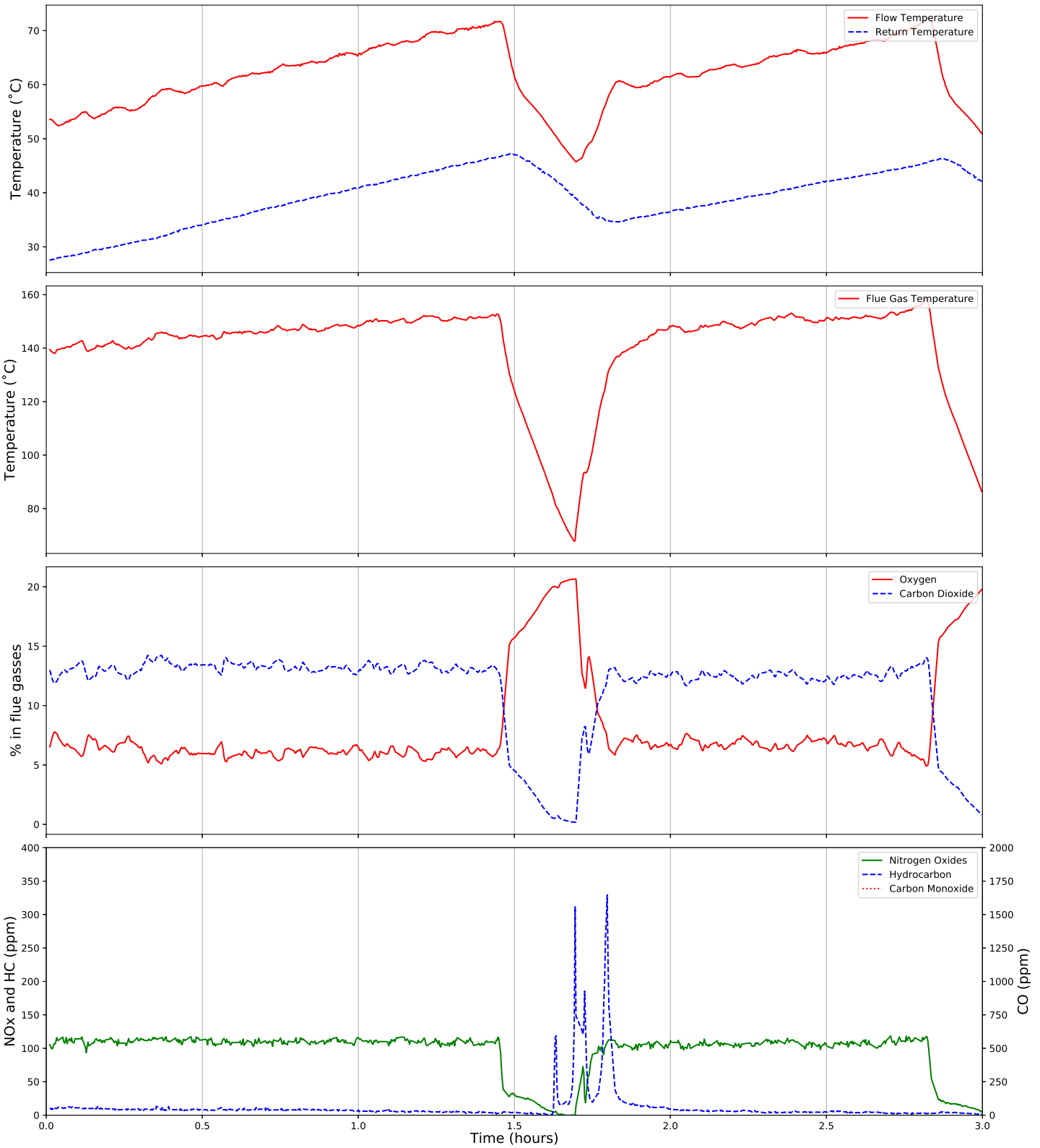
Operating pattern: Continuous

Load Factor: 100 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 (degraded) pellets



Test results adjusted for a full 24 hour period

Total fuel used: 146.23 kg
 Electrical energy used: 11,950 kJ
 Total energy used: 2,501,595 kJ

Dust emission: 15.9 g/GJ
 NOx emission: 88.4 g/GJ
 HC emission: 3.3 g/GJ

Test duration: 24 hours
 Useful heat output: 2,247,725 kJ
 Direct efficiency: 90 %

Test number: 22a

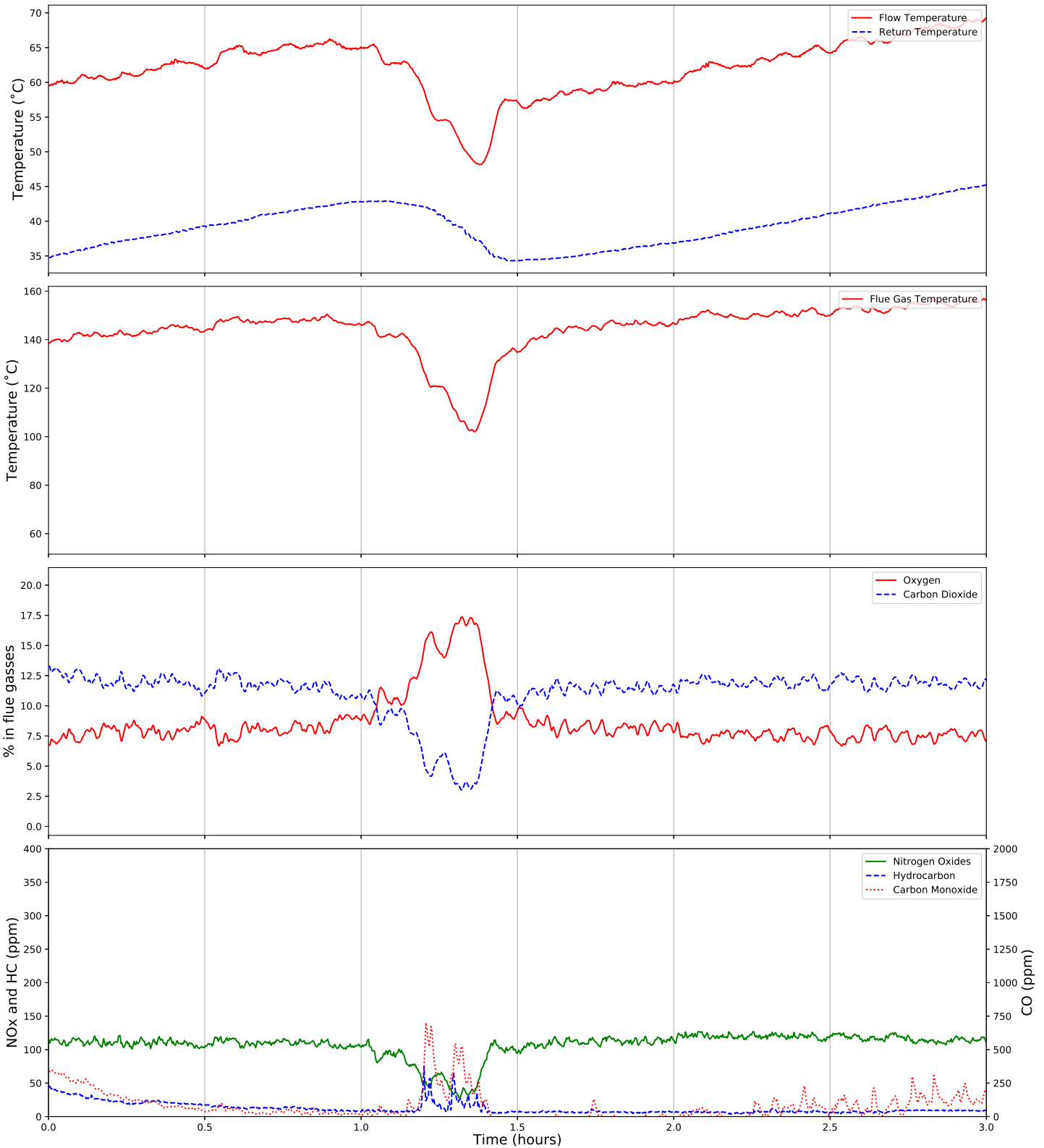
Operating pattern: Continuous

Load Factor: 100 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus B pellets



Test results adjusted for a full 24 hour period

Total fuel used: 137.20 kg
 Electrical energy used: 8,412 kJ
 Total energy used: 2,318,689 kJ

Dust emission: 44.8 g/GJ
 NOx emission: 103.1 g/GJ
 HC emission: 3.3 g/GJ

Test duration: 24 hours
 Useful heat output: 2,045,914 kJ
 Direct efficiency: 88 %

Test number: 22b

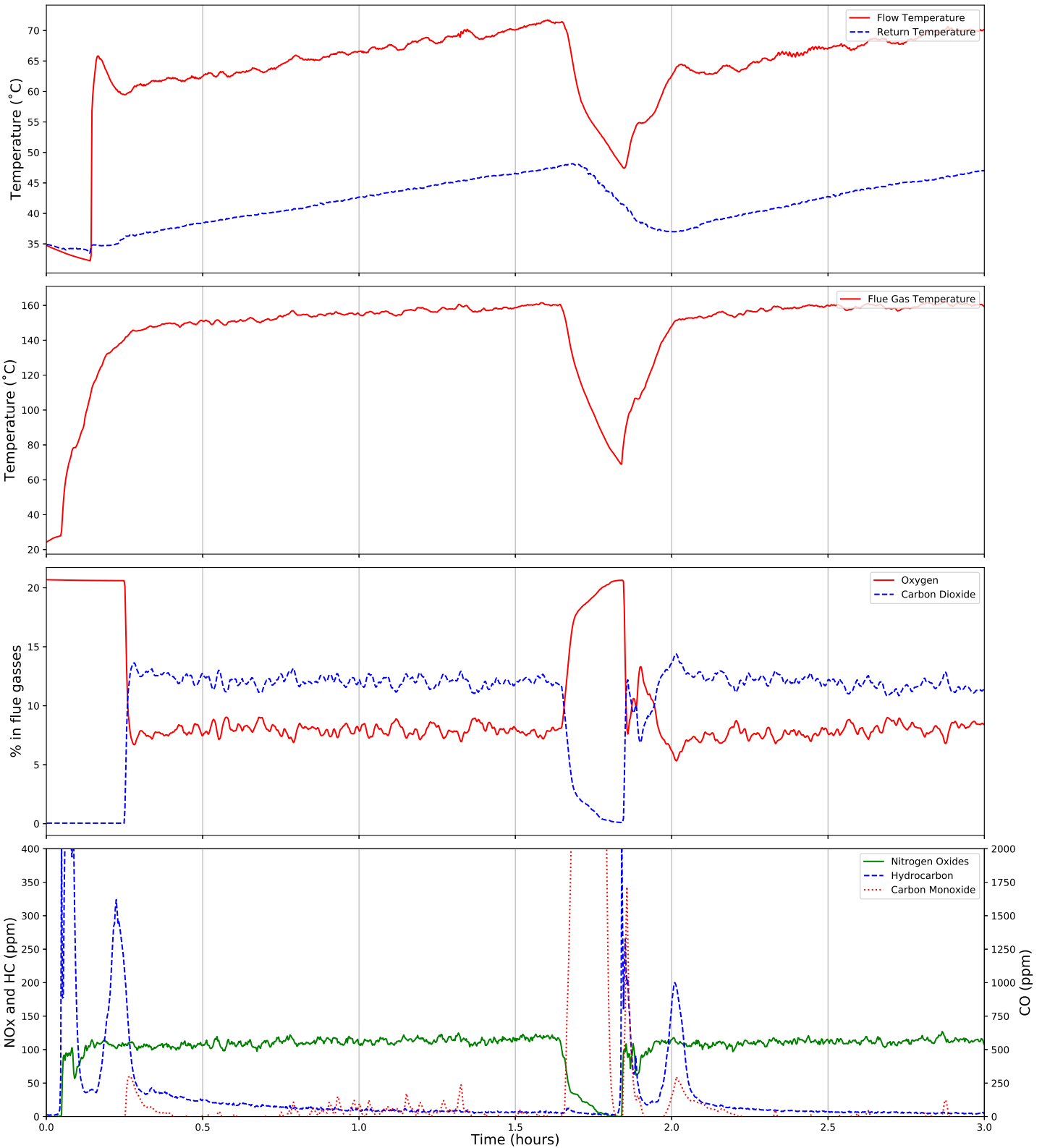
Operating pattern: Continuous

Load Factor: 100 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus B pellets



Test results adjusted for a full 24 hour period

Total fuel used: 146.37 kg
 Electrical energy used: 13,476 kJ
 Total energy used: 2,478,152 kJ

Dust emission: 50.0 g/GJ
 NOx emission: 100.0 g/GJ
 HC emission: 4.2 g/GJ

Test duration: 24 hours
 Useful heat output: 2,153,497 kJ
 Direct efficiency: 87 %

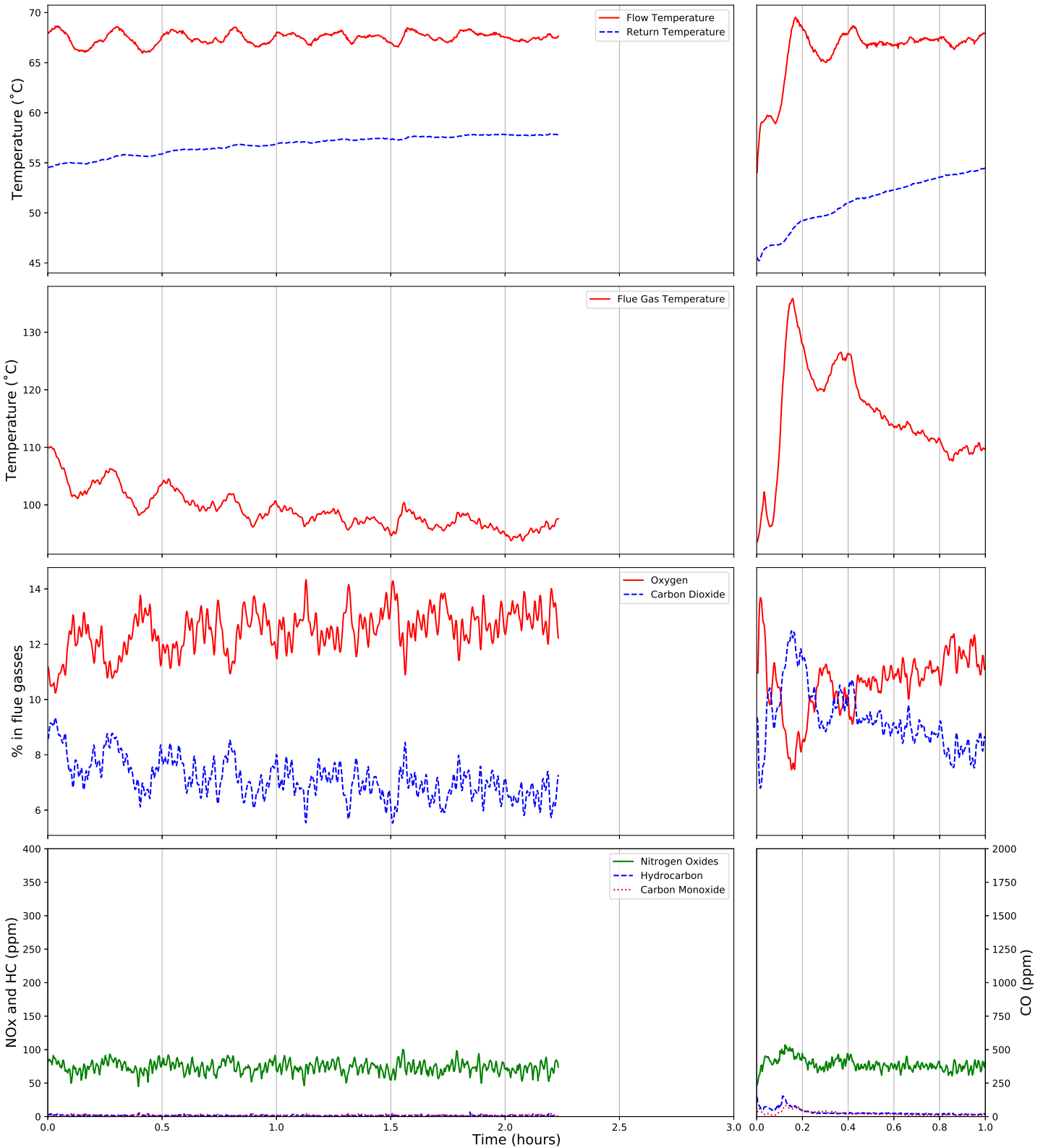
Test number: 23

Operating pattern: Unimodal
Modulation: 20 %

Load Factor: 30 %

Water Volume: 30.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 46.54 kg
Electrical energy used: 5,526 kJ
Total energy used: 797,916 kJ

Dust emission: N/A
NOx emission: 134.4 g/GJ
HC emission: 0.9 g/GJ

Test duration: 16 hours
Useful heat output: 662,418 kJ
Direct efficiency: 83 %

Test number: 24

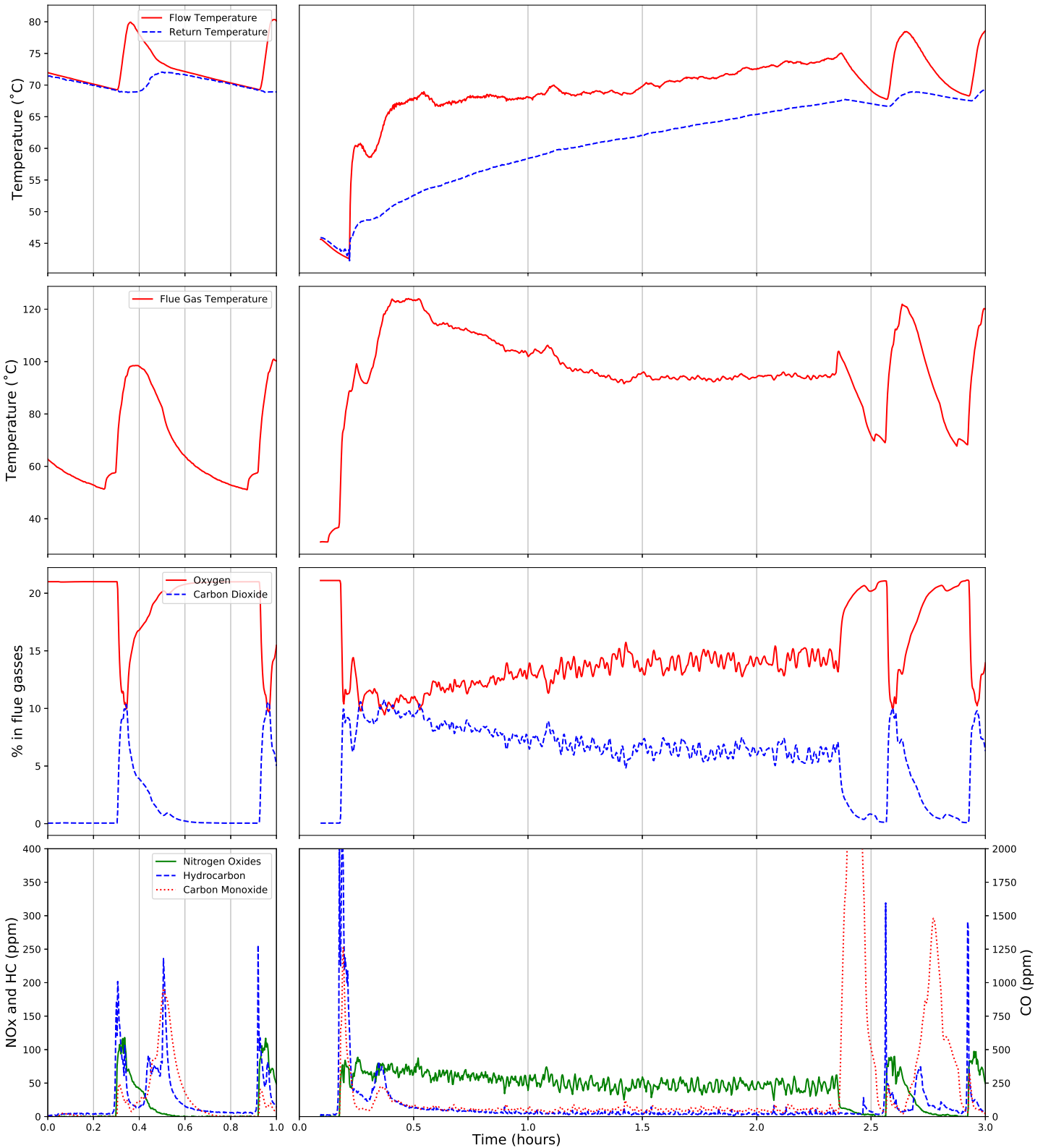
Operating pattern: Unimodal

Load Factor: 10 %

Water Volume: 30 l/kW

Modulation: 10%

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 20.79 kg
 Electrical energy used: 16,819 kJ
 Total energy used: 370,840 kJ

Dust emission: 60.4 g/GJ
 NOx emission: 82.4 g/GJ
 HC emission: 23.3 g/GJ

Test duration: 16 hours
 Useful heat output: 215,293 kJ
 Direct efficiency: 58 %

Test number: 25

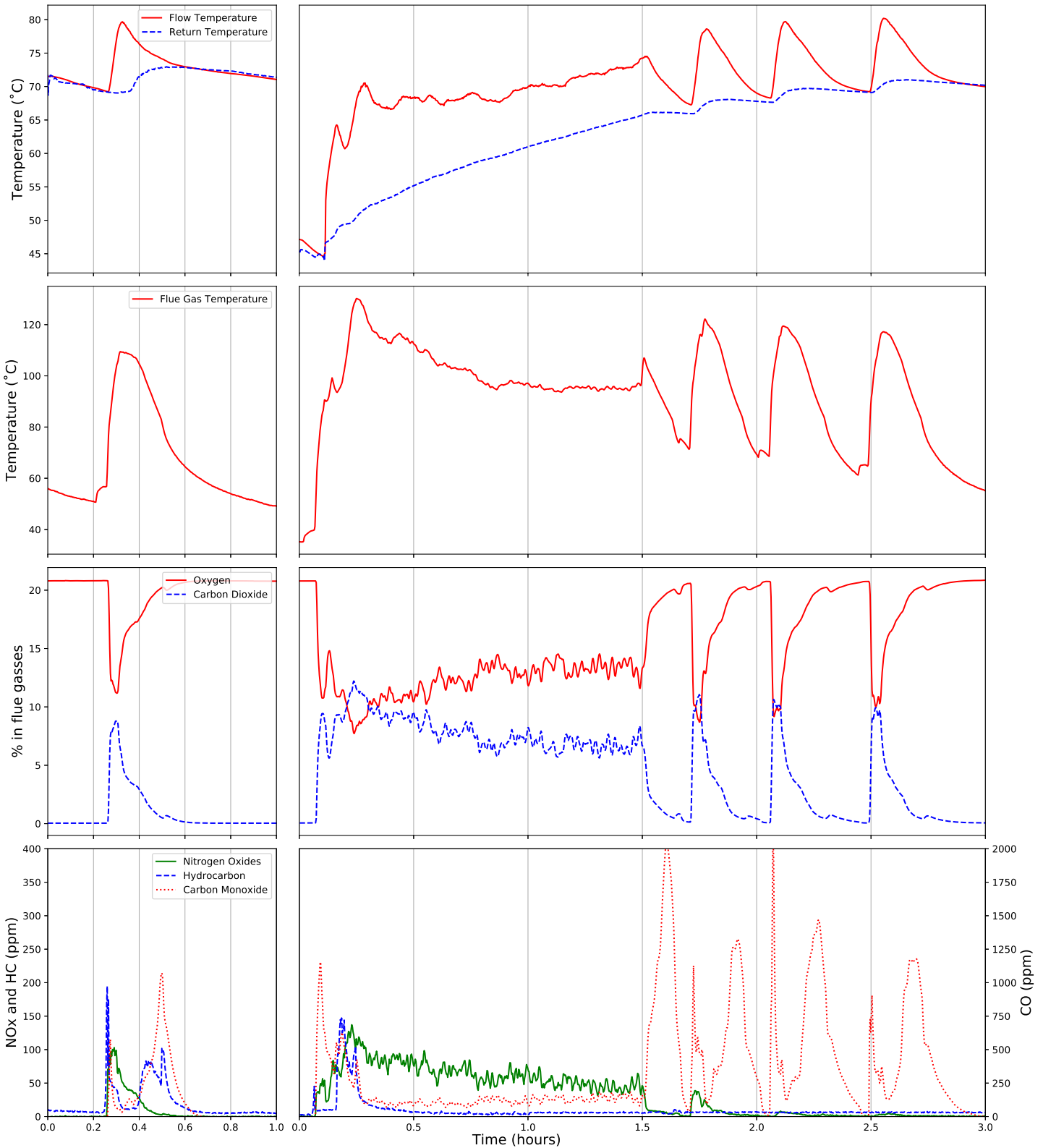
Operating pattern: Unimodal

Load Factor: 5 %

Water Volume: 30 l/kW

Modulation: 5%

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 13.77 kg
 Electrical energy used: 11,597 kJ
 Total energy used: 245,965 kJ

Dust emission: 82.0 g/GJ
 NOx emission: 79.2 g/GJ
 HC emission: 17.9 g/GJ

Test duration: 16 hours
 Useful heat output: 134,452 kJ
 Direct efficiency: 55 %

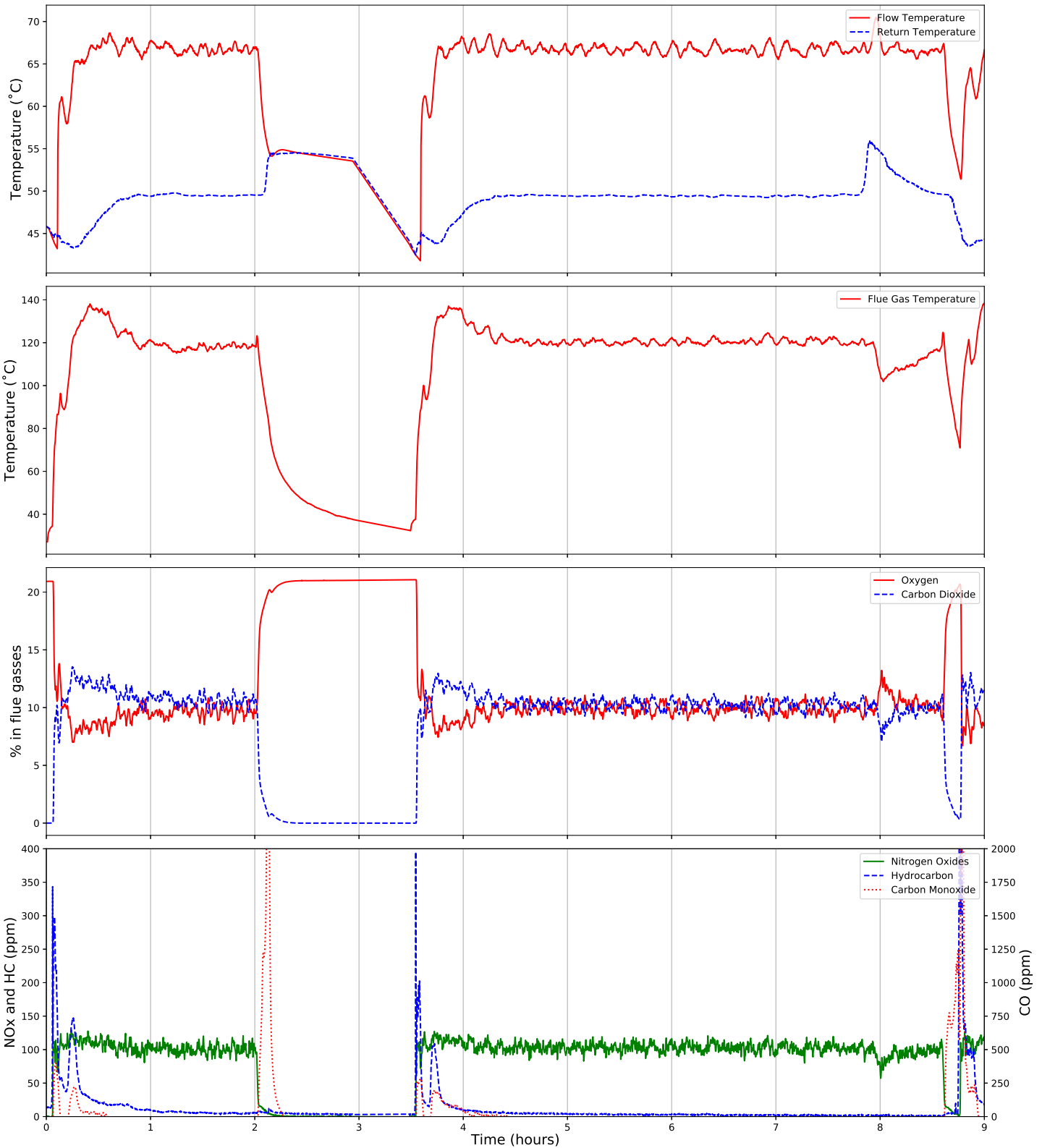
Test number: 26

Operating pattern: Bimodal
Modulation: 20 %

Load Factor: 30 %

Water Volume: 10.0 l/kW

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 39.14 kg
Electrical energy used: 4,894 kJ
Total energy used: 671,292 kJ

Dust emission: 13.7 g/GJ
NOx emission: 124.2 g/GJ
HC emission: 4.5 g/GJ

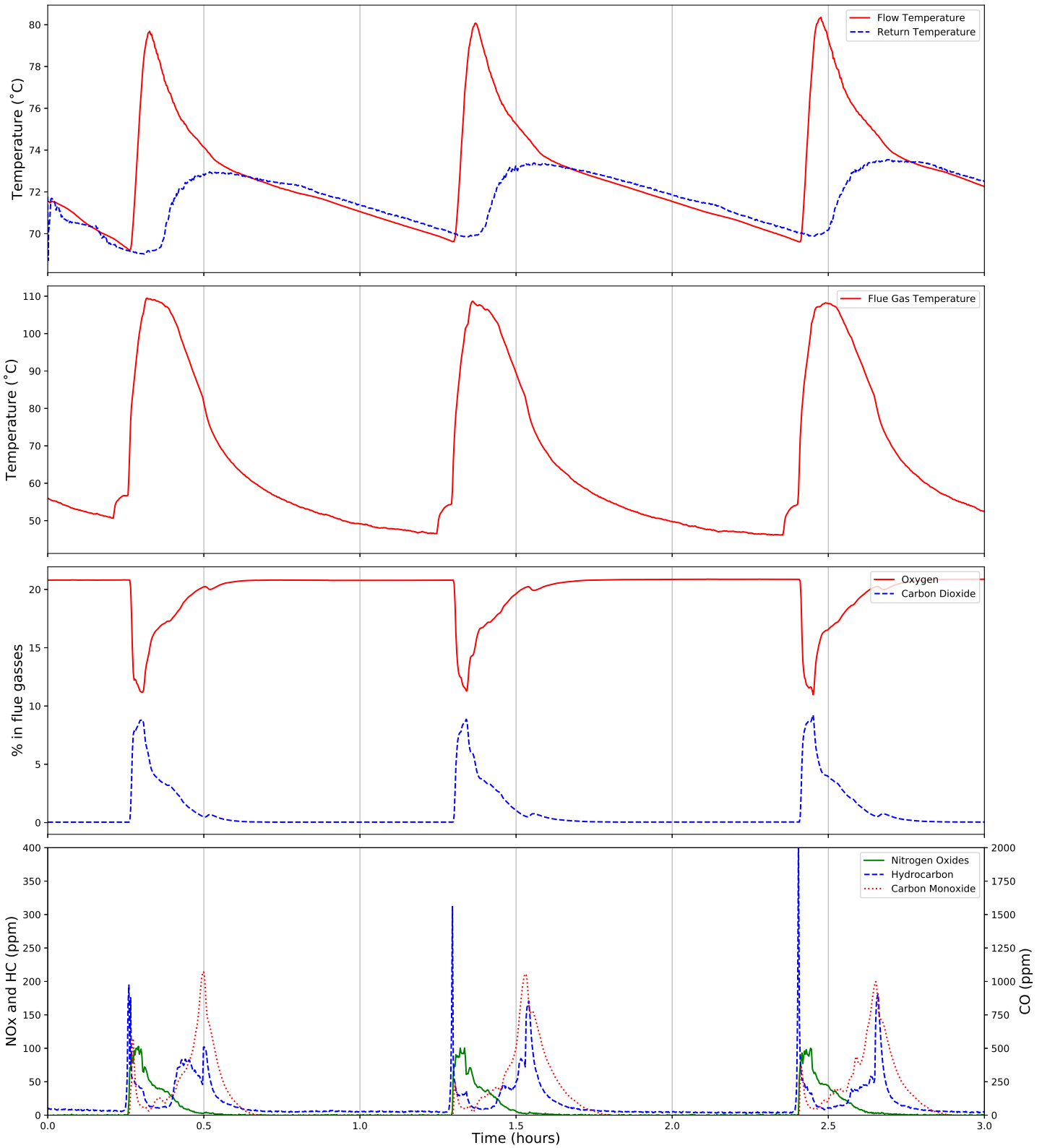
Test duration: 11 hours
Useful heat output: 623,342 kJ
Direct efficiency: 93 %

Test number: 27

Operating pattern: Continuous
Modulation: No

Load Factor: 5 %

Water Volume: 10.0 l/kW
Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

Total fuel used: 14.22 kg
Electrical energy used: 17,604 kJ
Total energy used: 259,727 kJ

Dust emission: 76.5 g/GJ
NOx emission: 91.0 g/GJ
HC emission: 32.6 g/GJ

Test duration: 24 hours
Useful heat output: 106,544 kJ
Direct efficiency: 41 %

Test number: 28

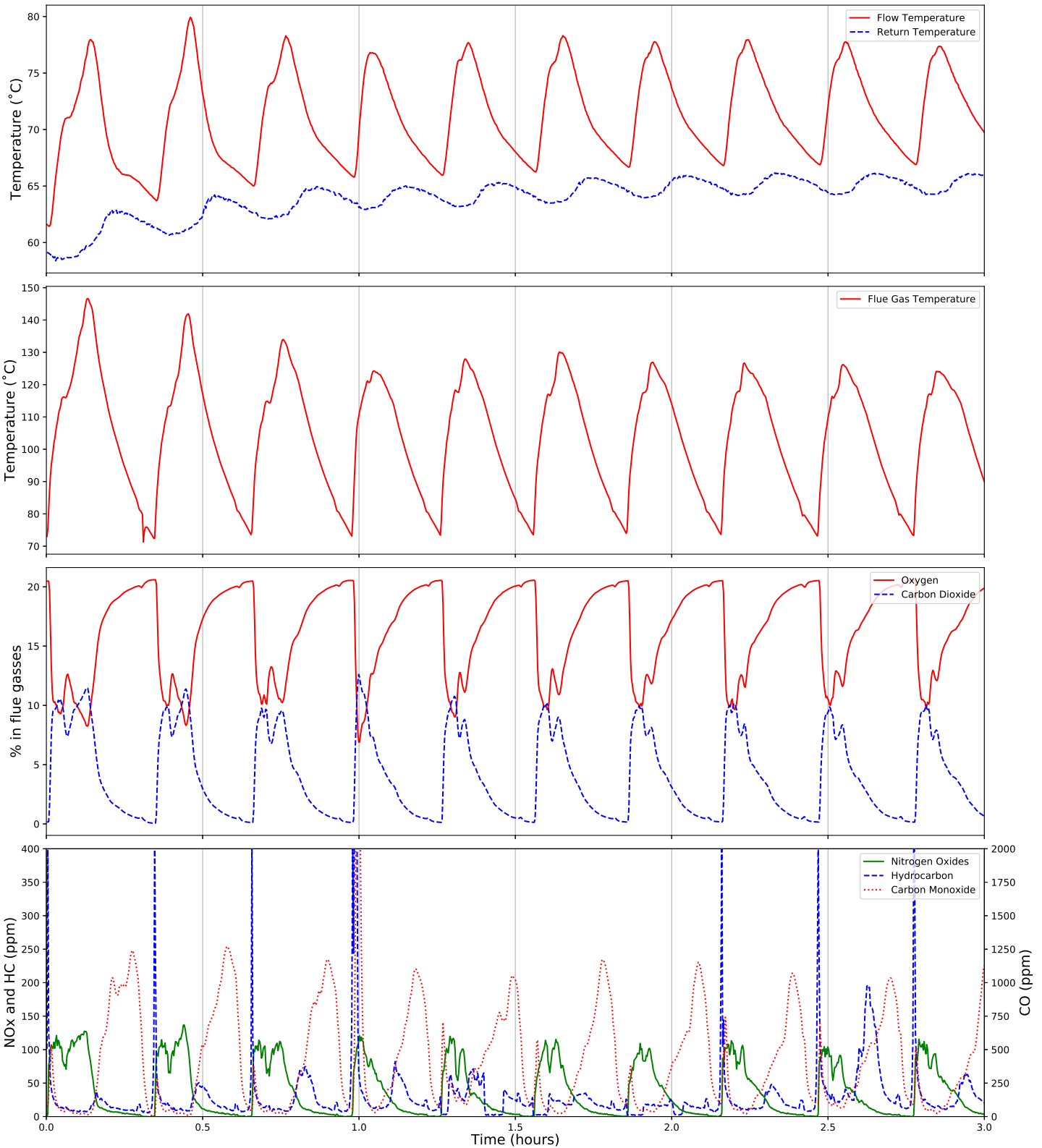
Operating pattern: Continuous

Load Factor: 30 %

Water Volume: 10.0 l/kW

Modulation: No

Fuel: EN Plus A1 pellets



Test results adjusted for a full 24 hour period

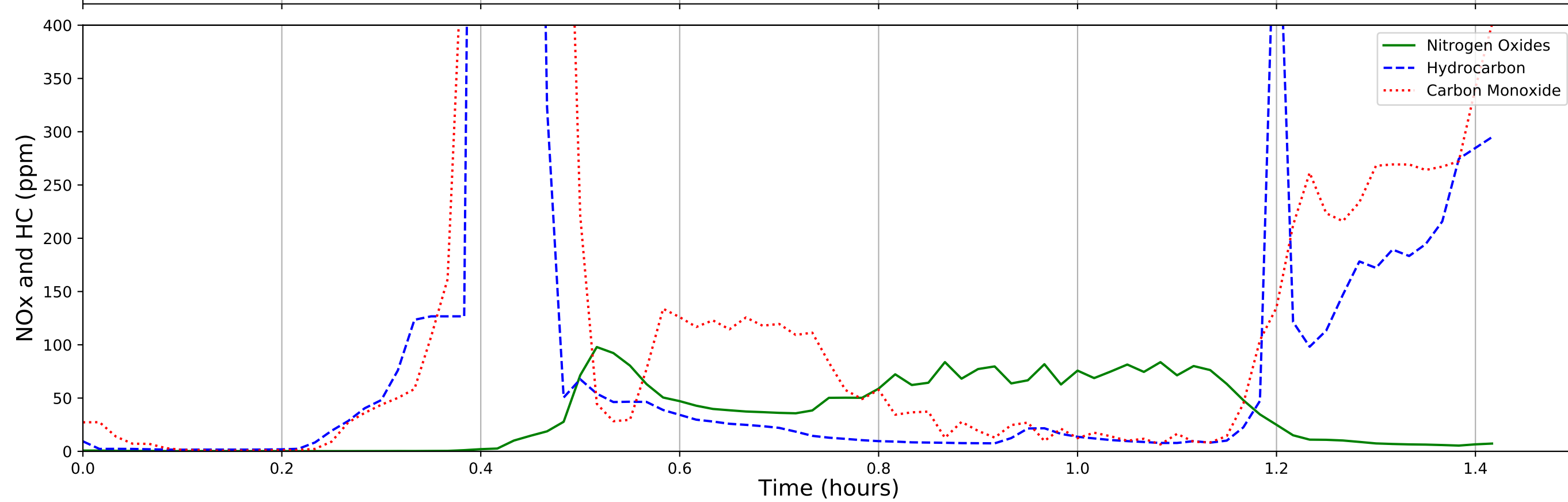
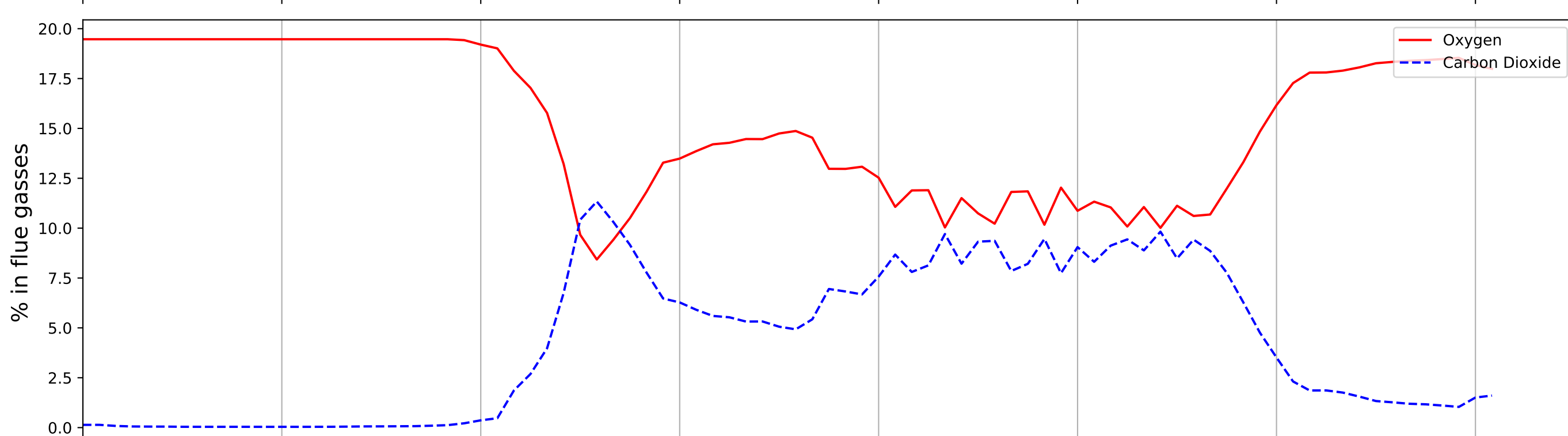
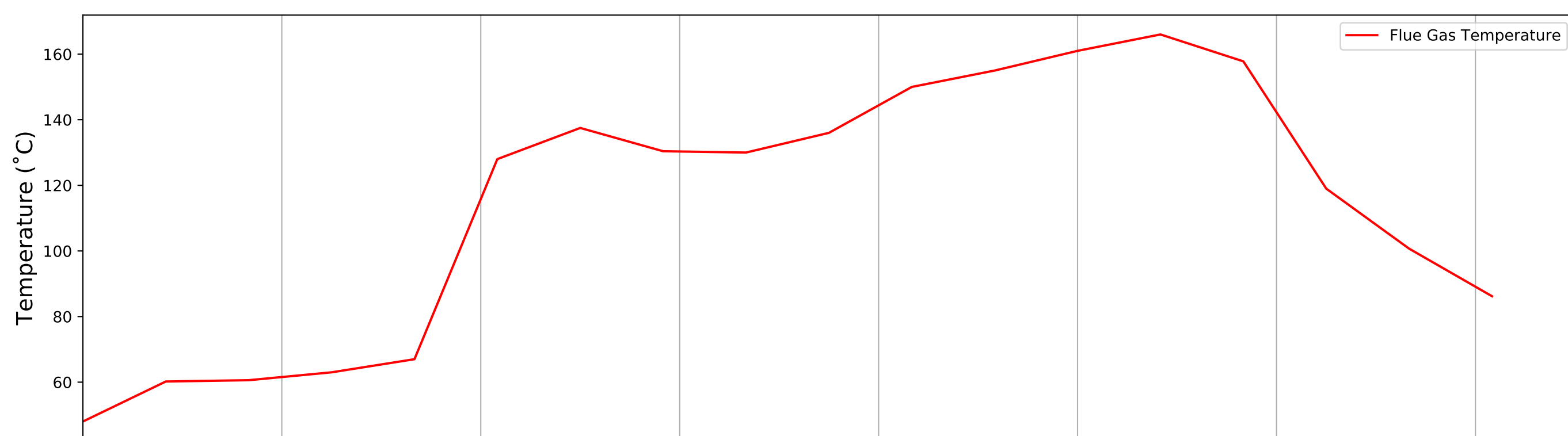
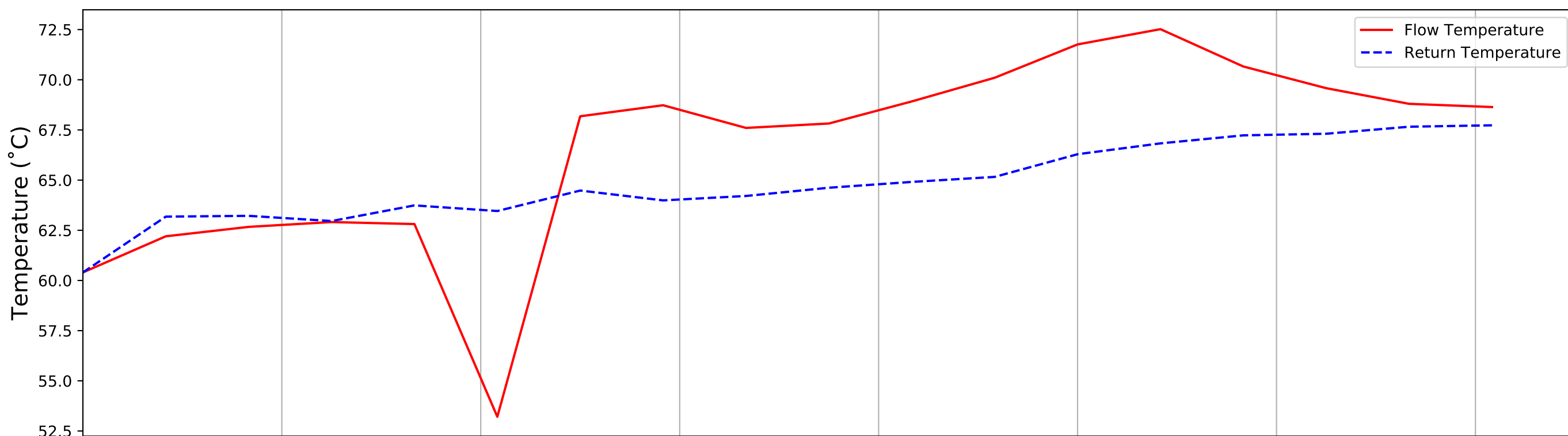
Total fuel used: 34.32 kg
 Electrical energy used: 29,127 kJ
 Total energy used: 613,490 kJ

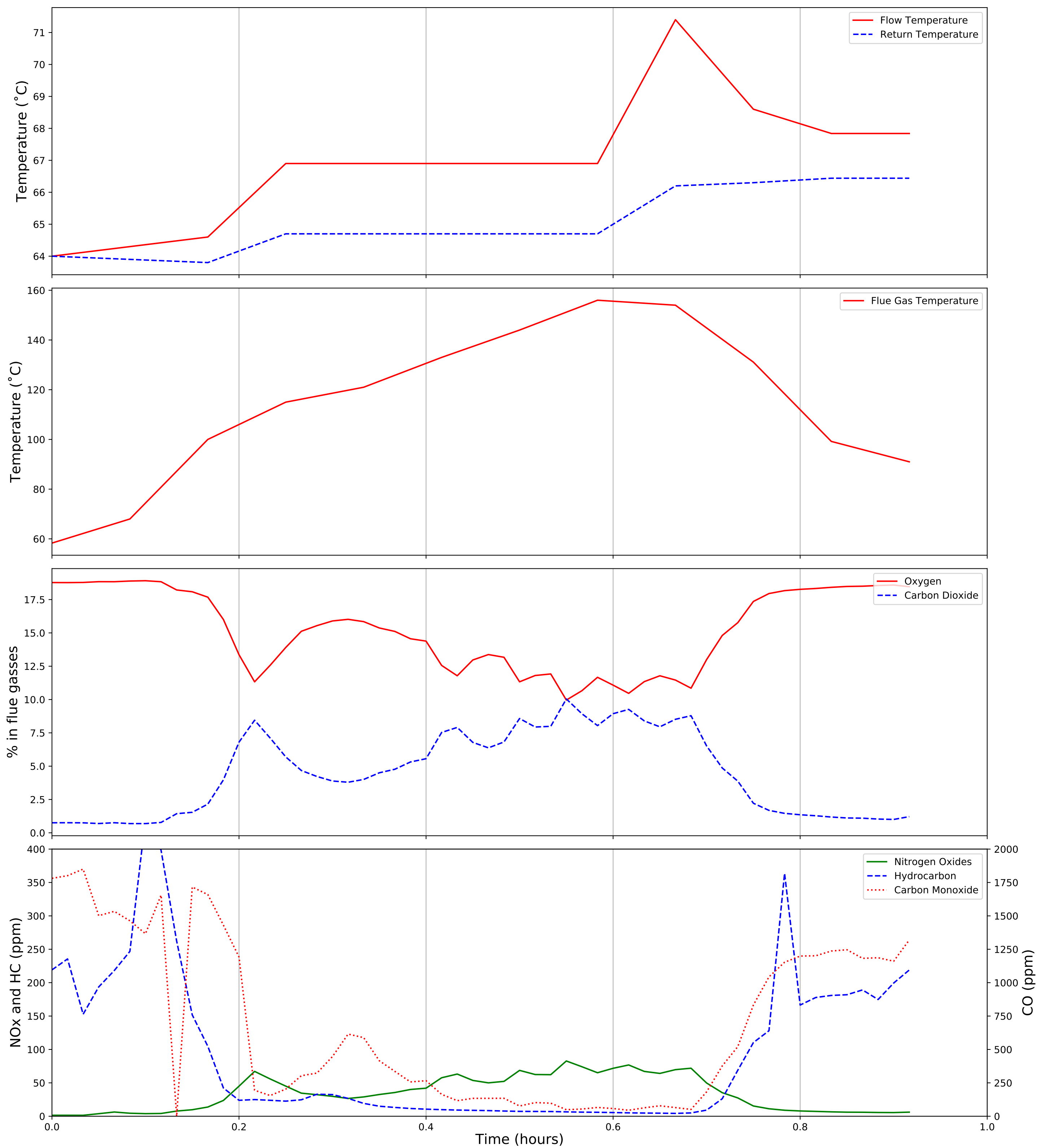
Dust emission: 63.0 g/GJ
 NOx emission: 102.2 g/GJ
 HC emission: 34.2 g/GJ

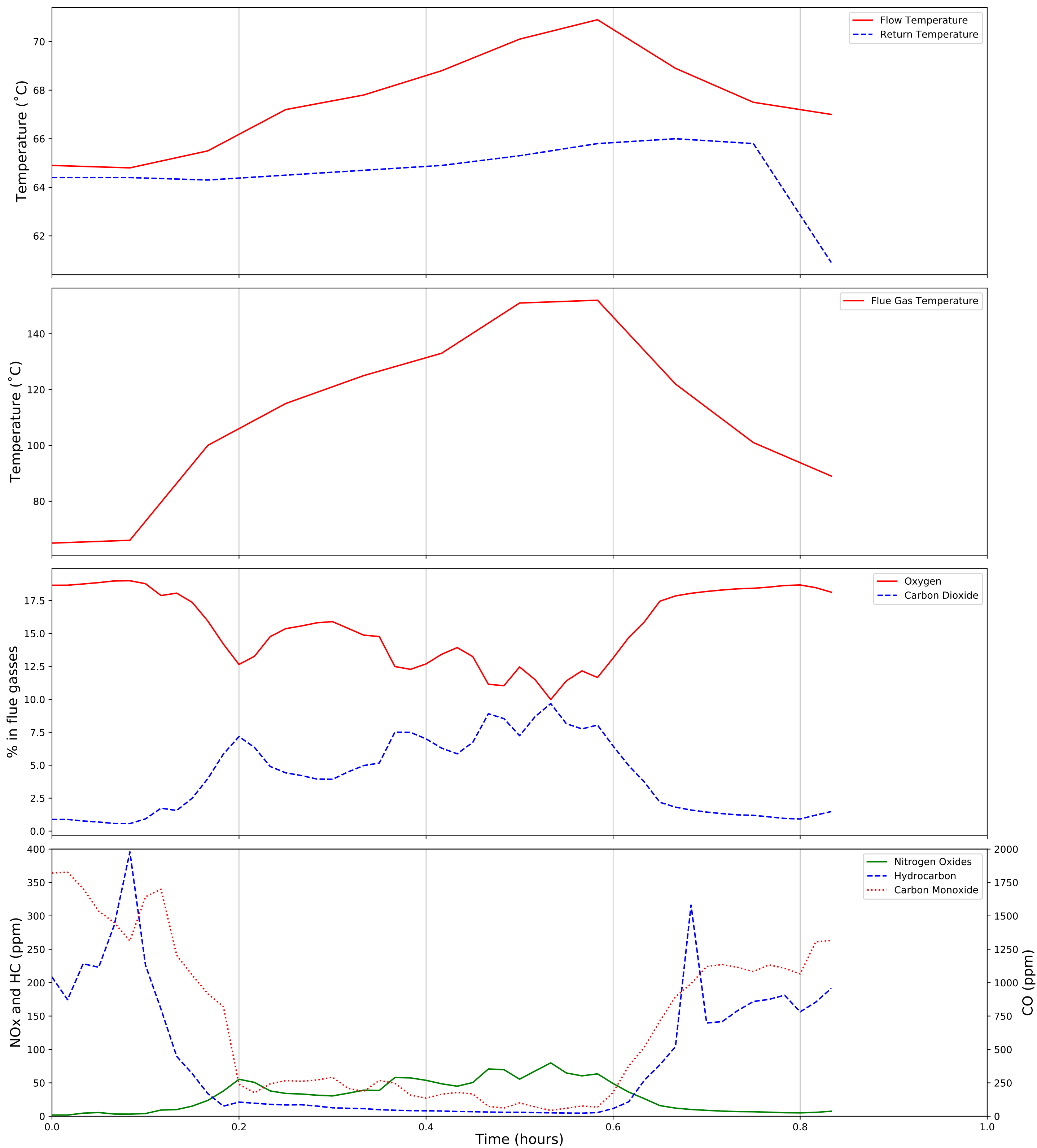
Test duration: 24 hours
 Useful heat output: 410,745 kJ
 Direct efficiency: 67 %

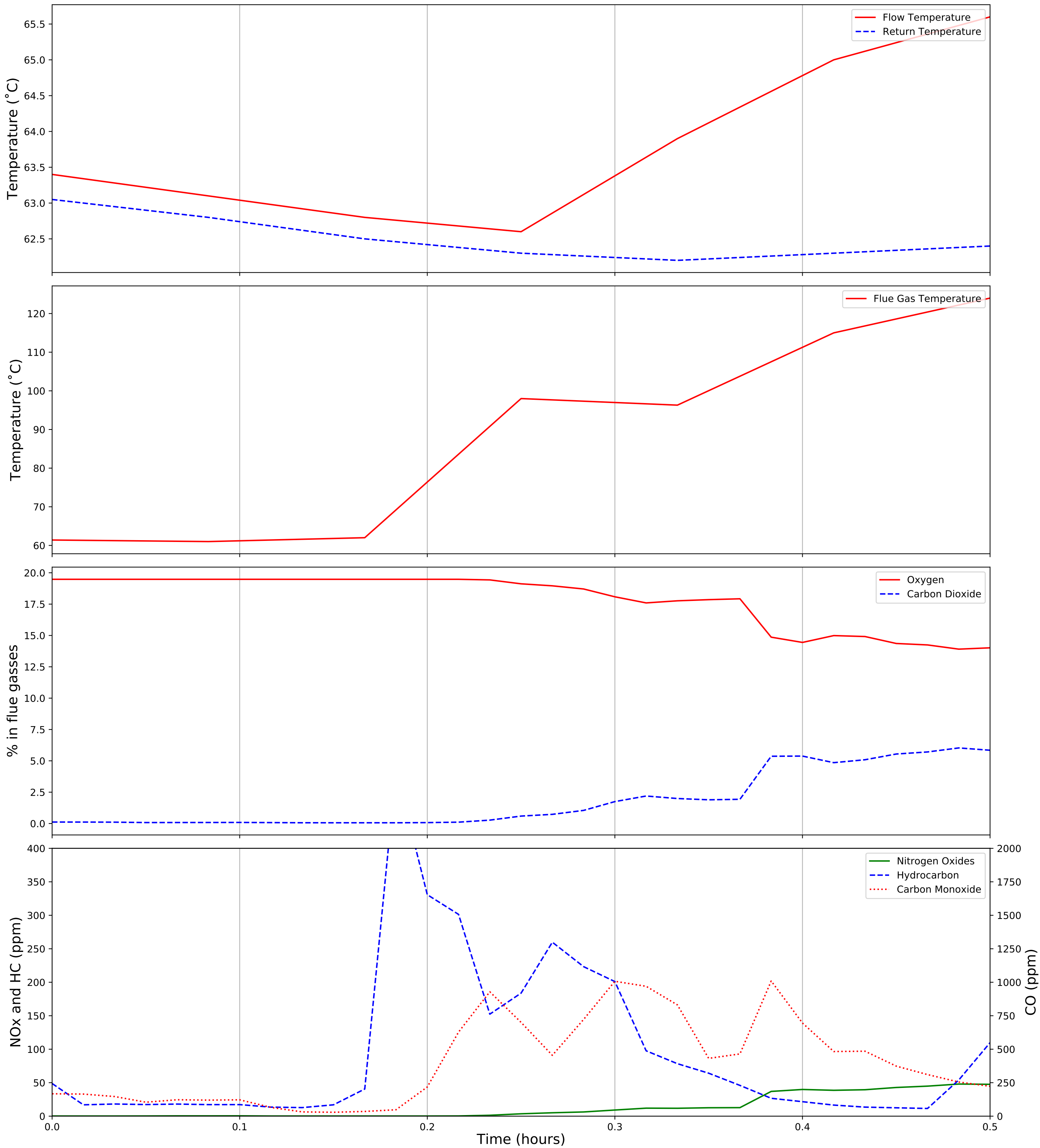
2 Laboratory trials – large boiler

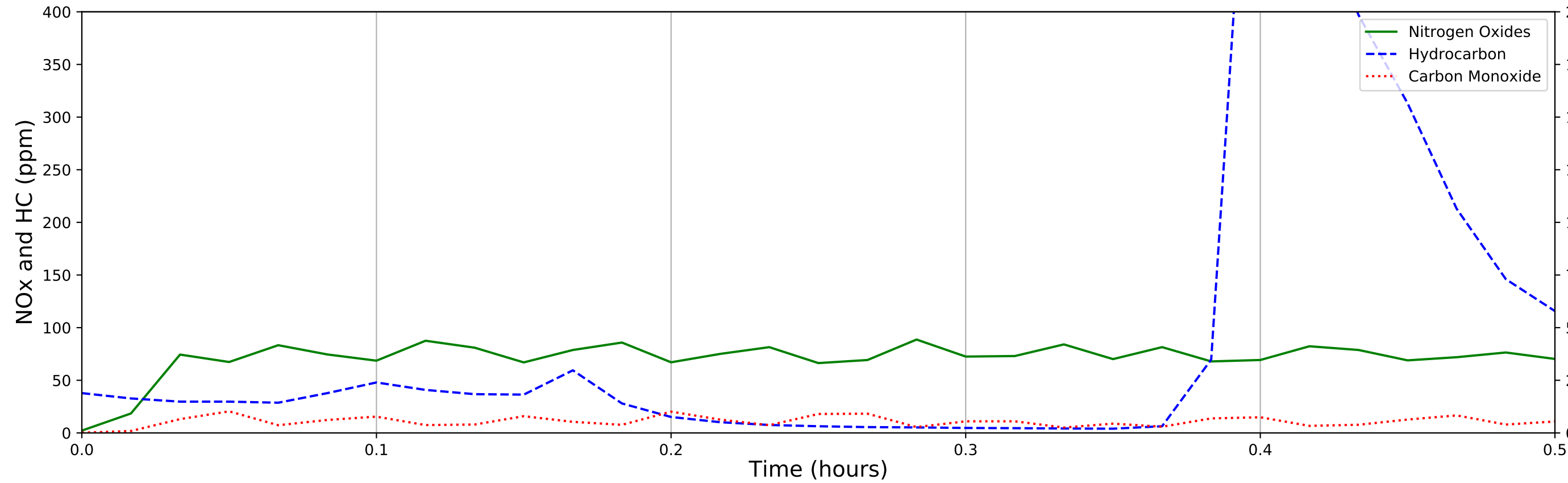
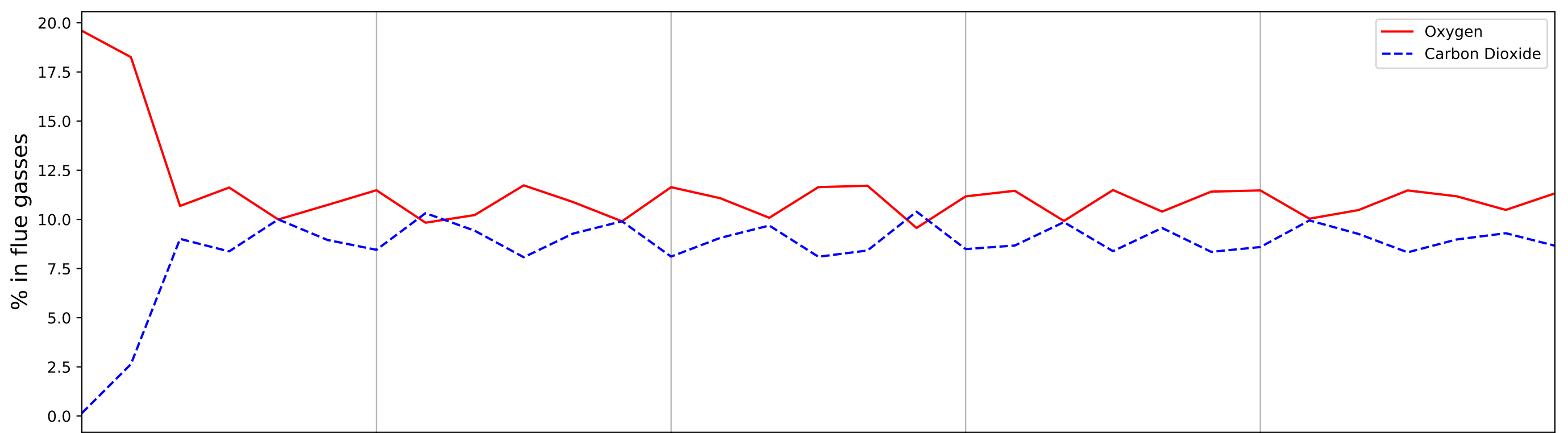
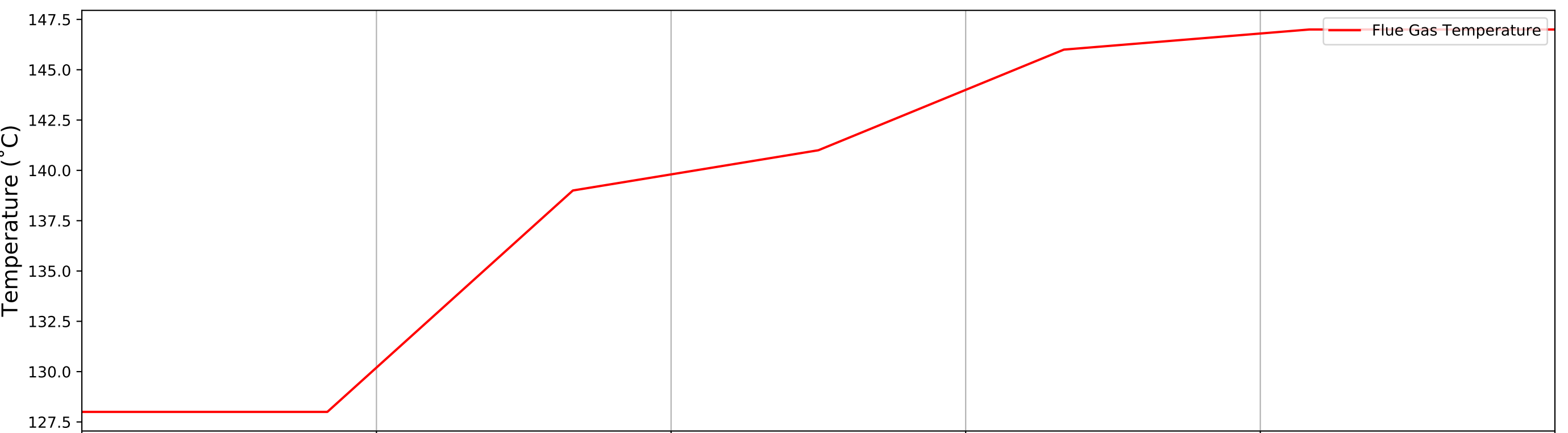
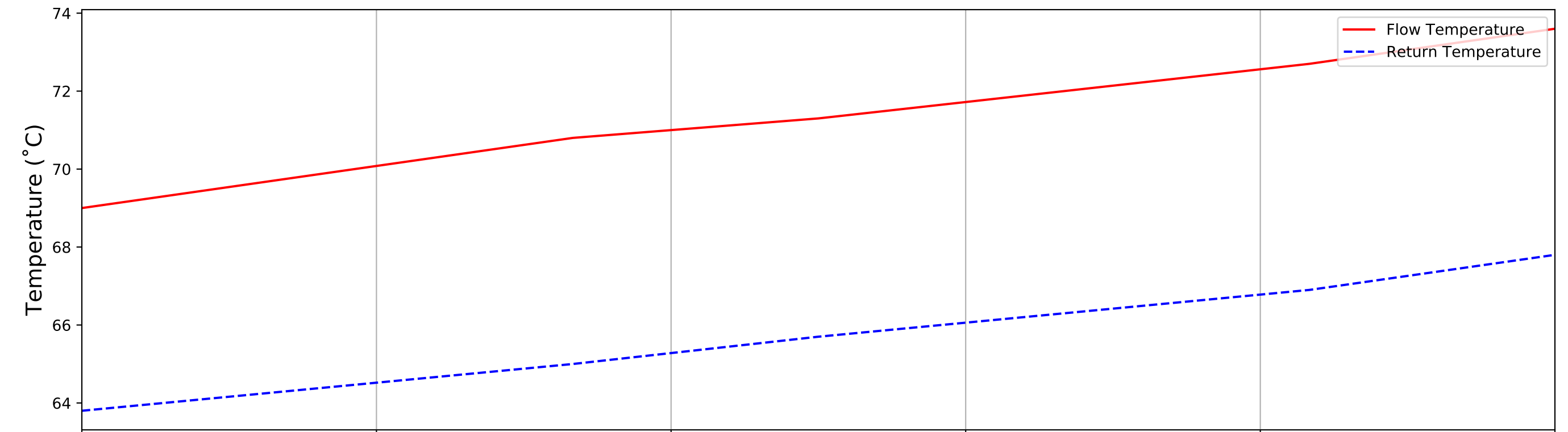
Test No.	1	2	3	4	5	6	7
Test Type	Full Run (cold)	Full Run (warm)	Full Run (warm)	Start-up (cold)	Steady state	Shutdown	Start-up (warm)
Test duration (h)	1.38	0.88	0.80	0.48	0.50	0.60	0.35
Fuel Energy in (kJ)	1,308,406	706,328	845,306		939,667		
Heat out (kJ)	993,003	516,000	666,000	150,000	717,000	453,000	207,000
Dust emission (g/h)	157	63	56	262	39	87	61
Dust emission (g)	217	56	45	127	19	52	21
Dust emission (g/GJ)	166	79	53		21		
NOx emission (g/h)	66	75	74	67	105	84	59
NOx emission (g)	91	66	59	32	53	51	21
NOx emission (g/GJ)	70	93	70		56		
HC emission (g/h)	1,816	774	742	6,035	124	2,442	898
HC emission (g)	2,512	684	594	2,917	62	1,465	314
HC emission (g/GJ)	1,920	968	702		66		
Efficiency net (%)	76	73	79		76		

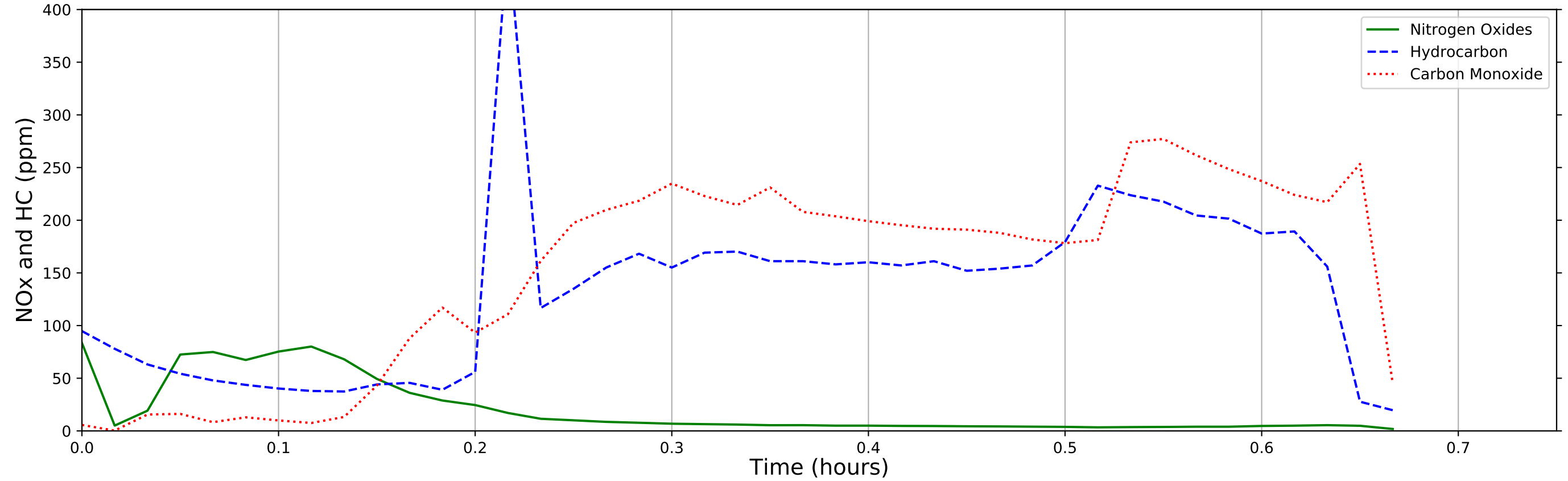
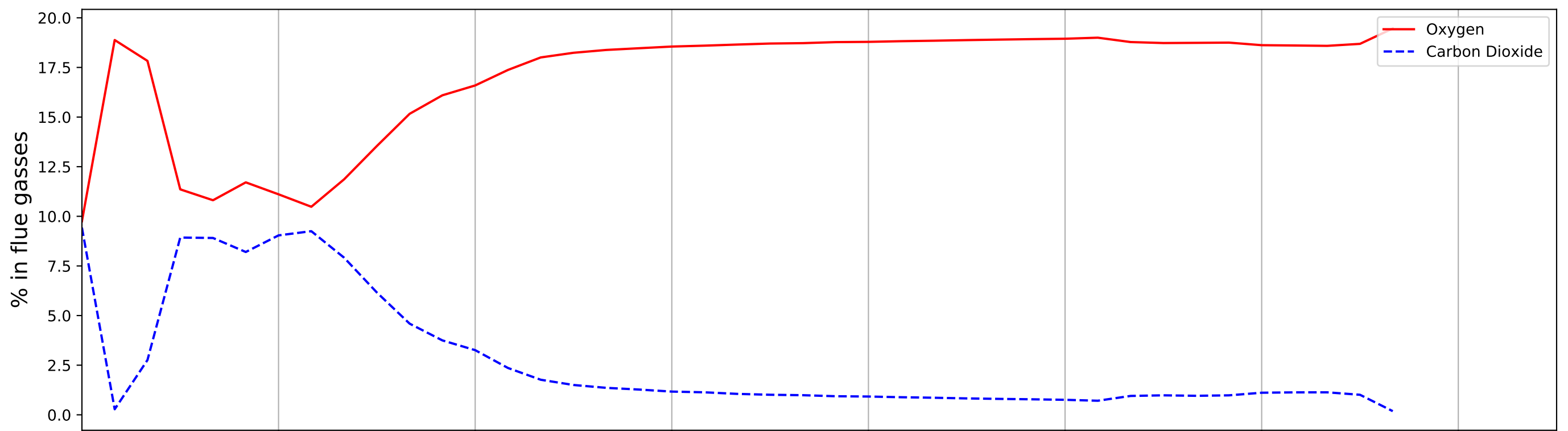
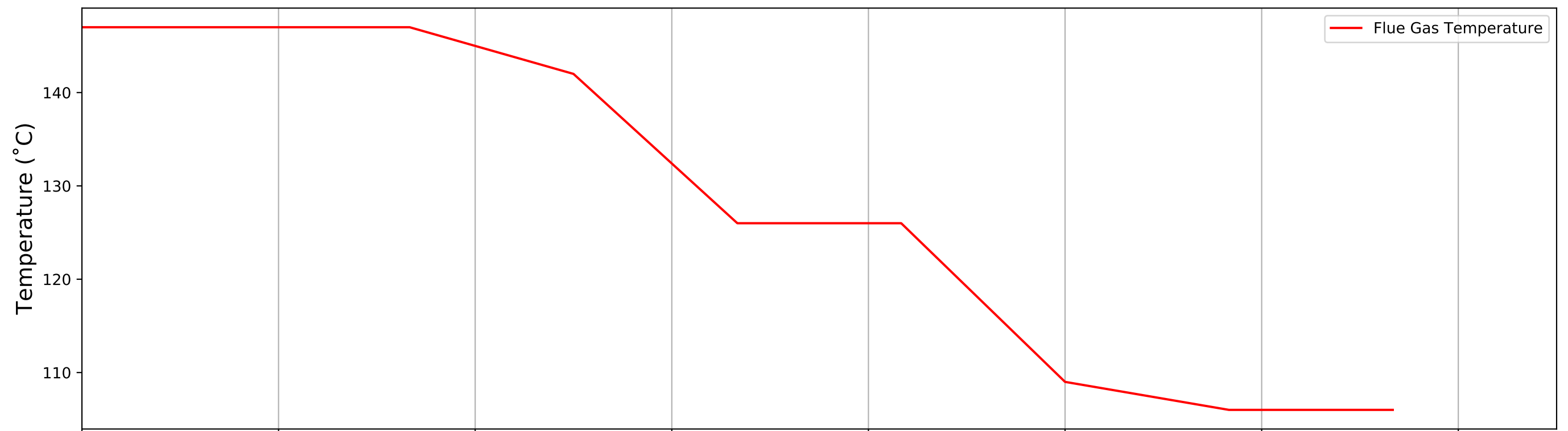
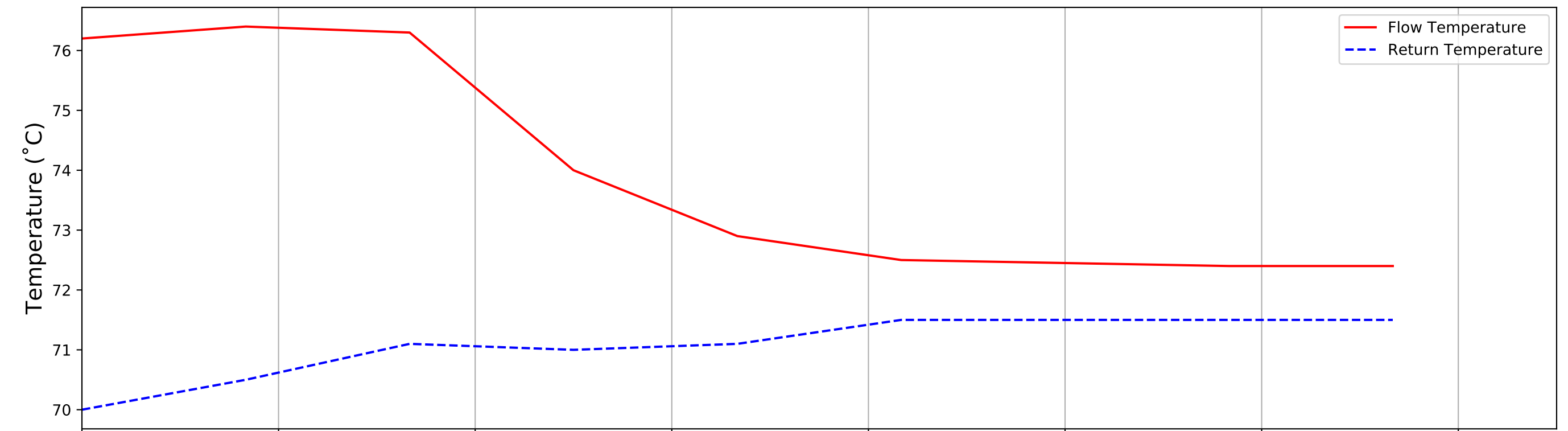


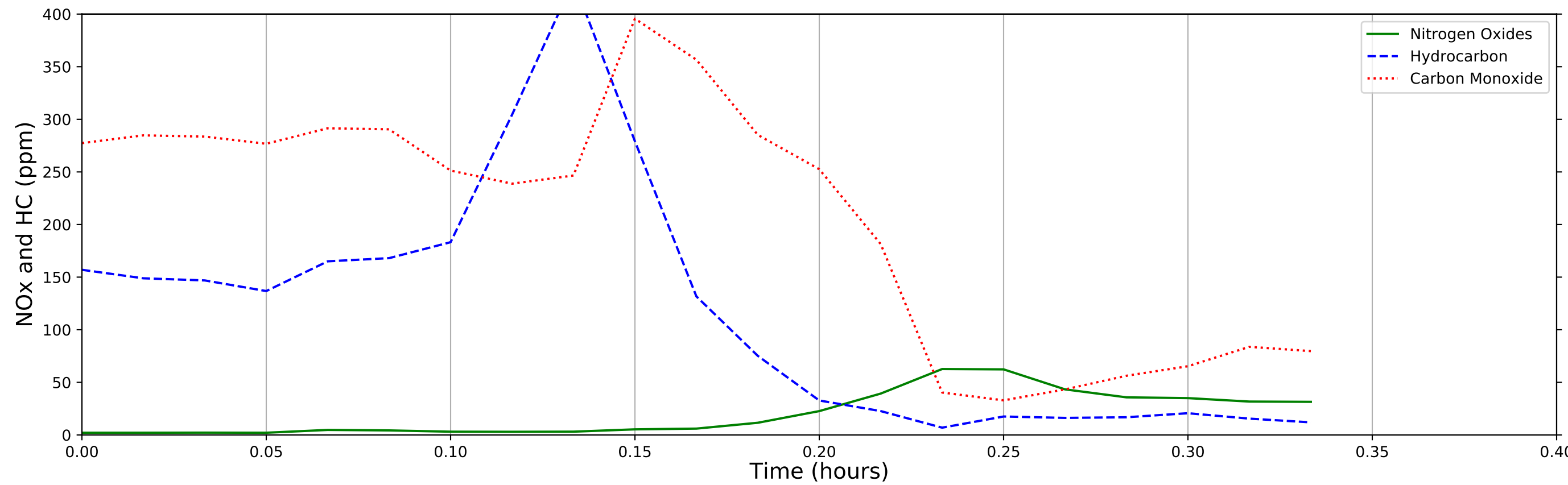
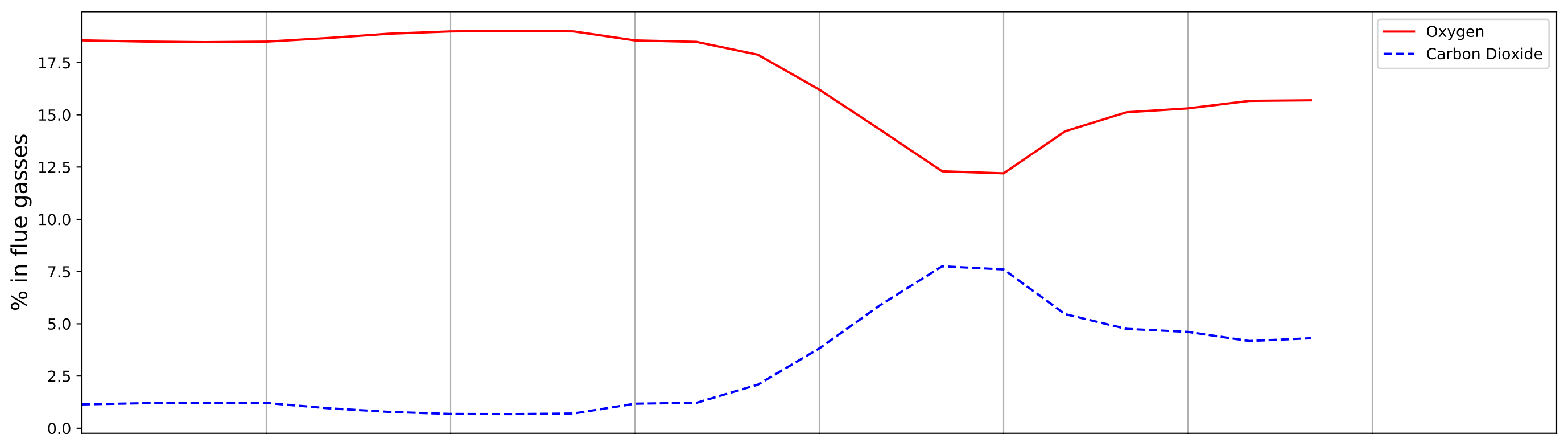
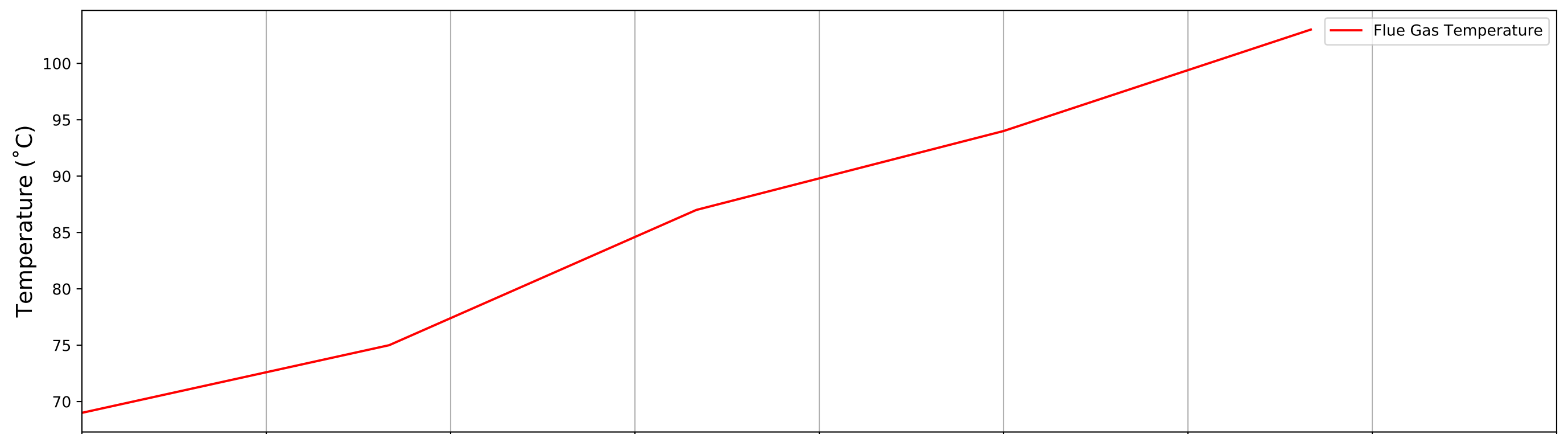
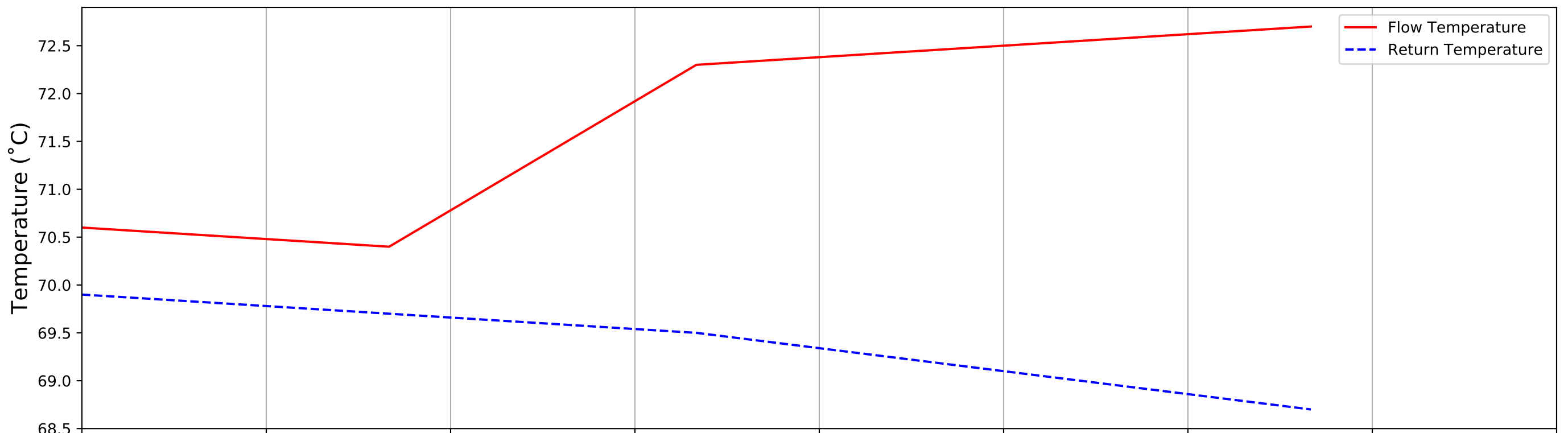












Heavy metal analysis of fuel samples from intervention sites

Fuel	Type	Total Moisture	Ash Content	Volatile Matter	Fixed Carbon	Total Sulphur	Chlorine	Carbon	Hydrogen	Nitrogen	Oxygen By Difference	Gross Calorific Value	Net Calorific Value	Arsenic	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Zinc	Antimony	Cobalt	Manganese	Thallium	Vanadium	Tin
		%	%	%	%	%	%	%	%	%	%	%	MJ/kg	MJ/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
		AR	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	AR	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB
B001	Chip	19.8	1.6	79.6	18.8	0.01	0	52.9	5.92	0.23	39.3	20.132	14.63	<0.1	0.22	4.34	3.61	0.01	3.65	5.69	19.66	0.11	0.4	198.16	0	0.71	0
B046	Chip	23.3	0.4	81.5	18.1	0	0.02	53.6	6.07	0.11	39.8	20.213	13.923	<0.1	0.09	1.06	3.1	<0.01	1.19	3.13	10.04	0	0	126.75	0	0.21	0
B127	Chip	18	0.3	81.5	18.2	0	0.01	52.2	5.94	0.18	41.3	20.253	15.109	<0.1	0.05	0.47	4.49	<0.01	1.38	0.62	13.29	0	0	81.34	0	0.26	0
B222	Chip	30.8	0.4	82.9	16.7	0	0	52.5	6.02	0.15	40.9	20.023	12.198	<0.1	0.18	1.25	7.95	<0.01	3.2	1.15	24.27	0	0.12	80.02	0	0.33	0
B250	Pellet	6.6	0.6	83.2	16.2	0	0.03	49.8	5.98	0.16	43.4	19.949	17.254	<0.1	0.12	0.42	2.6	<0.01	0.39	0.37	16.98	0	0.1	64	0	0.32	0
B271	Chip	24.6	0.4	81.9	17.7	0	0.07	51.2	5.86	0.2	42.3	20.119	13.606	<0.1	0.09	0.47	2.05	<0.01	1.02	0.81	9.12	0	0	83.61	0	0.33	0
B358	Pellet	6.7	0.4	84.1	15.5	0	0	50.3	5.93	0.05	43.3	20.056	17.343	<0.1	0.07	0.74	1.47	<0.01	1.18	0.2	6.45	0	0	51.57	0	0.44	0
B445	Chip	25.3	2.8	79.6	17.6	0.01	0.02	51.2	5.76	0.28	39.9	19.425	12.956	<0.1	0.06	4.88	2.94	0.01	4.72	1.08	13.17	0	0.19	11.09	0	0.61	0
B542	Pellet	6.6	0.3	83.3	16.4	0	0.03	50	5.89	0.1	43.7	20.067	17.382	<0.1	0.03	0.39	2.01	<0.01	0.6	0.24	10.05	0	0	61.62	0	0.41	0
B586	Log	17	1.3	82.4	16.3	0	0.01	51.3	5.9	0.21	41.3	19.713	14.882	<0.1	0.04	0.34	2.13	<0.01	1.2	15.82	11.4	0	0	82.91	0	0.28	0
B900	Pellet	8.1	0.3	83.3	16.4	0	0	50.3	5.91	0.1	43.4	20.176	17.16	<0.1	0.13	0.31	3.1	<0.01	0.47	0.61	5.76	0	0	102.99	0	0.42	0
B901	Pellet	8.1	0.3	83.3	16.4	0	0	50.3	5.91	0.1	43.4	20.176	17.16	<0.1	0.13	0.31	3.1	<0.01	0.47	0.61	5.76	0	0	102.99	0	0.42	0
B909	Log	13.7	3.5	76	20.5	0.02	0	54	5.81	0.64	36	20.755	16.489	<0.1	0.05	1.23	4.96	<0.01	1.58	1.89	20.04	0	0.27	20.3	0	0.82	0
B912	Pellet	6.8	<0.1	82.8	17.1	0	0.01	49.9	5.89	0.13	44	20.168	17.434	<0.1	0.05	0.75	2.52	<0.01	0.53	1.4	9.74	0.29	0	72.34	0	0	0
B919	Pellet	8.6	<0.1	83.7	16.2	0	0	50.7	5.3	0.15	43.7	20.282	17.269	<0.1	0.05	0.41	1.21	<0.01	0.48	0.21	4.96	0	0	61.45	0	0	0

mg[metal in dry fuel] / kg[dry fuel]

Heavy metal test result
 Below limit of detection

Heavy metal analysis of ash samples from intervention sites

Ash	Type	Total Moisture		Carbon								
		% AR	% DB	Arsenic mg/kg DB	Cadmium mg/kg DB	Chromium mg/kg DB	Copper mg/kg DB	Mercury mg/kg DB	Nickel mg/kg DB	Lead mg/kg DB	Zinc mg/kg DB	
B001	Chip	1.1	2.6	2.93	0.17	218.65	158.65	0.08	154.22	505.71	56.2	
B046	Chip	0.5	1.3	6.25	31.45	281.59	186.7	<0.01	118.67	279.58	571.49	
B127	Chip	1.7	11	1.2	0.35	187.34	230.52	0.04	96.78	18.94	89.1	
B222	Chip	1.5	6.5	4.82	0.75	97.31	334.84	0.05	67.32	10.72	171.01	
B250	Pellet	1.7	12.6	0.46	6.27	89.44	110.38	0.03	52.3	14.92	398.78	
B271	Chip	0.7	0.8	12.53	8.01	934.83	187.88	0.06	932.92	73.08	292.11	
B358	Pellet	5	35.9	0.3	0.43	244.66	111.39	0.07	171.47	3.17	35.17	
B445	Chip	0	3.2	3.55	3.66	81.55	409.08	0.03	49.56	27.35	166.27	
B542	Pellet	0.8	7.9	0.15	5.37	169.66	158.8	0.05	49.81	4.99	652.77	
B586	Log	0.6	5.8	0.66	1.29	83.09	221.75	0.06	34.55	119.77	503.6	
B900	Pellet	1.1	2.5	9.19	0.04	171.46	572.4	<0.01	107.68	1.96	50.59	
B901	Pellet	0.7	1.9	5.81	0.3	108.67	437.87	<0.01	92.54	0.98	28.56	
B909	Log	1.2	9.2	148.32	2.48	274.37	417.85	<0.01	23.78	37.69	558.16	
B912	Pellet	5.2	21.5	8.06	0.91	171.41	210.12	0.03	104.38	12.06	142.57	
B919	Pellet	0.7	4.1	2.3	35.63	306.43	568.65	0.05	134.08	59.32	1453.9	

mg[metal in dry ash] / kg[dry ash]

Heavy metal test result
 Below limit of detection

Fuel sample: Recycled Fuel 1 (wood chip)

Trace Metals in Fuel (Determined in Fuel via HF)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	18.8	18.8	18.8	18.80	0.00	0%
Arsenic	mg/kg	13.69	6.34	7.19	9.07	4.02	44%
Antimony	mg/kg	4.39	4.59	3.41	4.13	0.63	15%
Cadmium	mg/kg	0.46	0.85	0.22	0.51	0.32	62%
Chromium	mg/kg	34.15	28.81	35.89	32.95	3.69	11%
Cobalt	mg/kg	1.25	1.54	1.46	1.42	0.15	11%
Copper	mg/kg	32.56	29.33	37.28	33.06	4.00	12%
Lead	mg/kg	110.4	118.87	129.37	119.55	9.50	8%
Manganese	mg/kg	73.24	74.61	76.58	74.81	1.68	2%
Mercury	mg/kg	0.04	0.05	0.04	0.04	0.01	13%
Nickel	mg/kg	14.83	16.02	18.11	16.32	1.66	10%
Tin	mg/kg	1.84	1.98	1.70	1.84	0.14	8%
Thallium	mg/kg	0.1	0.1	0.1			
Vanadium	mg/kg	1.89	1.89	2.15	1.98	0.15	8%
Zinc	mg/kg	75.13	102.08	89.64	88.95	13.49	15%

Trace Metals in fuel (Determined in Ash)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	18.8	18.8	18.8	18.80	0.00	0%
Sample Mass taken for ashing	g	1.018	0.9780	0.9761	0.99	0.02	2%
Mass of ash obtained	g	0.0303	0.0310	0.0439	0.04	0.01	22%
Ash content	%	3.0	3.2	4.5	3.57	0.81	23%
Arsenic	mg/kg	4.89	5.37	5.83	5.36	0.47	9%
Antimony	mg/kg	3.07	3.08	4.64	3.60	0.90	25%
Cadmium	mg/kg	0.17	0.19	0.22	0.19	0.03	13%
Chromium	mg/kg	20.93	22.27	27.15	23.45	3.27	14%
Cobalt	mg/kg	1.06	1.49	1.62	1.39	0.29	21%
Copper	mg/kg	20.71	22.89	26.83	23.48	3.10	13%
Lead	mg/kg	88.79	103.22	135.83	109.28	24.10	22%
Manganese	mg/kg	50.28	54.96	66.91	57.38	8.58	15%
Mercury	mg/kg	0.01	0.01	0.01	0.01	0.00	0%
Nickel	mg/kg	9.75	10.06	12.73	10.85	1.64	15%
Tin	mg/kg	1.22	1.21	1.62	1.35	0.23	17%
Thallium	mg/kg	0.1	0.1	0.1			
Vanadium	mg/kg	1.38	1.47	2.09	1.65	0.39	23%
Zinc	mg/kg	56.14	67.13	122.5	81.92	35.57	43%

Test result	Color
Below limit of detection	Orange
Anomaly removed from data	Red

Fuel sample: Recycled Fuel 2 (wood chip)

Trace Metals in Fuel (Determined in Fuel via HF)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	21.9	21.7	22.0	21.87	0.15	1%
Arsenic	mg/kg	11.72	145.56	10.87	11.30	0.60	5%
Antimony	mg/kg	1.47	1.38	1.54	1.46	0.08	5%
Cadmium	mg/kg	1.03	0.15	0.37	0.52	0.46	89%
Chromium	mg/kg	18.78	23.68	19.10	20.52	2.74	13%
Cobalt	mg/kg	0.64	0.59	0.63	0.62	0.03	4%
Copper	mg/kg	61.87	55.82	52.36	56.68	4.81	8%
Lead	mg/kg	39.28	33.92	33.15	35.45	3.34	9%
Manganese	mg/kg	62.34	59.63	59.28	60.42	1.67	3%
Mercury	mg/kg	0.03	0.03	0.05	0.04	0.01	31%
Nickel	mg/kg	2.79	3.08	2.72	2.86	0.19	7%
Tin	mg/kg	3.44	2.20	2.23	2.62	0.71	27%
Thallium	mg/kg	0.12	0.10	0.10			
Vanadium	mg/kg	1.55	1.60	1.87	1.67	0.17	10%
Zinc	mg/kg	80.96	66.37	120.52	89.28	28.02	31%

Trace Metals in fuel (Determined in Ash)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	21.80	22.00	22.10	21.97	0.15	1%
Sample Mass taken for ashing	g	1.0141	1.0038	1.0331	1.02	0.01	1%
Mass of ash obtained	g	0.0143	0.0162	0.0147	0.02	0.00	7%
Ash content	%	1.4	1.6	1.4	1.47	0.12	8%
Arsenic	mg/kg	9.09	10.37	10.60	10.02	0.81	8%
Antimony	mg/kg	1.63	1.58	1.69	1.63	0.06	3%
Cadmium	mg/kg	0.04	0.05	0.04	0.04	0.01	13%
Chromium	mg/kg	19.06	20.82	21.28	20.39	1.17	6%
Cobalt	mg/kg	0.56	0.61	0.68	0.62	0.06	10%
Copper	mg/kg	97.84	48.60	45.79	64.08	29.27	46%
Lead	mg/kg	37.08	40.88	45.79	41.25	4.37	11%
Manganese	mg/kg	48.62	52.69	57.42	52.91	4.40	8%
Mercury	mg/kg	0.01	0.01	0.01			
Nickel	mg/kg	2.62	2.57	2.54	2.58	0.04	2%
Tin	mg/kg	2.32	2.55	2.78	2.55	0.23	9%
Thallium	mg/kg	0.10	0.10	0.10			
Vanadium	mg/kg	1.14	1.25	1.40	1.26	0.13	10%
Zinc	mg/kg	65.27	83.61	135.58	94.82	36.47	38%

Test result	Color
Below limit of detection	Orange
Anomaly removed from data	Red

Fuel sample: Field trial fuel B001 (wood chip)

Trace Metals in Fuel (Determined in Fuel via HF)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	19.4	19.4	19.7	19.50	0.17	1%
Arsenic	mg/kg	0.10	0.28	0.10			
Antimony	mg/kg	0.11	0.10	0.10	0.10	0.01	6%
Cadmium	mg/kg	0.21	0.23	0.26	0.23	0.03	11%
Chromium	mg/kg	2.55	2.65	2.45	2.55	0.10	4%
Cobalt	mg/kg	0.11	0.12	0.15	0.13	0.02	16%
Copper	mg/kg	1.99	1.89	1.95	1.94	0.05	3%
Lead	mg/kg	1.99	1.92	1.99	1.97	0.04	2%
Manganese	mg/kg	138.95	143.16	137.39	139.83	2.98	2%
Mercury	mg/kg	0.01	0.01	0.01			
Nickel	mg/kg	2.18	2.47	2.61	2.42	0.22	9%
Tin	mg/kg	0.11	0.10	0.10			
Thallium	mg/kg	0.10	0.10	0.10			
Vanadium	mg/kg	0.31	0.34	0.34	0.33	0.02	5%
Zinc	mg/kg	32.08	47.66	83.38	54.37	26.30	48%

Trace Metals in fuel (Determined in Ash)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	19.50	19.50	19.60	19.53	0.06	0%
Sample Mass taken for ashing	g	1.0152	1.0264	1.0240	1.02	0.01	1%
Mass of ash obtained	g	0.0077	0.0096	0.0089	0.01	0.00	11%
Ash content	%	0.8	0.9	0.9	0.87	0.06	7%
Arsenic	mg/kg	0.1	0.10	0.10			
Antimony	mg/kg	0.06	0.05	0.06	0.06	0.01	10%
Cadmium	mg/kg	0.03	0.02	0.03	0.03	0.01	22%
Chromium	mg/kg	3.02	1.97	2.28	2.42	0.54	22%
Cobalt	mg/kg	0.19	0.13	0.14	0.15	0.03	21%
Copper	mg/kg	1.55	1.30	1.31	1.39	0.14	10%
Lead	mg/kg	2.32	1.78	1.95	2.02	0.28	14%
Manganese	mg/kg	134.69	93.45	107.47	111.87	20.97	19%
Mercury	mg/kg	0.01	0.01	0.01			
Nickel	mg/kg	2.01	1.40	1.59	1.67	0.31	19%
Tin	mg/kg	0.10	0.10	0.10			
Thallium	mg/kg	0.10	0.10	0.10			
Vanadium	mg/kg	0.44	0.20	0.24	0.29	0.13	44%
Zinc	mg/kg	31.03	33.61	43.18	35.94	6.40	18%

Test result

Below limit of detection

Anomaly removed from data

Fuel sample: Field trial fuel B912 (pellet)

Trace Metals in Fuel (Determined in Fuel via HF)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	7.5	7.6	7.5	7.53	0.06	1%
Arsenic	mg/kg	0.10	0.15	0.10	0.12	0.03	25%
Antimony	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Cadmium	mg/kg	0.06	0.06	0.03	0.05	0.02	35%
Chromium	mg/kg	1.52	1.74	1.40	1.55	0.17	11%
Cobalt	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Copper	mg/kg	1.85	1.57	1.36	1.59	0.25	15%
Lead	mg/kg	1.26	1.37	1.16	1.26	0.11	8%
Manganese	mg/kg	69.60	72.51	67.95	70.02	2.31	3%
Mercury	mg/kg	0.01	0.01	0.01	0.01	0.00	0%
Nickel	mg/kg	1.54	1.47	1.19	1.40	0.19	13%
Tin	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Thallium	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Vanadium	mg/kg	0.29	0.39	0.34	0.34	0.05	15%
Zinc	mg/kg	83.96	92.53	96.19	90.89	6.28	7%

Trace Metals in fuel (Determined in Ash)

Test	Units	Sample 1	Sample 2	Sample 3	mean	sd	rsd
Total Moisture	%	7.50	7.50	7.50	7.50	0.00	0%
Sample Mass taken for ashing	g	1.0248	0.9928	1.0343	1.02	0.02	2%
Mass of ash obtained	g	0.0040	0.0035	0.0037	0.00	0.00	7%
Ash content	%	0.4	0.4	0.4	0.40	0.00	0%
Arsenic	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Antimony	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Cadmium	mg/kg	0.01	0.01	0.01	0.01	0.00	0%
Chromium	mg/kg	1.23	0.78	1.04	1.02	0.23	22%
Cobalt	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Copper	mg/kg	0.38	0.37	0.76	0.50	0.22	44%
Lead	mg/kg	0.41	0.42	1.28	0.70	0.50	71%
Manganese	mg/kg	21.85	21.29	42.53	28.56	12.10	42%
Mercury	mg/kg	0.01	0.01	0.01	0.01	0.00	0%
Nickel	mg/kg	0.38	0.34	0.68	0.47	0.19	40%
Tin	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Thallium	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Vanadium	mg/kg	0.10	0.10	0.10	0.10	0.00	0%
Zinc	mg/kg	20.42	20.80	72.82	38.01	30.14	79%

Test result

Below limit of detection	
Anomaly removed from data	

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