Domestic Boiler Emission Testing

Greater London Authority

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Executive Summary

London Atmospheric Emissions Inventory (LAEI) 2013 identified emissions from domestic gas combustion as the second largest individual source of NO_X pollution in London, after transport emissions. Domestic gas is predicted to replace transport as the largest source of NO_X by 2025.

The LAEI currently uses average emission factors for domestic gas taken from published data on pollutant emission rates provided by the manufacturers for models and types of boilers. This approach has been necessary due to a lack of empirical emission data for domestic boilers operating in-situ.

As the sample size of this study was limited (twelve) the objective was to provide an indication of real world emissions from a selection of gas-fired domestic boilers installed in properties in London. This can then be used to better inform the representativeness of the manufacturers stated emissions performance, or indicate if further testing is necessary.

This real world study did not collect data on particulate matter concentrations due to adverse weather on test days, nor quantify the amount of exhaust gas emitted from the flue, as domestic boilers are not installed with the kind of measurement ports associated with industrial plant. The exhaust emissions from a sample of domestic boilers that were of a range of ages and models were tested and the following information gathered for each boiler:

- concentration of oxides of nitrogen in exhaust (mg/m^3);
- concentration of carbon monoxide in exhaust (mg/m^3)
- oxygen content (% dry);
- carbon dioxide (% dry);
- details of age, boiler type/model, frequency of usage and servicing history.

The results of this small pilot study support the assumption that manufacturer's nominal NO_X emission rates are broadly representative of emissions from installed domestic boilers that are well maintained. No data was gathered on the emissions from boilers that are not operated in line with the manufacturer's servicing recommendations.

Whilst the results from the small sample set also suggest that emissions from gas fired boilers may increase with age, a larger dataset would be required to quantify any trend in emissions rates with age.

The LAEI 2013 methodology involves the calculation of maximum and minimum emission factors (assuming that all boilers emit NO_X equal to the most and least polluting boilers among the fleet respectively), and subsequently uses a mean emission factor. The results of this study support the use of an approach that takes account of both high and low emitting boilers amongst the fleet.

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1. Abbreviations

AQO	Air Quality Objective
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CO	Carbon Monoxide
DEFRA	Department of Environment, Food and Rural Affairs
EF	Emission Factor
EHS	English Housing Survey
EU	European Union
GCV	Gross calorific value
g/GJ	Grams per gigajoule
kg/kWh	Kilograms per kilowatt-hour
kPa	Kilopascal
kt/Mth	Kilotonnes per megatherm
LAEI	London Atmospheric Emissions Inventory
mg	milligram
NAEI	National Atmospheric Emissions Inventory
NCV	Net Calorific Value
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5 micrometre
PM_{10}	Particulate Matter with an aerodynamic diameter of less than 10 micrometre
ppm	Parts per million
RHI	Renewable Heat Incentive

2. Glossary

Term	Meaning Adopted in this Assessment
Air pollutants	Amounts of foreign and/or natural substances occurring in the atmosphere that may result in adverse effects on humans, animals, vegetation and/or materials
Ambient air quality	The concentrations of gases and particles in the atmosphere (tropospheric boundary layer) to which the general population would be exposed, as opposed to the concentration of pollutants emitted by a specific source
Annual mean concentration	The average (mean) of the hourly pollutant concentrations measured or predicted for a one year period
Emission factors	The average emission rate of a given pollutant for a given source, relative to units of activity. Used to model future pollution concentrations under different scenarios
Emissions inventory	The estimation of the amount of pollutants emitted into the air from all sources.
EU limit values	Limits set by the European Union on air quality to be achieved by member states. In the UK this EU Directive is prescribed under the Air Quality Limit Values (England) Regulations (2003) and subsequent amendments. For nitrogen dioxide the annual mean limit value and the annual mean objective value are set at the same concentration.
Gases	Substances present in ambient air in a gaseous state. For example nitrogen dioxide, sulphur dioxide or carbon monoxide.
Gross calorific value	Calorific value is a measure of heating power, and refers to the amount of energy released when a fuel is completely combusted under specific conditions. The Gross Calorific Value considers that the water of combustion is condensed, and so the heat energy in the water is recovered.
National Air Quality Objectives	A series of objectives set by the Government's Expert Panel on Air Quality to be achieved either without exception or with a permitted number of exceedances within a specific timescale. For nitrogen dioxide the annual mean limit value and the annual mean objective value are set at the same concentration
Net calorific value	Calorific value is a measure of heating power, and refers to the amount of energy released when a fuel is completely combusted under specific conditions. The Net Calorific Value considers that the combustion products contain water of combustion to the vapour state, and so the heat energy in the water is not recovered.
Particulate Matter	Solid particles or liquid droplets suspended or carried in the air

3. Introduction

3.1 Domestic Boiler Emissions

Domestic boilers in London are a significant emission source in urban areas, and specifically for NO_X. The London Atmospheric Emissions Inventory (LAEI) 2013[1] recognises that domestic gas combustion emissions are currently the second largest individual source of NO_X pollution in London, after transport and are predicted to replace transport as the largest source of NO_X by 2025. The approach taken by the Greater London Authority (GLA) to quantify these emissions is by use of an emission factor (EF) expressed as the mass of pollutant emitted. as a function of energy consumed from a fuel over a period of time. Commonly reported units for EFs of pollutants from combustion sources are; kt / Mth, kg / kWh and g / GJ. Emission factors allow estimates to be made on emission by mass of pollutants, if consumption of the fuel is known. This provides a more practical alternative to physically measuring emissions from a number of given sources.

Emission factors used in previous versions of the LAEI have been taken from those published annually by the UK National Atmospheric Emissions Inventory (NAEI)[2] or EMEP/EAA[3]. The EFs published by the NAEI have been subject to scrutiny as generic EFs are applied[4,5]. The LAEI 2013[1], however, estimated emissions from domestic gas using borough-specific EFs.

These data were calculated using data on the share of boiler types in London and EFs provided by the manufacturers[6]. This approach has been constrained by the lack of empirical emission data from domestic boilers. In the wake of recently reported disparity between manufacturer reported and real-world emissions from diesel engines in the motor industry, it is worthwhile considering if the current representation of emissions from domestic boilers is appropriate.

The objective of this review is to provide a desk based review of the methods for deriving EFs of pollutants from domestic boilers, and commenting on their applicability to real-life emissions. This aim will be achieved objectively by considering the current London boiler fleet in terms of manufacturer, age and reported EFs, and applicable laws and legislation on behalf of the boiler industry. This report considers only gas-fuelled boilers as the current fleet of boilers in the UK and London is largely fuelled by natural gas.

3.2 Compliance

There is currently no UK legislation regarding emissions from domestic boilers. European Standards, which were originally established to deal with aspects of safety, rational use of energy and fitness for purpose, address the topic of boiler emission classes. European Standard EN15502[7] outlines NO_X-classes relevant to a 'limit concentration' or emission rate of NO_X. Manufacturers are required to state the NO_X class of the boiler in its technical instructions and are presented in Table 1.

[1] LAEI 2013, https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013
[2] NAEI 2015, http://naei.beis.gov.uk/data/ef-all
[3] http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009
[4] DEFRA 2003, Emission factors programme Task 7 – Review of Residential & Small-Scale Commercial Combustion Sources
[5] King, K. and Stewart, R. (2017) NAEI improvement task - Comparing LAEI and NAEI methods for domestic gas combustion. 2017 Air Quality Pollutant Inventory Improvement Task (AQ_IP_2017_41) Prepared by Aether and Ricardo Energy & Environment for Department for Environment, Food and Rural Affairs. Prepared by Katie King of Aether and Robert Stewart of Ricardo Energy & Environment ED62553109 | Issue Number 2 | Date 19/10/2017 [NOT A PUBLISHED REPORT]
[6] Reducing Harmful Emissions from Buildings – Updating LAEI buildings emissions, Report to the GLA (unpublished)
[7] BSI Standards Publication on Gas-fired heating boilers; Part 1: General requirements and tests, EN15502-1:2012+A1:2015

Table 1: BSEN15502 NO_X classes for gas-fired heating boilers

NO_x - Class	NO_X concentration limit (mg/kWh) NCV	NO_X concentration limit (mg/kWh) GCV
1	260	
2	200	
3	150	
4	100	
5	70	
6		56

These NO_X classes now provide means to conform with incoming EU directives, commission regulation 813/2013. This regulation states that from 26 September 2018 emissions of NO_X, expressed as NO_2, from heaters shall not exceed 56 mg/kWh fuel input in terms of gross calorific value (GCV), for gas fuelled boiler space heaters and gas fuelled boiler combination heaters. While NO_X emissions from boilers are of key interest in the scope of emissions inventories, it is generally considered that there is little measurable particulate matter (PM) emission from gas boilers, accordingly there are no current or proposed regulations regarding PM emissions.

Pollutant emissions from domestic boilers contribute towards ambient pollutant concentrations and hence towards compliance with limit values stipulated in the Ambient Air Quality Directive 2008/50/EC[8]. As emissions from these sources impact on local levels as well as national, it is important to also consider local policy. The London Plan[9] outlines improving air quality as one of the key policy objectives. With regard to boilers, the associated supplementary guidance[10] states that new development proposals should meet the minimum standards outlined in document, and that:

> *"Where individual and/or communal gas boilers are installed in commercial and domestic buildings they should achieve a NO_x rating of <40 mgNO_x/kWh."*

[8] Council of European Communities (2008), Ambient Air Quality and Cleaner Air for Europe Directive, 2008/50/EC
[9] Mayor of London (2016). The London Plan, The Spatial Development Strategy for London Consolidated with Alterations since 2011.
[10] Mayor of London (2014) Sustainable Design and Construction, Supplementary Planning Guidance – London Plan 2011

4. Boiler Emissions and Emission Factors in Literature

While this report is timely in the context of an incoming EU directive pertaining to the emission of NO_X from domestic boilers, the issue of EF use and generalisation is not a new one, this section covers published sources of information on EFs for domestic boilers.

DEFRA[4] reported on the topic, covering several fuel sources and pollutants. The report extensively collated studies reporting different EFs of pollutants and compared them to those published by the NAEI. The report included information on EFs from international inventories such as the USEPA's AP-42[11] and the EEA's EMEP-CORINAIR[12], as well as smaller studies which were not employed by the NAEI. The 2003 DEFRA report identified the domestic natural gas combustion sub-section as the largest single sub-section of fuel consumption and the most in need of reviewing EFs. However, the report postulated that no change in the contemporary NAEI EFs was necessary based on the two extra sources of EFs it identified. The DEFRA report concluded by calling for expansion of NAEI EFs allowing a more complete mix of technologies and fuels to be represented and to adopt a calculator based approach whereby aggregate EFs are calculated on the basis of fuel use, knowledge of the equipment pool, and the most up-to-date EF information.

The LAEI 2013 updated its methodology to produce a borough specific inventory for NO_X emissions from boilers[6]. The GLA report by AMEC Environment and Infrastructure UK Limited details the use of boiler type trend data and consideration of boiler ages specific to each London borough. Together with emission data from the manufacturer, this enables the calculation of EFs to represent each borough. Manufacturer emission data, believed to account for around 60% of the London boiler fleet, were used. The results of this report led to the increase in EFs used in the LAEI 2013, relative to the 2010 version which preceded it. The AMEC report considered the age of boilers as having a potential role in elevated emissions of pollutants. However this was not included in the conclusive EF calculation due to there being "little evidence to suggest a function by which emissions can be seen to increase with boiler age". The only available report regarding the effect of age on emissions[13] concludes that there is no considerable difference in VOC or CO emissions with boiler age, but NO_X emissions increased from 53.9 – 62.3 g/GJ (full – maximum load) to 67.3 – 84.6 g/GJ for one conventional boiler.

The small amount of literature from public bodies regarding NO_X emissions from gas-fuelled domestic boilers is similarly reflected in scientific journals. A scoping review of fuel and energy journals from Elsevier undertaken as part of this study found only two articles published on the topic. The more recent of the two serves as an emission inventory for Athens, where EF applicability is questioned[14]. The other reports on a modified EF derivation in Italy based on the boiler emissions from the country's leading boiler manufacturer, in a similar fashion to the AMEC study[15]. The majority of studies published in scientific literature on the topic of boiler emissions concern biomass combustion. The popularity of biomass boilers has spiked since the Renewable Heat Incentive (RHI) put forward by the UK government in 2014. However, in terms of raw numbers, the biomass fleet is a long way behind gas-fuelled boilers and is unlikely to overtake since the RHI is not applied to new build houses.

This section of the report has considered published literature on the topic of emissions from gas-fired domestic boilers. The scarcity of information highlights the difficulty faced in assigning EFs to boilers in a considered way. As the aim of this study is to provide background to facilitate the study of real-life EFs from domestic boilers, the next step in this report is to assess the current boiler fleet in London, taking into account the manufacturer's reported EFs.

[11] AP-42, https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emission-factors
[12] EMEP-CORINAIR, https://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep
[13] ATMOSPHERIC EMISSIONS FROM GAS FIRED HOME HEATING APPLIANCES, ,2007, Cernuschi *et al*
[14] Famela *et al.* 2016. Atmospheric Environment 137, 17-37
[15] Aste *et al.*2013. Energy Policy 53, 353-360

5. Current Boiler Fleet

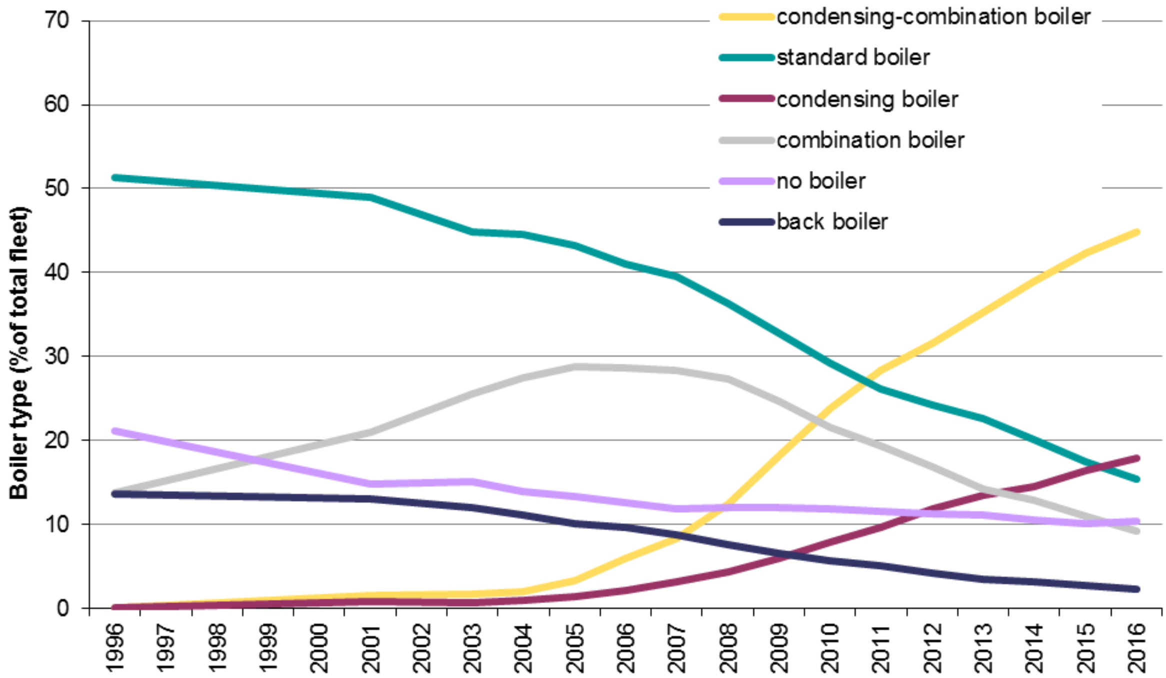
5.1 Boiler Age

The current boiler types by percentage of total fleet in England are detailed in Figure 1. These data were reproduced from the English Housing Survey[16], commissioned by the Ministry of Housing, Communities & Local Government. It is considered to be representative of the London boiler stock.

The data in Figure 1 indicates that since 2011, condensing-combination boilers have overtaken standard boilers as the most prevalent boiler in England, accounting for almost 50% of boilers in the country.

Additionally, condensing boilers have recently (2015) overtaken standard boilers in terms of percentage composition of the fleet. This is informative in the context of conducting a study into real-life emissions testing, as the NO_X emissions from condensing boilers have been shown to be low relative to non-condensing boilers[5]

Figure 1: Boiler types by percentage of total fleet for England between 1996 and 2016



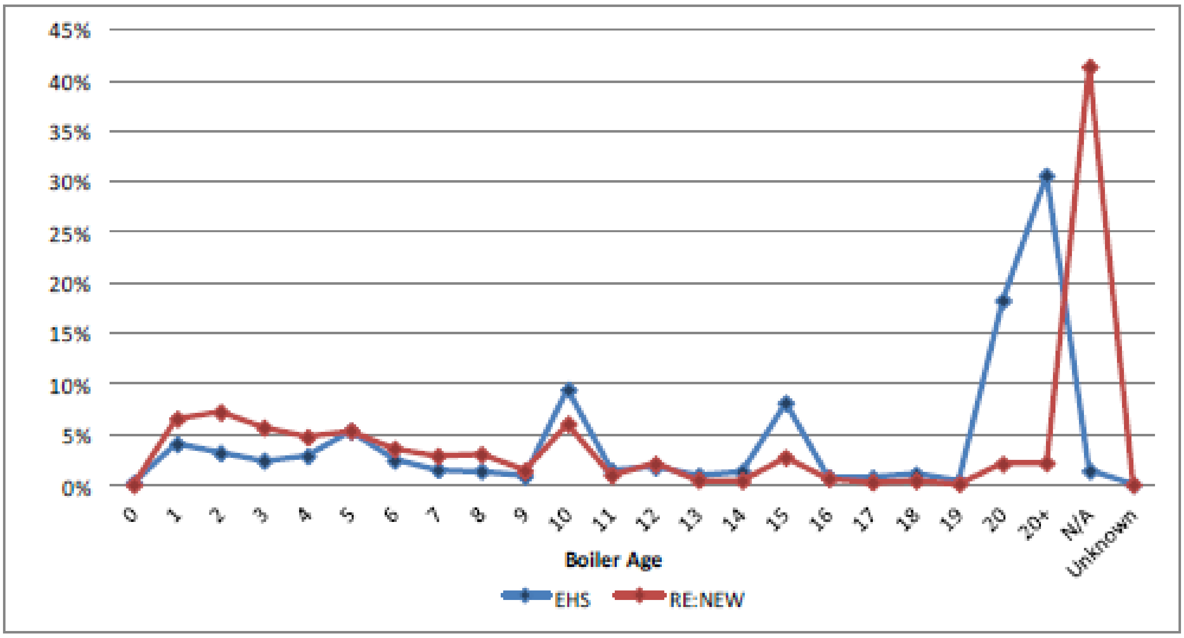
Source: Reproduced from Ministry of Housing, Communities & Local Government, English Housing Survey Headline Report, 2016-17: Section 2 housing stock tables

A further review of the age profiles of boilers in London[5] indicated an age distribution peak of around 2-years, with a gradual decrease to approximately 10-years. Further spikes at rounded numbers (5, 10 and 15 years) were hypothesised to represent estimated values.

These data indicated that over 50% of boilers are likely to be less than 10-years old, although there is thought to be a plateau of older boilers beyond 10-years old.

[16] Ministry of Housing, Communities & Local Government, English Housing Survey Headline Report, 2016-17, available at https://ldeal:www.gov.uk/government/collections/english-housing-survey

Figure 2: Boiler Age Profile in London



Source: From AMEC Environment & Infrastructure Ltd (2015) in partnership with Aether Ltd, based on data from RE:NEW and EHS studies

5.2 Boiler Manufacture and Model Types

A review of the range of domestic boilers currently on the market in terms of specific manufacturer and model indicates that there is a very large number available that are likely to be present in homes across the UK, including London.

Additionally, as discussed above, the age of installed boilers extends beyond 20 years, and so the number of different types that may be present in homes is considerable. The tables in Appendix A contain information on a relatively small number of models of domestic boilers that are likely to be present in London.

The information for models and years in which they were produced has been taken from the Building Research Establishment (BRE) boilers database[17], NO_X emission factors for each model are taken from manufacturers' technical specification as stated. It is noted that there are relatively few published EFs, especially for some of the older generation of boilers. Enquiries were made to popular manufacturers requesting disclosure of NO_X emissions testing methods, specifically to what standards emissions are reported and whether or not the process is done in house. The responses are detailed below:

> ***Vaillant*** *- "We test our products to all required standards and processes including the NO_X calculations. Tests are completed within our extensive R&D facility and then all data is retested / verified by external test bodies. The UK is not directly responsible for the testing information as we only set the original targets and specification that is in line or better than the market requirements."*[18]

> ***Ideal*** *- "Our testing methods to determine NO_X classifications are stringently controlled by the EN standard that we use to demonstrate compliance with the Gas Appliance Directive (GAD) and the Eco-design directive. In the case of our appliances the relevant standards are included in EN 15502-1:2012+A1:2015. Once these tests are conducted they must also be*

[17] Building Energy Performance Assessment database, available at: https://www.ncm-pcdb.org.uk/sap/index.jsp, accessed March 2018

[18] Vaillant (2018), Information requested through customer services, response received from Technical Assistant at Vaillant Derbyshire 12/02/2018

independently verified by a third party notified body (in our case BSI), without their ratification a CE certificate cannot be issued for the appliance.

It should be noted that the officially recognised figure that determines classification of a modulating boiler is a figure weighted to the partial loading of the appliance during its operation. This weighting calculation is once again clearly detailed in the standard."[19]

Worcester Bosch - *"The NO_X measurements are taken as per EN15502-1-2012+A1-2015 clause 8.13. The measurements are taken at partial heat inputs of the maximum central heating heat input.*

The tests are conducted in house but a notified body audits and validates the results".[20]

As detailed in the English Housing Survey[16], the installation of condensing boilers in new-build houses and as replacements has been mandatory since the mid-2000s. It is therefore expected that the trend shown in Figure 1, where the proportion of condensing boilers as part of the English fleet is increasing, is likely to continue. This is a positive step toward the reduction of NO_X emissions and will be a contributor to the anticipated reduction in future EFs for the sector.

5.3 Literature Summary

The literature cited in this document suggests that the derivation of EFs from domestic boilers is in need of review. Whilst the latest LAEI methodology on the topic is much improved relative to past estimates, there still exists a large degree of uncertainty, namely, the degree to which NO_X emissions vary with age of boiler.

It may be expected that emissions as stated by the manufacturer are likely to be accurate for new boilers due to the nature of the in-house testing and the emissions testing from a third party, the BSI. This study will show how applicable the testing protocol is to real life usage and emissions.

The uncertainties regarding this and the degree to which boiler emissions change with age can be addressed with a sampling campaign of boilers currently in use in the London area, whereby NO_X and PM emissions are quantified. Ideally a large number of boilers should be tested and should represent the current boiler stock in terms of age, type, frequency of usage and servicing. In order to compare the actual and nominal emission rates, the boilers tested should have manufacturer specified EFs available.

[19] Ideal (2018), Information requested through customer services, response received from Domestic Technical Support at Ideal Boilers, Hull, 19/02/2018

[20] Worcester Bosch (2018), Information requested through customer services, response received from Technical Support at Worcester Bosch, 19/02/2018

6. Boiler Emission Testing

6.1 Methodology

The objective of this survey was to determine real world emissions from a selection of gas-fired domestic boilers in the London area so that evaluation of the measured values in comparison to the manufacturers stated emissions performance would be possible.

The original target parameters were particulate matter (PM_{10} and $PM_{2.5}$) and oxides of nitrogen. Measurements of oxygen, carbon dioxide and carbon monoxide were added to the scope so that the combustion efficiency of each boiler could also be ascertained. Flue gas flow measurements were intended as a means of calculating mass emissions of each parameter.

John Galbraith undertook the survey on behalf of NEL (TUV SUD Ltd) between 13 and 15 March 2018 [21].

6.2 Measurement techniques

As domestic boilers are much smaller than industrial boilers it prevented the use of NEL's industry standard UKAS accredited test methods. The domestic setting and the absence of facilities normally available in an industrial location determined that the portability and ease of use of the test equipment would be key to the success of the test programme.

However, to ensure the integrity of the test data, NEL employed accepted and well documented measurement techniques and the tests were performed by a suitably qualified and experienced technician. A brief description of the measurement techniques employed is outlined in Table 2.

Table 2: Description of measurement techniques

Parameter	Measurement technique	Equipment type
Oxides of nitrogen	Portable extractive chemical cell analyser. The analyser draws a gas sample through a bank of chemical cell detectors specific to each component of interest.	Testo 350 portable emission analyser (MCERTS approved)
Oxygen		
Carbon dioxide		
Carbon monoxide		
Temperature	Thermocouple	
Particulate Matter (PM_{10} and $PM_{2.5}$)	Portable extractive analyser using light scatter effect to measure PM_{10} and $PM_{2.5}$.	Dustrak 8533
Moisture	Derived from measured oxygen and carbon dioxide content of flue gas plus typical domestic gas composition	N/A
Flow	Direct measurement with pitot tube and manometer	S-type pitot and Testo manometer

6.3 Measurement strategy

In order to obtain a representative sample, a 30-minute test was carried out on each boiler operating on the most strenuous load wherever possible, i.e. heating / hot water setting with boiler in continuous operation. Real-time data from each cell was automatically logged at intervals of 30 seconds. Samples were taken from the flue gas exit of each boiler, as illustrated in Figure 3.

[21] NEL (2018) Domestic Boiler Flue Gas Survey London 13-15 March 2018 – Emissions report

Figure 3: Flue gas analyser set up

Source: From NEL (2018) Domestic Boiler Flue Gas Survey London 13-15 March 2018 – Emissions report

6.4 Sample Group

The sample group was obtained from volunteers employed by AECOM and the Greater London Authority. Due to time constraints, it was recognised that the small nature of the sample group may not fully represent the distribution of boiler types and ages in the London area, but the boilers sampled are considered to be broadly representative of the current situation.

Safe access to a ground-floor location was considered to be essential to minimise health and safety risks, whilst it is also recognised that practical considerations would constrain the size of the sample group.

The sample equipment type are provided in Table 3, and were clustered around the Wimbledon and Croydon areas of south and south-east London in order to collect the greatest number of samples in the limited time period. The locations have been anonymised for inclusion in this report. Emissions tests were undertaken on those boilers listed in Table 3 in bold font.

Table 3: Sample Group

ID	Install Date	Last Service
5	2008	May 2016
14	**Not known**	**Not known**
26	**Not known**	**Not known**
10	**2017**	**Not yet serviced**
12	2017	Not yet serviced
15	1999	2016
16	2016	No service record
17	2013	2016
23	**2017**	**Not known**
2	**2018**	**Not yet serviced**
3	2014	2017
8	2017	Not yet serviced
13	**2008**	**No service record**
18	**Not known**	**< 2015**
11	2017	Not yet serviced
19	Not known	Not known
20	Possibly 2012	2015
21	2007/08	2018
25	Approx. 2016	Not known
27	Approx. 2010	Not known
29	Approx. 2009	Not known
1	2012	2018
6	**2011**	**2018**
7	Not known	Not known
9	**Not known**	**Not known**
22	2016	2017
24	**2004**	**2017**
28	**Approx. 2013**	**Not known**

ID	Install Date	Last Service
23a	2016	Not yet serviced
23b	1999	2017

Note: Those boilers in **bold** font were tested.

6.5 Deviations from scope

The analyser uses a light scatter technique to determine the particulate concentration and therefore requires a relatively dry gas sample. The moisture content of the flue gas from the sampled boilers was too high for the particulate matter analyser to be used. It is noted that particulate matter samples taken from gas-fired industrial boilers typically produce results below the limit of detection for the accredited industry standard test method.

Additionally, representative flow measurements were not possible due to the layout/configuration of the boiler flue gas outlets. The lack of an appropriately positioned sampling port meant that a standard S-type or N-type pitot could not be used.

6.6 Test results

Emissions from 13 boilers were tested by NEL. The results of the tests are presented in Table 4. All the boilers tested are combination-condenser boilers, except for sample 23b, which is non-condensing. This 19 year old boiler is a Class 2 boiler. Whilst the Class of sample 24 is not specified, all other boilers tested are Class 5.

Exhaust flow rates were variable through the sample period, and so a conversion factor published by BREEAM[22] to convert from mass-concentration to mass-energy was used (multiplied by 0.857 to convert mg/m^3 to mg/kWh). The emission rate was also converted back to 0% excess oxygen. These normalised NO_X emission rates are presented in Table 5.

Table 4: Test Results Summary

ID	Age	Class	Flue measurements, Average of 30 Minute Test					
			O_2 % dry	CO_2 % dry	H_2O % wet	Flue Temp. °C	NO_X mg/m^3	CO mg/m^3
28	5yrs	5	5.7	8.7	14.8	57.9	28.6	8.0
24	14yrs	Not spec.	7.7	7.5	13.0	57.1	23.7	15.8
6	7yrs	5	6.2	8.4	14.4	56.8	21.5	7.5
13	10yrs	5	5.3	8.9	15.1	57.1	30.9	12.6
9	<15yrs	5	9.0	6.8	12.0	58.0	162.8	6.1
2	<1yr	5	4.8	9.2	15.5	57.4	49.3	32.8
26	<13yrs	5	5.0	9.0	15.3	55.5	42.7	16.9
18	<13yrs	2	15.3	3.4	6.3	110.8	61.5	20.9
10	1yr	5	5.5	8.8	15.0	43.7	24.1	3.4
14	<13yrs	5	7.2	7.8	13.5	59.6	11.2	3.8
23	1yr	5	5.2	9.0	15.2	51.2	37.0	16.6
23a	2yrs	5	7.2	8.0	13.8	51.2	13.0	3.6
23b	19yrs	2	9.4	6.6	11.6	146.9	90.2	51.0

Note: Boiler 18 is rated as Class 2 to achieve emissions rate of 200 mg/kwh, although product literature states that 30 mg/kwh is achievable.

[22] BREEAM (2016) International New Construction Technical Manual, SD5075 – 1.1:2013; section 12 Pollution , Pol 02 Emissions. Available at: http://www.breeam.com/BREEAMInt2013SchemeDocument/content/12_pollution/pol_02.htm

6.6.1 Comparison to Emission Factors

Of the thirteen boilers, the manufacturer's nominal NO_X emission rate could not be identified for the boiler 24, leaving the sample size for comparison of emission rates at twelve boilers. Conversion to normalised NO_X emission rates are presented in Table 5. Emissions from six of the boilers were below the manufacturer's nominal NOx emission rate (where 'NO_X mg/kWh % difference' < 100%), whilst six of them were above (where 'NO_X mg/kWh % difference' >100%),

The greatest percentage difference was recorded for boiler 18, with more than six times the manufacturer's nominal NO_X emission rate. The emissions test showed that this boiler was operating with a high percentage of excess oxygen; 15% dry O_2, >200% excess O_2 (Table 4 and Table 5). Data collected for the sample group included installation date and date of last service, however the age of this boiler was not provided. With reference to Table A1, the boiler must be 13 years old or younger (manufactured from 2005-present), and it has not recently been serviced. As such it is reasonable to conclude that the boiler was not operating efficiently.

For the remaining boilers, the percentage difference between the normalised NO_X emission rate derived from the tests and the manufacturer's nominal emission rates range from 33% to 177%, with an average of 94%.

The distribution of the measured emissions compared to the stated manufacturer rates broadly indicates that the worst-performing units are those that have not been serviced regularly. Where units have been serviced, this broadly correlates with lower emissions regardless of the age. This indicates that the maintenance of the units is a potentially significant factor.

It is recognised that the sample group may be biased towards newer boilers, and so the effects of long-term servicing may have greater importance to the emissions from the London-wide fleet. The fleet age is discussed in Section 5.1.

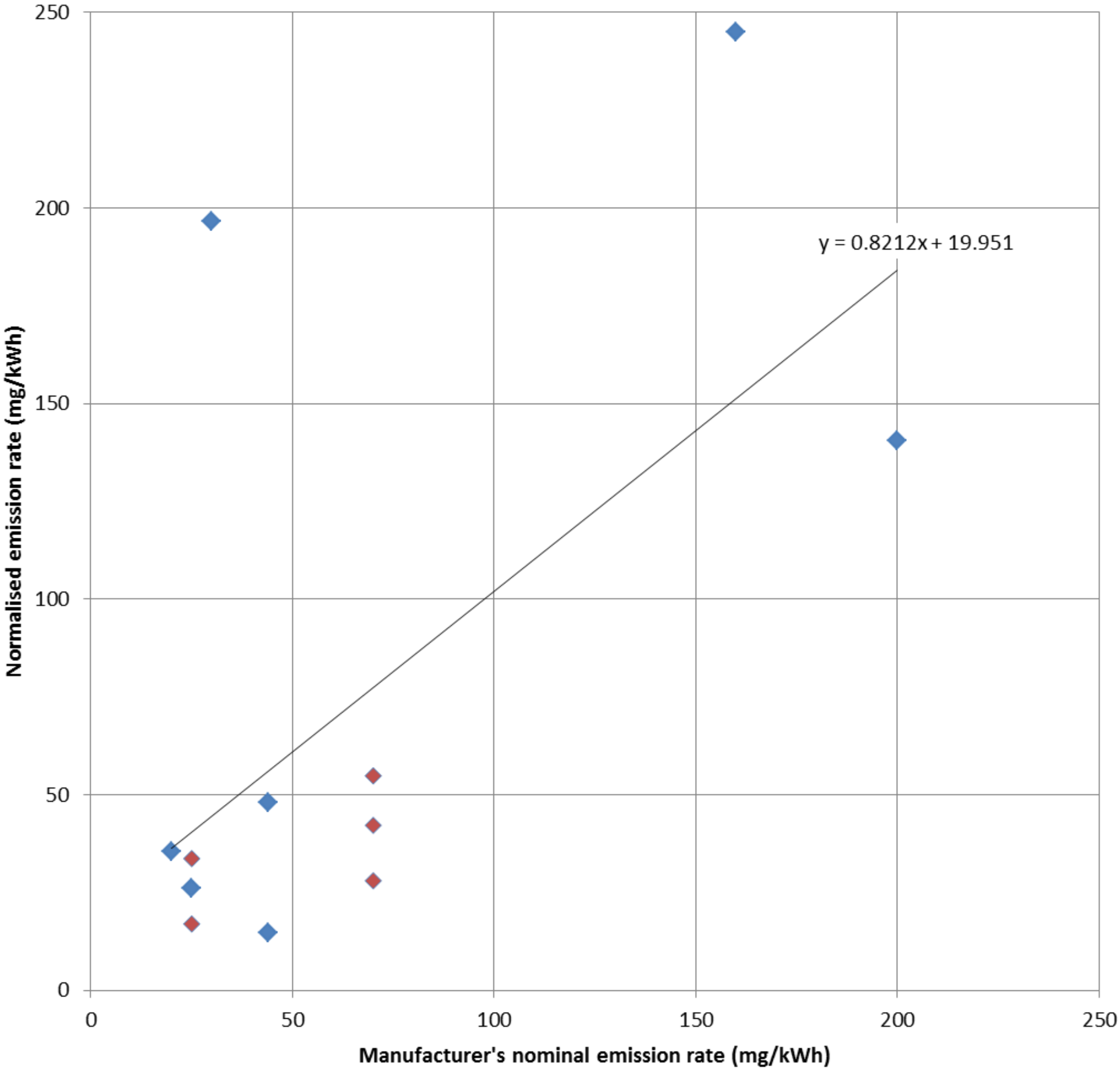
Figure 4 shows the relationship between the manufacturer's nominal emission rate and the measured emission rate for the remaining 11 boilers. The linear relationship (line of best-fit) indicates that overall emissions from the 11 boilers are on average slightly below those stated by the manufacturer.

Table 5: Comparison of NOx emission rates

ID	Calculated factor	Calculated O_2 % excess	Normalised NO_X mg/kWh	Manufacturer's nominal emission rate mg/kWh	NO_X mg/kWh % difference
28	1.4	39.3	33.7	25	135%
24	1.6	37.5	32.2	Unknown	-
6	1.4	30.6	26.2	25	105%
13	1.3	41.4	35.5	20	177%
9	1.8	285.9	245.0	160	153%
2	1.3	64.0	54.8	70	78%
26	1.3	56.1	48.1	44	109%
18	3.7	229.5	196.7	30*	656%
10	1.4	32.7	28.0	70	40%
14	1.5	17.1	14.6	44	33%
23	1.3	49.3	42.2	70	60%
23a	1.5	19.8	17.0	25	68%
23b	1.8	163.9	140.5	200	70%

Note: Boiler 18 is rated as Class 2 to achieve emissions rate of 200 mg/kwh, although product literature states that 30 mg/kwh is achievable.

Figure 4: Normalised and manufacturer's nominal NO_X emission rate (11 boilers)



Note: Red <5 years old, blue >5 years old

Five of the boilers tested were new – one or two years old (IDs 2, 10, 23, 23a, 23b). Table 5 shows that all of these emitted NO_X at a rate below that stated by the manufacturer. Three of the boilers tested were known to be 5 years old or more (IDs 28, 6, 13 – 5, 7 and 10 years old respectively). Table 5 shows that these boilers emitted 35%, 5% and 77% more than the manufacturer's nominal emission rate, respectively. Whilst the sample size is small, this is consistent with the theory that emissions from serviced boilers increase with boiler age.

7. Conclusions

Concentrations of NO_X emitted from 13 boilers in the London area were measured. The age of the boilers ranged from new to 14 years whilst for some the age and/or service history was unknown. Although the sample size was small, the composition was considered to be broadly representative of the London gas-fired boiler fleet.

For twelve of the boilers, the measured NO_X concentrations were converted to NO_X emission rates in order to directly compare against the manufacturer’s nominal emission rate for each individual boiler. With the exception of one boiler, measured and nominal emission rates compared well, with an average of 94% agreement.

These results suggest that it is reasonable to assume a manufacturer’s nominal NO_X emission rate to represent emissions from a boiler. Using these figures, however, will not necessarily account for emissions from those boilers that are not operating in line with the manufacturer’s servicing recommendations.

Whilst the results from the small sample set also suggest that emissions from gas fired boilers increase with age, it has not been possible to quantify this increase.

The LAEI 2013 methodology involves the calculation of maximum and minimum emission factors (assuming that all boilers emit NO_X equal to the most and least polluting boilers among the fleet respectively), and subsequently uses a mean emission factor. The current study further supports this approach that takes account of both high and low emitting boilers amongst the fleet.

Whilst it was not possible to measure particulate matter due to the high moisture content of the flue gas, it is noted that particulate matter samples taken from gas-fired industrial boilers typically produce results below the limit of detection for the accredited industry standard test method.

7.1 Further Work

The preliminary findings of this report could be further supported by an additional, larger study. This could include emissions testing from a larger sample set, across a larger geographical area of London. In order to be able to try to quantify the change in emissions with boiler age, the age and service history of all of the boilers will need to be known. This could also allow for analysis of the relationship between the frequency of boiler maintenance and pollutant emission rates.

Unfortunately it was not possible to measure particulate matter due to the wet weather on the test days. For future tests, the flexibility to change test days would be helpful in order to mitigate potentially wet weather.

Appendix A Published Emission Factors for Current and Recent Boilers

Table A1: Manufacturer and model data for Condensing - Combination Boilers, including years of production and reported NO_X EFs

Model	Years Produced	NO_X Emission Factor
	Vaillant	
EcoTEC Exclusive	2016-present	Class 6
EcoTEC Plus	2004-present	Class 5
EcoTEC Pro	2004-present	Class 5 – 27.3 or 33.4 mg/kWh depending on model
EcoFIT Pure	2016-present	Class 5
EcoMAX	1999-2000	Not specified
Home Combi	2015-present	Class 5
	Viessmann	
Vitodens 100	2014-2016	Class 5 (<39 mg/kWh)
Vitodens 050	2014-present	Class 5 (<39 mg/kWh)
Vitodens 200	2016-present	Class 5 (<39 mg/kWh)
	Worcester-Bosch	
Greenstar i	2005-present	44 mg/kWh
Greenstar Si compact	2005-present	25 mg/kWh
Greenstar CDi classic	2005-present	30 mg/kWh
Greenstar CDi highflow	2008 - present	23 mg/kWh
26	1998-2002	Class 3
533	2015-present	Not specified
	Baxi	
100	2016-present	Class 5
200	2016-present	Class 5 (38-40)
400	2016-present	Class 5 (38-40)
600	2017-present	Class 5 (28.3-29.7)
Avanta	2008-2015	Not specified
Duo-Tec	2011-2015	Class 5 (20-23)
EcoBlue Advance	2014-present	Class 5 (20-24)
EcoBlue +	2015-present	Class 5 (20-24)
Platinum	2005-2007	Class 5 (20-23)
	Vokera	
Evolve C	-present	Class 6
Linea One	-present	Class 5
Unica I	-present	Class 5
Vision C	-present	Class 5
Compact A	-present	Class 5
	Glow Worm	
Energy	-present	Not specified
Ultimate	-present	Class 5

Model	Years Produced	NO_X Emission Factor
Energy 35 Store	-present	Not specified
Betacom3	-present	Class 5
Easicom 3	-present	Class 5

Table A2: Manufacturer and model data for Combination Boilers, including years of production and reported NO_X EFs.

Model	Years Produced	NO_X Emission Factor
	Vaillant	
Tubomax	1995-2000	Not specified
AquaPlus	2003-2010	Not specified
Combicompact	Not specified-1996	Not specified
T3W	Not specified-1988	Not specified
	Worcester-Bosch	
24	1997-2002	Class 3
25	2000-2001	Class 2
28	1997-present	Class 2
80	1999-2001	
	Baxi	
Combi 105e	2001-2011	Class 3
80 Maxflue	2001-2003	Class 3
133 HE	2004-2007	Not specified
EcoBlue		Class 5 (16-24 mg/kWh)
Megaflo		Class 5 (20-29)

Table A3: Manufacturer and model data for system Boilers, including years of production and reported NO_X EFs.

Model	Years Produced	NO_X Emission Factor
	Vaillant	
Solo 3	2001-2006	260
	Vaillant	
EcoFIT	2016 - present	Class 5
EcoMAX	1995-2000	Class 5
Home Regular	2015-present	Class 5
Thermocompact	Unspecified – 1996	Not specified
	Ideal	
Concord CXSD	1997-2002	150
Concord CXD	1995-2000	150
	Viessmann	
Vitodens 100	1999-2005	Class 5 (<39 mg/kWh)
Vitodens 200	Unspecified - 2005	Class 5 (<39 mg/kWh)
	Worcester-Bosch	
15 CBi	2000-2001	260
Greenstar Ri	2003- present	35-59 mg/kWh
14/19 CBi	2001 – present	260
24 CBi	2000-2001	260

Model	Years Produced	NO_X Emission Factor
	Vokera	
Evolve S	-present	Class 6
Mynute I	-present	Class 5
Mynute 35HE	-present	Class 5
Vision S	-present	Class 5
	Glow Worm	
Energy	-present	Not specified
Ultimate	-present	Class 5
Easicom 3	-present	Class 5