Test report

Measurement of emissions from diesel fired heaters, January - March 2021

DANISH TECHNOLOGICAL INSTITUTE

Requested by

Movia Public Transport (Trafikselskabet Movia)

Performed by

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List of abbreviations

B7:	Conventional diesel mixed by 7% biodiesel and 93% fossil diesel
ECU:	Electronic Control Unit which controls the electronical functions in the bus
ETM:	Environmental Test Manual – for third part testing of the heaters
HVO100:	100% Hydrotreated Vegetable Oil - diesel made by e.g. slaughterhouse waste or edible oils extracted from plants, such as olives, sunflowers and soybeans
PM:	Particulate Matter
PN:	Particle Number
PTOs:	Public Transport Operators

1. Introduction

Movia Public Transport (Trafikselskabet Movia) has commissioned Technological Institute to perform a study of emissions from diesel fired heaters installed in a number of Euro VI and battery electric buses used to deliver bus services in Movia's contracts with Public Transport Operators (PTOs). Moreover, Technological Institute was commissioned to prepare an Environmental Test Manual (ETM) for control of environmental performance of diesel heaters. The ETM is reported in a separate report.

Emissions from the bus engines are more strictly regulated than emissions from the heaters. When type approved, heaters have more lenient emissions requirements than the bus engines and there is no following up when the heaters have been set to operation.

Technological Institute has been requested to measure emissions and combustion efficiency on a number of bus heaters to make an overview of the condition of the heaters.

The study has been co-funded by the Horizon 2020 Programme of the European Union.

2. Summary

Below a summary of the study in English and Danish.

2.1. English

This report describes testing of a number of bus heaters, in buses owned and operated by PTOs with contracts on public bus services within Movia's area (Zealand and islands).

In the project, 64 buses from 7 PTOs were tested[1]. The buses were equipped with 5 different heater models and used two different fuels – either HVO biodiesel (HVO100) or conventional diesel (B7). The tests included measurement of CO_2, CO, NO_x and particle emissions and heater combustion efficiency.

The tests were carried out in situ at the PTOs' bus depots, January to March 2021. Two test methods were used. One method to simulate real-life operation, where the heater starts and stops automatically according to coolant temperature, and one method to test the heaters by manually turning them on and off and measuring at a well-defined time in each on-period.

The study revealed that it can be challenging to test in situ. Partly because the buses are difficult for the PTOs to manage without during a normal working day and partly because measuring outside a lab can be challenging to do with precision and consistency each time.

One of the main challenges test-wise was that the heater controller and the bus's electronic control unit (ECU) influence differently on how the heater operates from one bus to another.

Also, the fact that the exhaust pipes were different in design and often difficult to mount the test equipment on was a challenge.

Finally, the test equipment was challenged in the demanding conditions, which in some cases were temperatures below 0ºC and snow, rain and wind.

The test results should therefore not be seen as exact laboratory results, but as reasonable indicators on how the heaters perform real life.

[1] Two of the tested buses operate outside Movia's area.

The tests show very varying results. Some heaters perform with very low CO and particle emission, even below Heavy-Duty Euro VI[2] limits, and some heaters perform in the other end of the scale with very high CO and particle emissions.

Soot emission also shows very varying results and roughly follows the variation in the particle emission. NO_x emission, however, is constantly low and below Euro VI limits in all tests.

The exhaust gas temperature is generally high from most of the heaters. This has a negative influence on the combustion efficiency and is due to dirt in the convection part in the heater.

The difference in efficiency between the best and the poorest performing heater roughly gives a difference in fuel consumption around 25% or 1 litre pr. hour.

Measurement results have been compared across operators, age of heaters, heater models and fuels. The compared measurements have been gas emissions, particle emissions, exhaust gas temperatures and combustion efficiency.

The comparison shows that NO_x levels are almost the same across all measurements.

CO varies significantly, both with operator, heater age and heater model. No significant difference is seen between the two fuels regarding CO.

Particle emissions show the same picture as CO, except that it is extremely fuel dependent. Particle emissions are significantly lower from HVO100 than from conventional diesel.

Combustion efficiency does not vary with age of the heater, but it varies with the other parameters.

The overall impression is that a significant number of the heaters need to be serviced. They need cleaning and adjustment and some of them probably need a nozzle replacement or other replacement in the fuel supply.

High exhaust temperatures and CO_2 level (combustion air supply) out of range are the most common problems and apply for more than $^2/_3$ of the tested heaters.

Some PTOs have a service maintenance plan for their heaters and some also manually operate the heaters in the summertime to assure that they keep working properly, also when they have minimum runtime. Most PTOs do not have a service maintenance plan but repair the heaters when broken.

The project shows that some PTOs could need training of their mechanics in how to service the heaters and make sure they work optimally.

A simple method for regularly test of the heaters has been developed and tested in the project. The method measures CO_2, CO, soot and temperatures to test if the heater is properly serviced and adjusted. The method can be used both by the mechanics in the bus workshops and by an independent measuring body.

2.2. Danish

Denne rapport beskriver test af et antal busfyr i busser, der ejes og drives af busoperatører med kontrakter om offentlig busdrift indenfor Movias område (Sjælland og øer).

I projektet blev 64 busser fra 7 busoperatører testet. Busserne var udstyret med 5 forskellige fyrmodeller og anvendte to forskellige brændstoffer – enten HVO biodiesel (HVO100) eller konventionel diesel (B7). Testene omfattede måling af CO_2, CO, NO_x og partikelemissioner og forbrændingsvirkningsgrad.

[2] Strictest EU emission limits for Heavy-Duty diesel Truck and Bus Engines (steady-state testing)

Testene blev udført på operatørernes garageanlæg fra januar til marts 2021. Der blev anvendt to testmetoder. Én metode til at simulere normal drift, hvor fyret starter og stopper automatisk afhængig af kølevæsketemperaturen, og en metode til at teste fyrene ved manuelt at tænde og slukke for dem og måle over et veldefineret tidsrum i hver tændingsperiode.

Undersøgelsen afslørede, at det kan være udfordrende at teste in situ. Dels fordi busserne er vanskelige for operatørerne at undvære i løbet af en normal arbejdsdag, og dels fordi målinger uden for et laboratorium kan være udfordrende at udføre præcist og ensartet hver gang.

En af de største udfordringer testmæssigt var, at fyret og bussens elektroniske styreenhed (ECU) regulerer fyret forskelligt fra den ene bus til den anden.

Derudover var udmundingen på udstødningsrørene meget forskelligt konstrueret og ofte vanskelig at montere testudstyret på.

Endelig blev testudstyret udfordret under de krævende forhold, som i nogle tilfælde var temperaturer under 0 ºC samt sne, regn og vind.

Testresultaterne skal derfor tages med forbehold og må ikke opfattes som nøjagtige laboratorieresultater, men som gode indikatorer for, hvordan fyrene fungerer i drift.

Testene viser meget forskellige resultater. Nogle fyr har meget lave CO- og partikelemissioner, selv under Heavy-Duty Euro VI-grænserne[3], og nogle fyr ligger i den anden ende af skalaen med meget høje CO- og partikelemissioner.

Sodemissionen viser også meget varierende resultater og følger omtrent variationen i partikelemission. NO_x-emissionen er imidlertid konstant lav og under Euro VI-grænser i alle tests.

Udstødningstemperaturen er generelt høj fra de fleste fyr. Dette har en negativ indflydelse på forbrændingsvirkningsgraden og skyldes snavs i konvektionsdelen i fyret.

Forskellen i virkningsgrad mellem bedst og dårligst præsterende fyr giver en forskel i brændstofforbrug på rundt regnet 25 % eller ca. 1 liter pr. time.

Måleresultaterne er sammenlignet på tværs af operatører, alder på fyrene, fyrmodeller og brændstoffer. De sammenlignede målinger er gasemissioner, partikelemissioner, udstødningsgastemperaturer og forbrændingsvirkningsgrader.

Sammenligningen viser, at NOx-niveauerne stort set er de samme på tværs af alle målinger.

CO varierer betydeligt, både med operatør, fyrets alder og fyrmodel. Dette gælder ikke med brændstoffet, hvor der ingen væsentlig forskel ses mellem de to brændstoffer.

Partikelemissionerne viser det samme billede som CO, bortset fra at de er ekstremt brændstofafhængige. Partikelemissionerne er betydeligt lavere fra HVO100 end fra konventionel diesel.

Forbrændingsvirkningsgraden varierer ikke med fyrets alder, men den varierer med de øvrige parametre.

Det samlede indtryk er, at en stor del af fyrene har behov for service. De trænger til rensning og justering, og nogle af dem kræver sandsynligvis udskiftning af dyse eller andre komponenter i brændstoftilførslen.

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[3] Strengeste EU-emissionsgrænser for lastbil- og busmotorer (steady-state test)

Høje udstødningstemperaturer og CO_2-niveauer (forbrændingsluftmængde) uden for det optimale område er de mest typiske problemer og ses ved mere end $^2/_3$ af de testede fyr.

Nogle operatører har en servicevedligeholdelsesplan for deres fyr, og nogle kører med fyrene manuelt om sommeren for at sikre, at de fungerer optimalt, også hvor de ellers har minimal driftstid. De fleste operatører har ikke en serviceplan, men reparerer fyrene, når de går i stykker.

Projektet har vist, at nogle operatører kunne have gavn af uddannelse af deres mekanikere i, hvordan man servicerer fyrene og sørger for, at de fungerer optimalt.

I projektet er der udviklet og testet en simpel metode til regelmæssig test af dieselfyr. Metoden måler CO_2, CO, sod og temperaturer for at teste, om fyret er korrekt serviceret og justeret. Metoden kan bruges både af mekanikerne i værkstederne og af en uvildig måleinstans.

3. Measurements

Below a description of testing conditions, setup and test methods.

3.1. Test setup and conditions

The tests have been performed January to March 2021. 7 PTOs with 13 bus depot premises have participated. 2-6 buses have been tested at each location.

All together, heaters in 64 buses have been tested. 52 have been tested with method 1, and 12 have been tested with method 2. See description of the methods below.

8 different Euro VI bus models and 5 different heater models have been tested.

The fuel has been either conventional diesel (diesel B7) or HVO biodiesel (HVO100).

The heaters have been tested real life and in operating buses. Some buses have been tested early morning before operating, some during the day between operating and some late day after operation.

Some have been tested outside on the bus depot parking spot and some inside the washing workshop. If tested inside, the doors to the workshop have been open to secure a low ambient temperature.

Measured parameters:

- Gas emissions - CO_2, O_2, NO_x and CO
- Particle emissions - PM and PN
- Temperatures - Exhaust gas, ambient, bus cabin and coolant
- Soot - Soot was only measured in test method 2
- Other - Battery voltage, ambient pressure, and relative humidity

3.2. Measurement equipment and setup

Gas emissions have been measured with TESTO-350 handheld instrument. Particle emissions have been measured with Pegasor Mi3. Temperatures have been measured with TESTO-350 Weather station or thermocouples type K. Pressure and humidity have been measured with a weather station and battery voltage has been measured with a multimeter.

See measurement equipment list below.

Table 1. Test equipment

Id	Type	Equipment	Range
270-A-2436	Datalogger	HP34970A	-
153444	Particles PM	Pegasor Mi3	0-300 mg/m^3
153444	Particles PN	Pegasor Mi3	6e2-1,3e9 #/cm^3
194336	Gas emission NO	TESTO 350	0-3000 ppm
194336	Gas emission NO_2	TESTO 350	0-500 ppm
194336	Gas emission CO	TESTO 350	0-3000 ppm
194336	Gas emission CO_2	TESTO 350	0-40 Vol. %
194336	Gas emission O_2	TESTO 350	0-25 Vol. %
194336	Exhaust gas temperature	TESTO 350	÷40-1000 ºC
-	Soot number	Buhl Bønsøe	-
8603	Weather station	Rosenborg	÷40-60 ºC
-	Thermoelement	Type K	÷50-800 ºC
270-A-2493	Voltmeter	Fluke 177 multimeter	0-30 V

Combustion efficiency has been determined by subtracting the exhaust gas loss in %. Exhaust gas loss has been calculated on basis of CO, CO_2 and the exhaust gas temperature.

The individual on-periods have been determined using exhaust gas temperature and CO_2 as indicators. Peak emissions and average emissions have been measured for each on-period.

3.3. Measuring real life – challenges

Measuring on bus heaters real life can be challenging.

Some buses have not been accessible on the day for the measurement, either because of breakdown or that they have had to replace broken-down buses. Some were almost ready for testing and then pulled out in sudden need of operation.

Weather has been very different, varying from quiet, sunny and 10ºC to windy, snowy and below zero.

Some buses have been in operation right up to test with the heater warm and in good operating condition, and others have been cold and not in operation since the day before.

One of the main challenges test-wise has been that the heater controller and the bus ECU influence differently on how the heater operates from one bus to another.

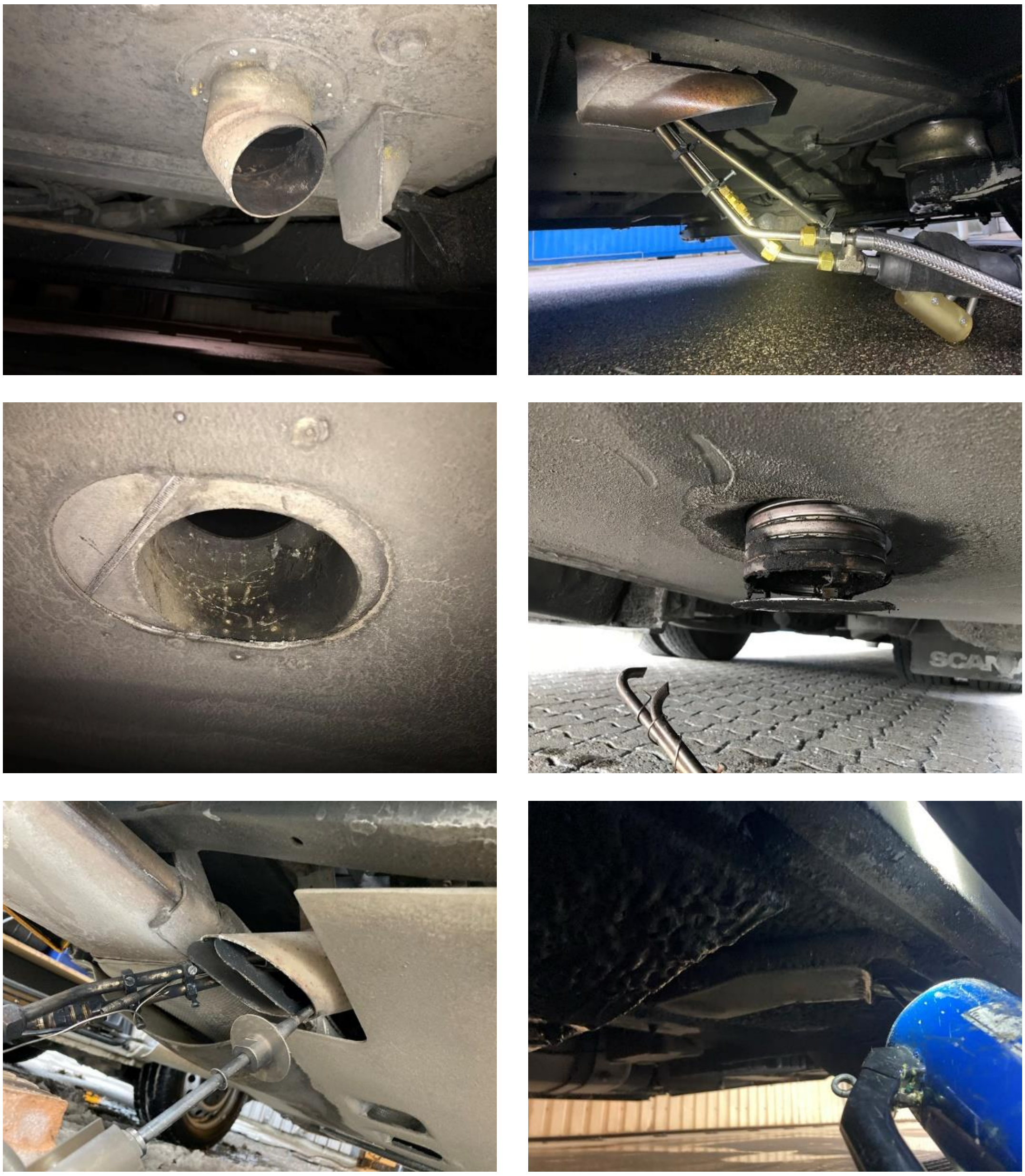
Also, the fact that the exhaust pipes are very different in design and often difficult to mount the test equipment on has been a challenge.

Finally, the test equipment has been challenged by the demanding weather conditions.

The test results should therefore not be seen as precise laboratory results but as reasonable indicators on how the heaters perform real life.

The photos below show examples of the difference in exhaust pipe designs.

Picture 1-6. Difference in exhaust pipe design



As the pictures show, the exhaust pipe can have many different shapes. This can be a challenge when mounting the test equipment.

Earlier projects have indicated risk of layering at the exhaust pipe since the distance from the combustion is relatively short. This means that the emissions are not necessarily fully mixed at the outlet.

Therefore, before the tests, it was planned to make a full flow measuring pipe around the tailpipe. However, as the pictures of the varying outlets show, this was not possible. Instead, small pipes from the measurement equipment were placed inside the exhaust pipe, app. 50mm inside the outer edge.

In the first tests, measurements were performed to check if there was layering. No such was found but note that this can be an uncertainty factor.

It was also checked that gasses, particles and temperatures were measured representatively and that the measurement equipment did not affect the heater performance, e.g. increased the CO_2 because of obstruction of some of the exhaust pipe inner area, and thereby reducing air supply. No such impact was found either.

In some cases, it was necessary to wreck obstructions in the exhaust pipe apart to have the pipes for the measuring equipment properly in place.

3.4. Measurement procedure

Movia has requested a general overview of the condition of the heaters and how they perform real life. Therefore, the heaters were tested in their current condition, meaning that they were not cleaned or adjusted before the tests.

Two methods were used to test the heaters. One to simulate real life operation as closely as possible and one to test the heaters more as in a bench test.

The second method is intended to be used in future regular tests of the heaters.

The methods are described below.

Real lift test cycle (RLTC)

The test is performed outdoors on the PTO's bus depot premises with the engine idling or with a charger connected to the 24V battery. If a charger is used, it must be ensured that the voltage is sufficient and at least what the manufacturer of the heater recommends.

If possible, the measurement is performed without pre-heating the heater.

Measurement is performed at heater settings used by the operator in daily operation. The heater is not adjusted before or during the measurement.

NO_x ($NO + NO_2$), CO, CO2, O_2, PM (particle mass) and PN (particle number) and exhaust gas temperature are measured and logged continuously. Battery voltage, cabin temperature and ambient temperature are measured at minimum as point measurement, at the start, in the middle and at the end of the measurement period.

The cabin target temperature in the bus is set to 18 - 22ºC for diesel buses and 16 - 22ºC for electric buses before the measurement is started.

The measurement starts when the heater is turned on.

When the measurement starts, the doors in the bus are opened for half a minute and closed again. After three minutes they are opened again and closed after half a minute. This continues throughout the full measurement period.

The measurement extends over 45 minutes after the heater is turned on.

After the measurement, photos of the heater and exhaust pipe and observations regarding measurement data are taken, and the performance and condition of the heaters are noted.

Finally, the equipment is dismantled, and the bus is returned to operation.

Environmental Test Manual Procedure (ETMP)

The measurement is performed on the PTO's bus depot premises with the engine idling or with charger connected to the battery. If a charger is used, it must be ensured that the voltage is sufficient and at least what the manufacturer of the heater recommends.

A total of four on-periods are run through. In each period, the heater is started manually and runs until the exhaust gas temperature and CO are stable.

The first on-period counts as pre-test while the last three are valid.

To remove the heat produced, the desired temperature in the bus is set to max, the cabin fans are set to max and the doors are opened.

The following parameters are measured

- NO_x CO, and CO_2 (NO_x only in this project, not in future tests)
- PM and PN (only in this project, not in future tests)
- Soot number
- Exhaust gas temperature, coolant temperature and ambient temperature
- Voltage if the measurement is made with a charger connected to the 24V battery

During each on-period, the heater runs for 6 minutes or until CO and exhaust gas temperatures over the last 20 seconds have not uniquely changed more than 1%. A soot sample is made while CO is stable.

When measurements are finished, the equipment is dismantled, and the bus is returned to operation.

Heater cycles

In the RLTC method (method 1), the heater and its controller are regulated according to the coolant temperature. The coolant temperature is affected by opening and closing the doors, the initial temperature in the bus cabin, the ambient temperature and the combustion efficiency of the heater.

This gives a wide range of heater cycles.

In the ETMP (method 2), the heater controller is not supposed to intervene. Here the heater is turned on and off before the coolant temperature reaches the thermostat switch off temperature, and therefore, in theory, this should result in comparable conditions from test to test.

Examples

Examples on results from the two test methods are shown below.

First, two examples of the most common heater cycles when testing with method 1 are shown. The cycles are illustrated by CO_2, CO and temperatures.

CO_2 and exhaust gas temperature show when the heater is on.

Example 1

In the first example, the heater has one constant on-phase during the complete test period. The water temperature shown on the second graph never reaches the thermostat switch off temperature. 11 of the tested heaters/buses showed this behaviour.

Figure 1. Test example no. 1 – gas emissions

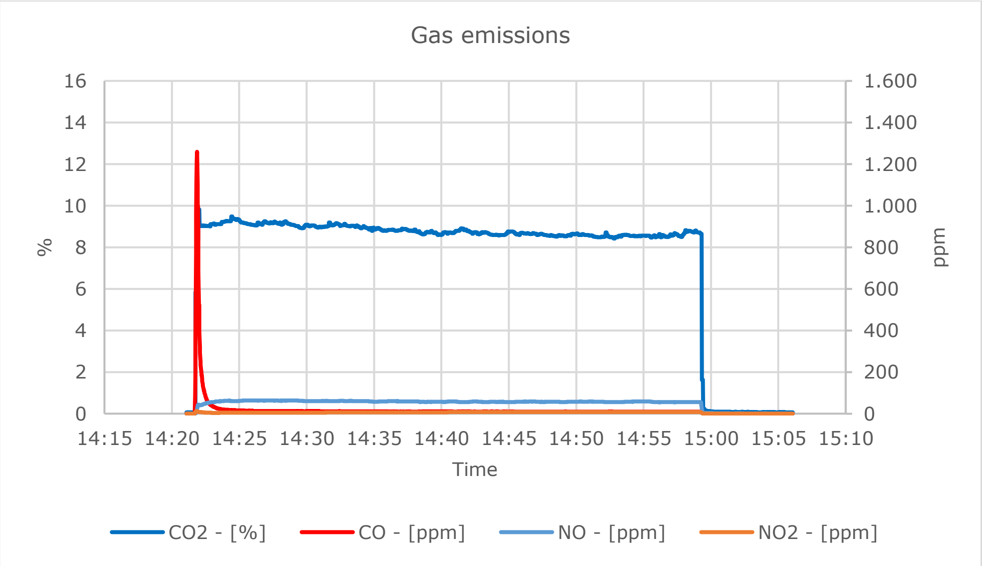
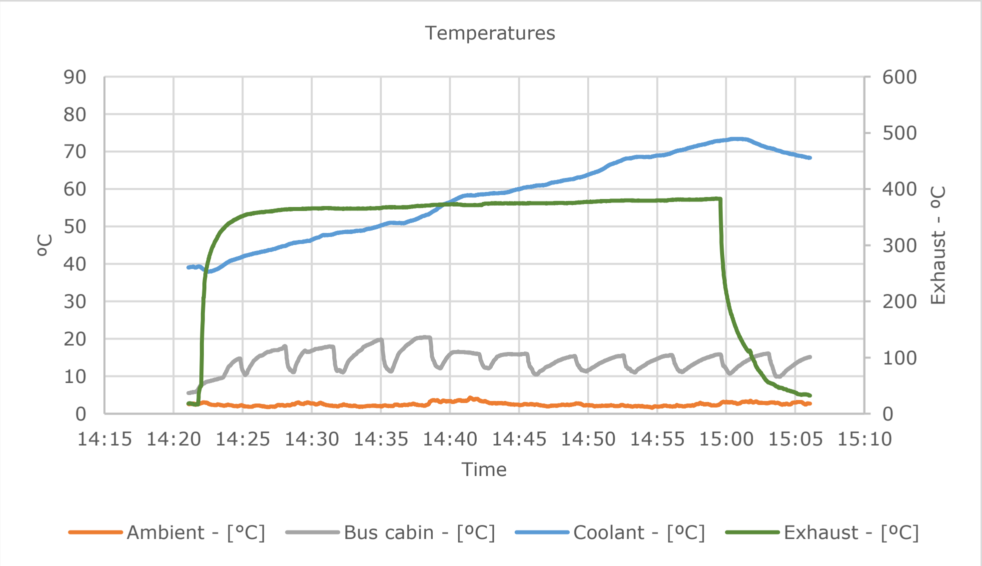


Figure 2. Test example no. 1 – temperatures



Example 2

In the second example, the heater reaches the thermostat switch off temperature in 12 minutes. Hereafter, the thermostat turns the heater off and on to keep the water temperature at around 70ºC. This gives 15 on-phases. 10 of the tested heaters/buses showed a similar behaviour.

Figure 3. Test example no. 2 – gas emissions

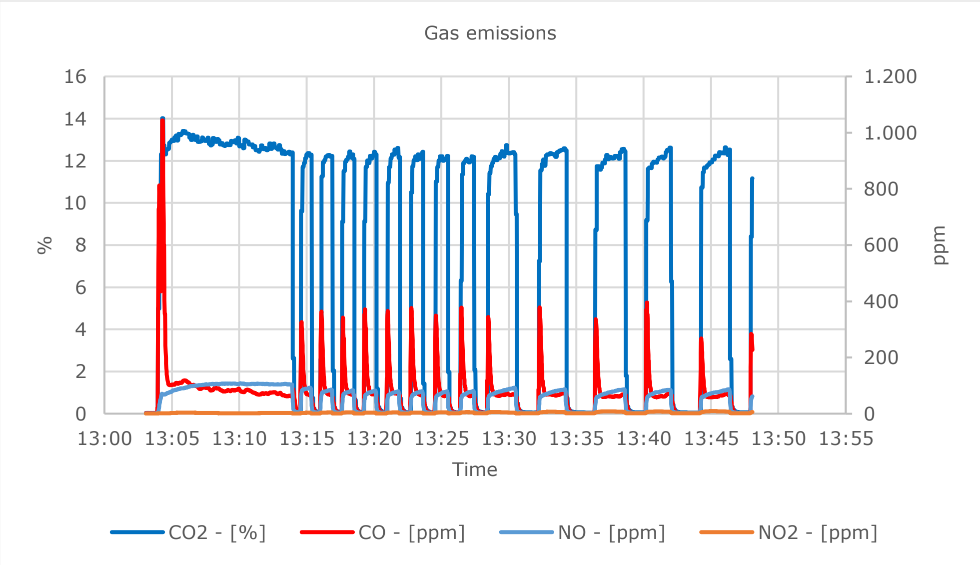
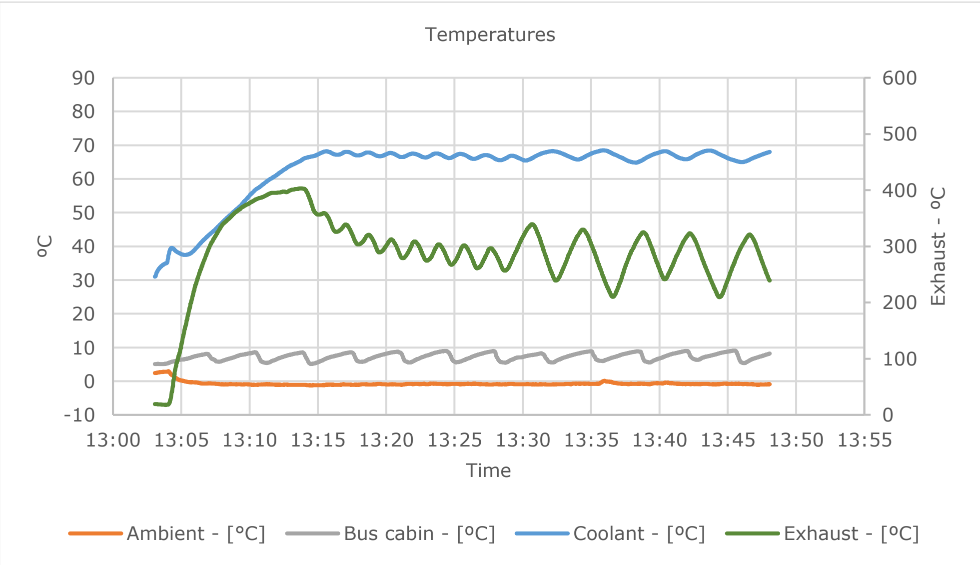


Figure 4. Test example no. 2 - temperatures



Since the start phase gives the highest emissions of CO, particles and soot, heater two is disadvantaged in comparison to heater one - because it is too efficient.

Example 3

Two examples from tests with method 2 are shown below.

In the first example, the heater has been manually started and stopped four times. The duration of each period was 5-6 minutes.

Figure 5. Test example no. 3 – gas emissions

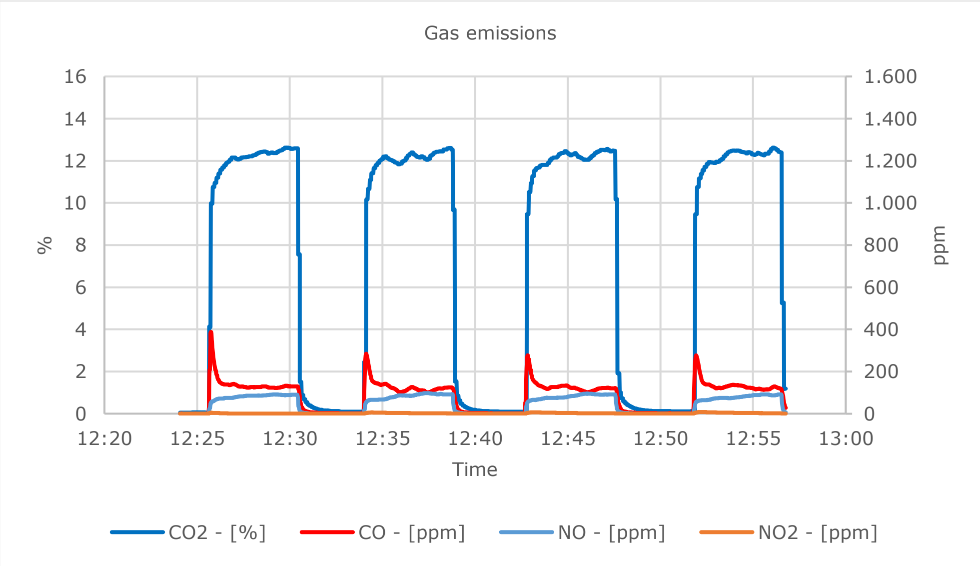
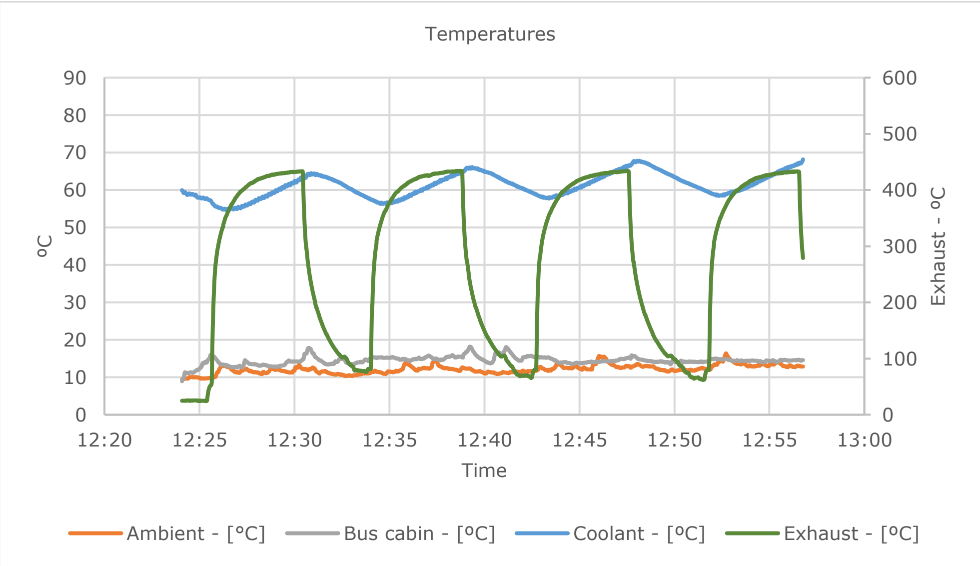


Figure 6. Test example no. 3 – temperatures



This gives very similar cycles and comparable results, and emissions and exhaust gas temperature are stable at the end of each on-period.

Example 4

In the second example, the heater controller or/and the bus ECU stops the heater several times during heating up, despite the coolant being far from the thermostat switch off temperature.

Figure 7. Test example no. 4 – gas emissions

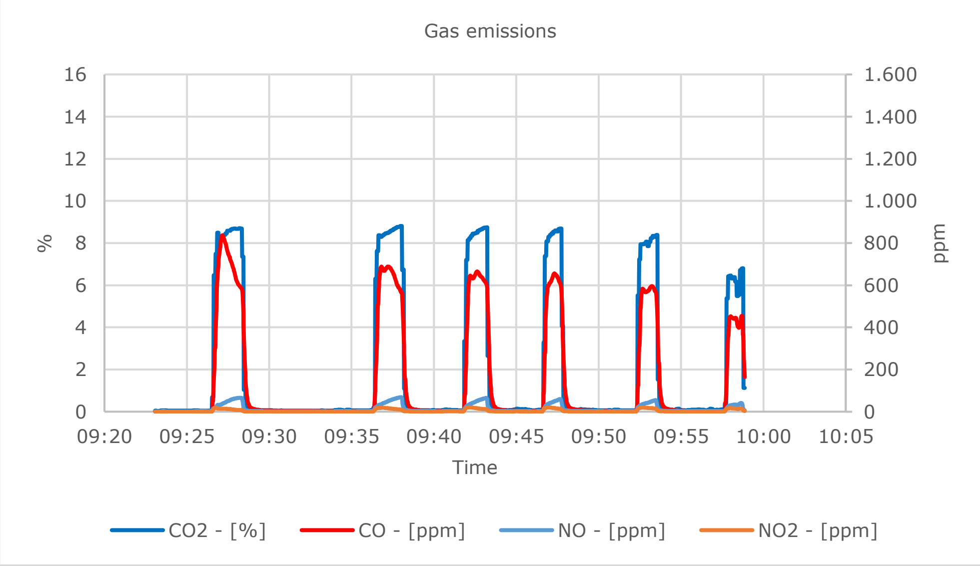
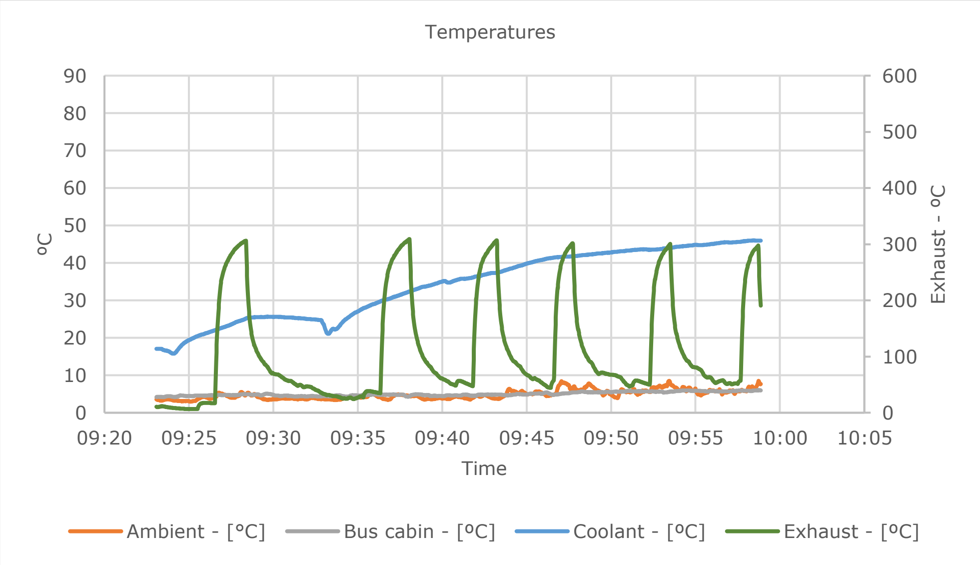


Figure 8. Test example no. 4 - temperatures



The short cycles mean that the exhaust gas temperature is not completely stable in the end of each on-phase. This must be considered when evaluating whether the exhaust gas temperature – and the combustion efficiency - is ok.

3.5. Data handling and calculation

According to the difference in behaviour as described above, and in order to compare the measurements in the best possible way, it was decided to split the measurement results in peak values and average values.

Peak values are the highest value at each on-period, and average values are the last 20 seconds at each on-period, which is defined as the stable period.

This gives the best opportunity to compare the heaters, since they run in very different ways, especially when tested with the first method.

The data is handled in the same way when tested by method two. Here, however, the difference in heater cycle from test to test is reduced to a minimum.

4. Test results

The measurement results are shown below. The average results for each parameter are calculated for the last 20 seconds of each on-period and averaged with corresponding values from the other on-periods.

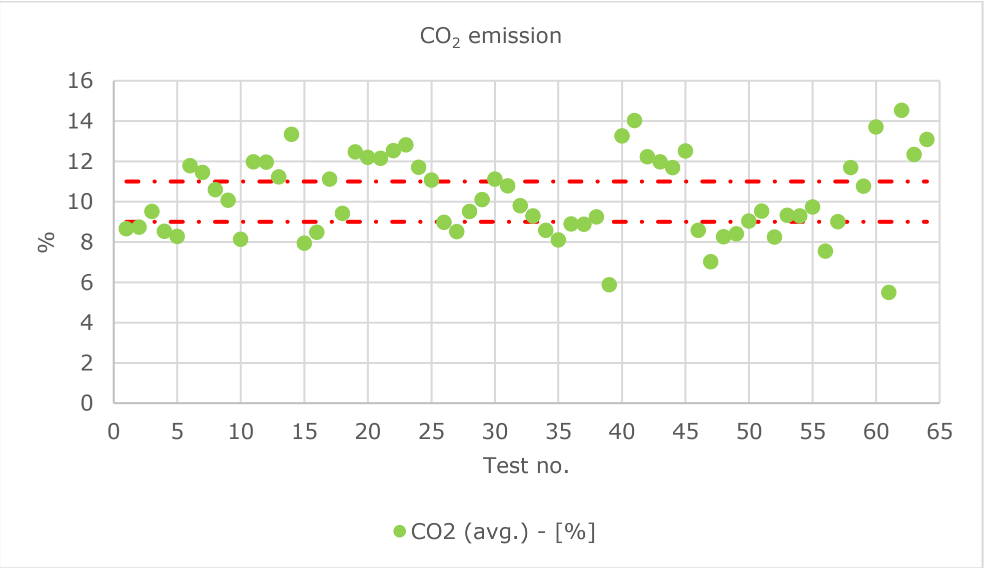
The max values are the highest values during all the on-periods.

Note that the difference in behaviour, as explained above, can make the comparison slightly uncertain. It is, however, evaluated that it is possible to make a reasonable comparison for a good overview.

4.1. Carbon dioxide - CO_2

The CO_2 emission is a good indicator on the air/fuel ratio; if the amount of air and fuel is appropriate, the heater is properly adjusted. If CO_2 is too low, the combustion gets too much air, hence too little fuel, and oppositely if CO_2 is too high.

Figure 9. CO_2 emission



Experience suggests that heaters of this type have the best combustion when CO_2 is between 9 and 11%$_{vol}$. As the figure shows, not many of the heaters fulfil this recommendation. 17 heaters are between 9 and 11%$_{vol}$, and 47 are outside the range.

Above 11%, the risk of particle and soot emission increases while there is not enough air to secure a proper combustion. Below 9% $_{vol}$, the amount of air is too large for the amount of fuel and this "cools" the combustion which also increases the risk of incomplete combustion.

4.2. Carbon monoxide – CO

The CO emission is a good indicator of the overall quality of the combustion. This, along with particles and soot, indicates whether the combustion is complete with all combustible gasses being combusted.

When type approved[4], the heaters must be below 1000 ppm, but experience suggests that heaters of this type can be significantly lower than that. 300 ppm and even 100 ppm is realistic.

Below, the CO average and max values in ppm are shown in the first graph, and average values only are shown in the second graph.

Figure 10. CO emission - average and max values

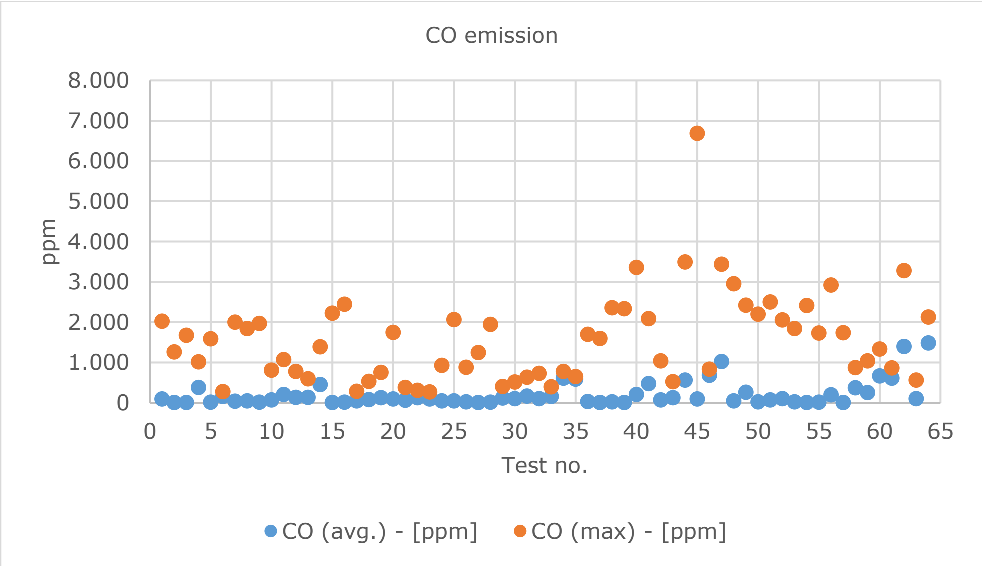
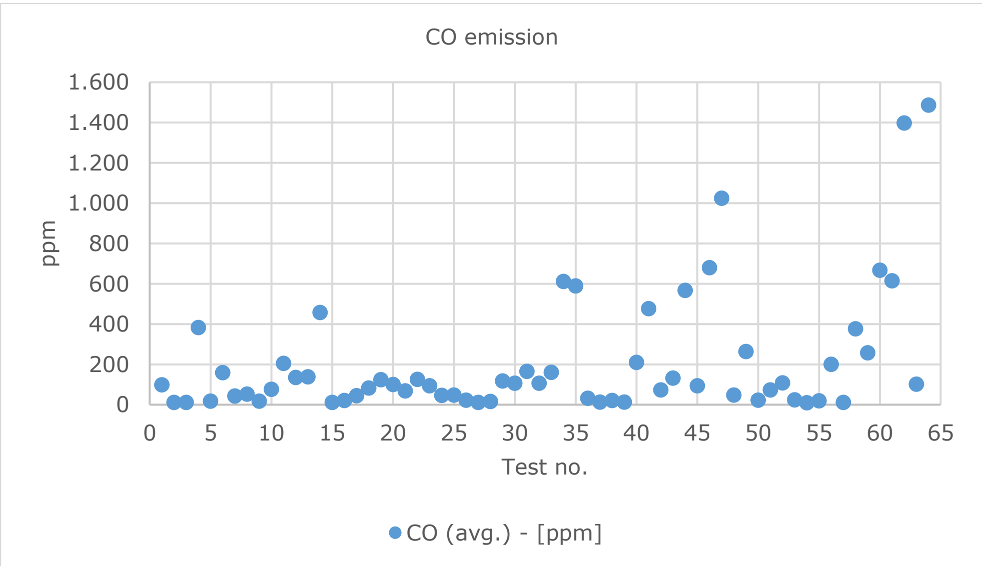


Figure 11. CO emission - only average values - zoom to 1600 ppm



In the ignition phase (max values), most of the heaters are between 500 and 3000 ppm, with a few below 500 ppm and a few above 3000.

In the stable period (avg. values), most of the heaters are below the upper recommended limit of 300 ppm, and app. half the heaters are below 100 ppm. Some heaters, however, are significantly higher, varying between 400 and 1.500 ppm.

[4] Type approval of diesel heaters is made in accordance with directive UN ECE R121.

High CO levels in the stable period normally appear when the air fuel ratio is out of range, due to either too little or too much air relative to the fuel amount.

High CO level at ignition can indicate that fuel nozzle or other issues regarding the fuel supply are out of normal range - or out of order.

4.3. Particulate matter – PM

PM is, as CO, a good indicator on the combustion quality. PM normally occurs when the combustion has too little air relative to fuel, or if the fuel is not properly added to the combustion – if, for example, the nozzle does not work properly.

Figure 12. PM emissions

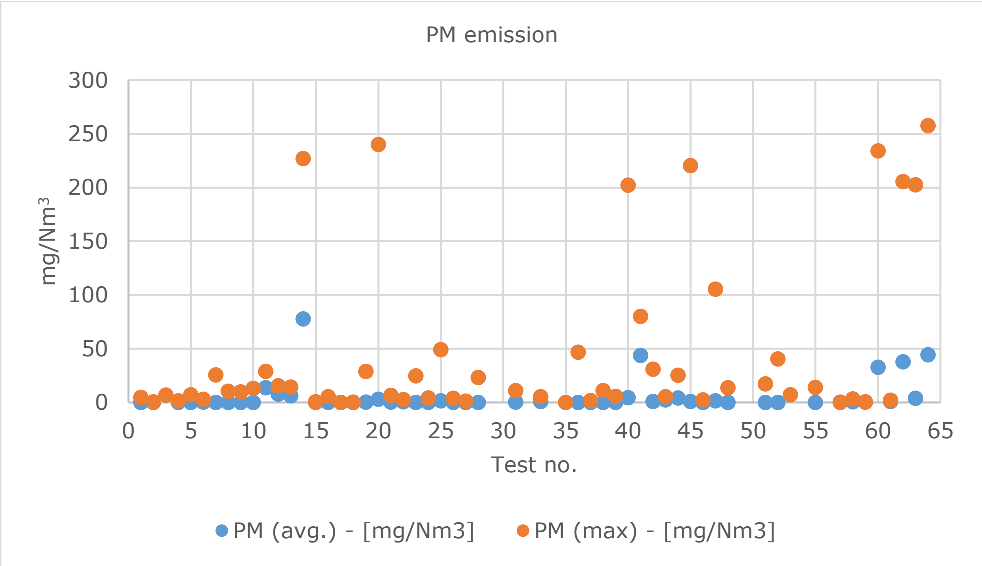
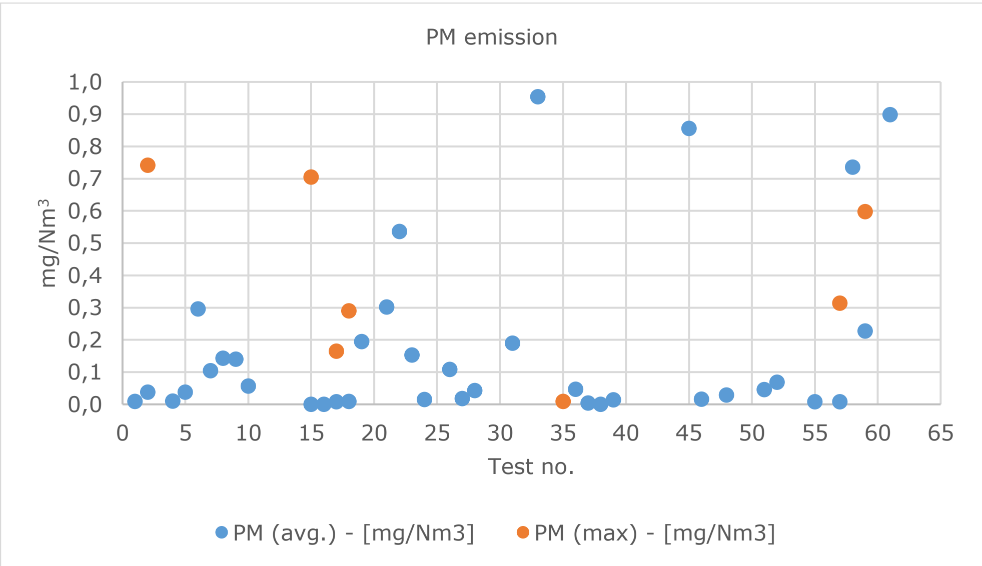


Figure 13. PM emissions – zoom to 0-1 mg/Nm³



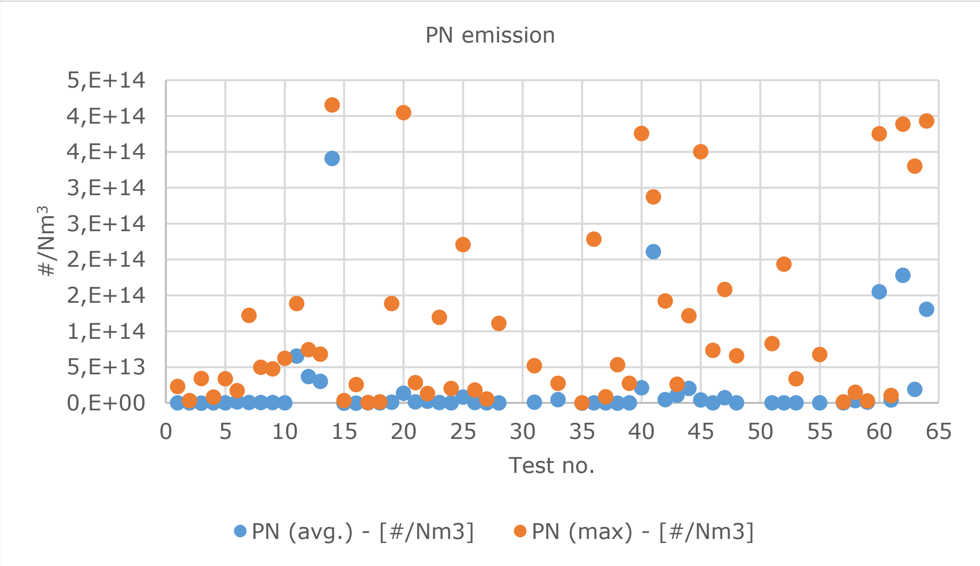
The avg. values are low in most of the tests, but some are very high. In these tests, a lot of smoke was observed, especially at the ignition phase.

The max values were generally high, and most of the heaters also emitted visible smoke/particles at ignition.

4.4. Particulate number – PN

PN indicates as PM the combustion quality and correlates almost 100% with PM. See values below.

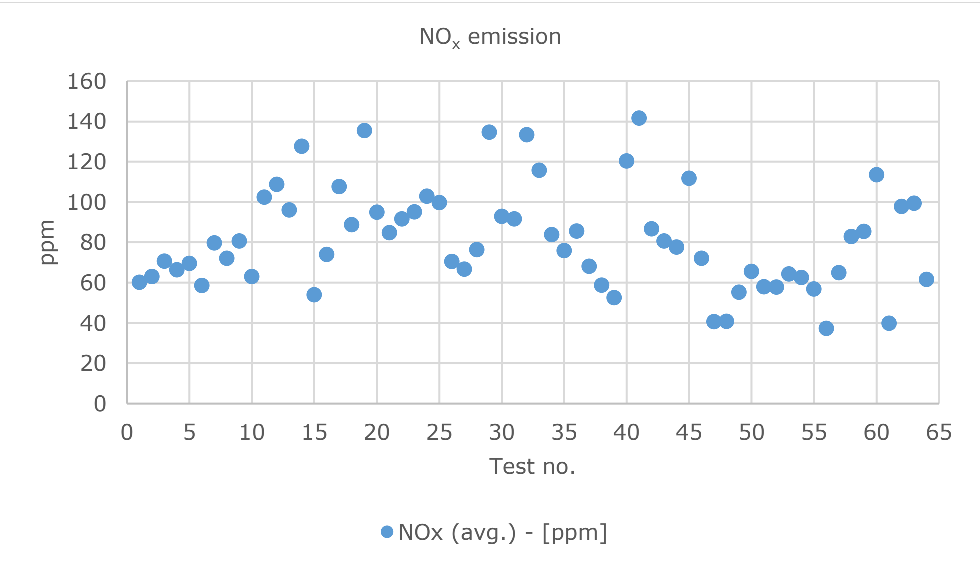
Figure 14. PN emission



4.5. NO_x

NO_x is fuel depending and has an opposite reaction on the combustion quality compared to CO and particles. The better conditions, the higher NO_x. Below the values are shown.

Figure 15. NO_x emission



The values vary quite a lot, but they are all below the Euro VI limits when calculated as g/kWh. See paragraph 4.9.

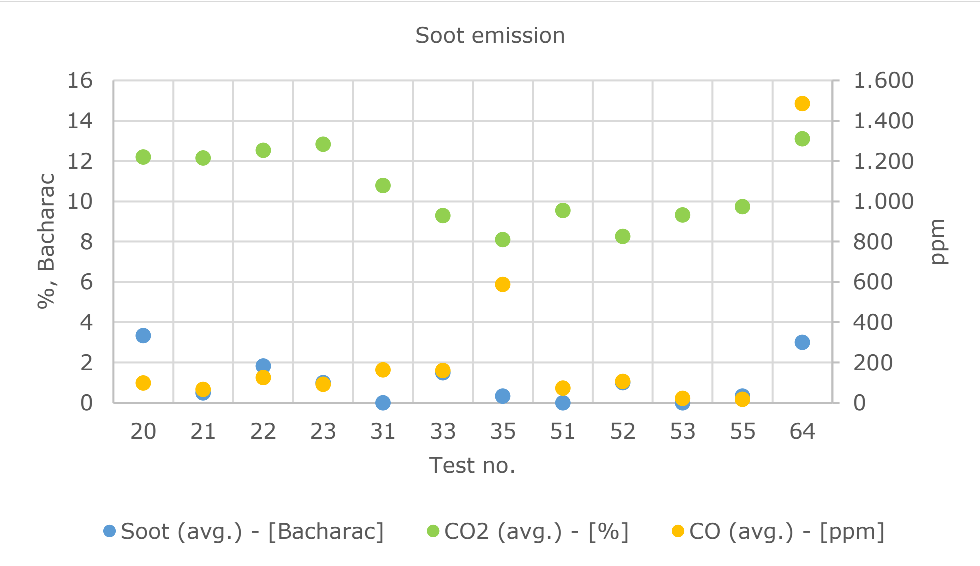
4.6. Soot

Soot was measured in the last 12 tests to see if this could be a useful measurement on the combustion quality in future tests. Soot is easy to measure, and measurement equipment is relatively cheap, so it would be a good tool to have on the workshops where the buses are serviced.

Soot and PM will normally show same tendency, but PM is complicated to measure, and the equipment is expensive.

Results from the 12 tests along with CO, PM and CO_2 are shown below.

Figure 16. Soot emission



As the figure shows, some heaters have low CO but high soot number. Heater no. 20, 22 and 64 have CO below 200 ppm but a Bacharach[5] number above 1.

These heaters also have very high CO_2 levels, and this makes good sense regarding soot, since soot often appear when there is a lack of air.

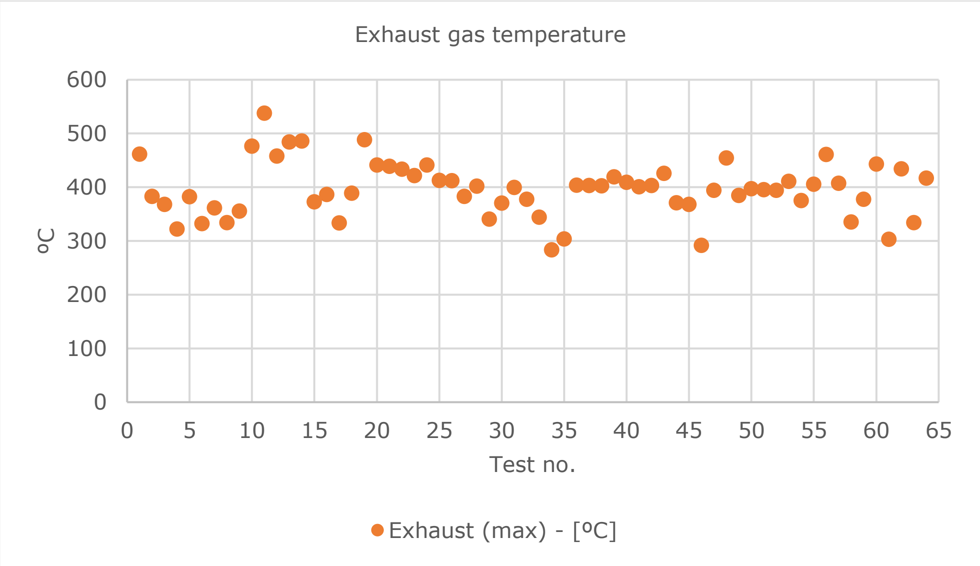
4.7. Exhaust gas temperature

Exhaust gas temperature tells whether the heater convection part is clean or dirty. If dirty, the exhaust gas temperature increases and this gives a lower combustion efficiency. Combustion efficiency is primarily depending on the amount of exhaust gas, hence CO_2 level, and the temperature of the gas.

The temperature is shown below.

[5] The soot number, or Bacharach number, is measured by sucking a sample of the exhaust gas through a piece of paper. The Bacharach number is decided from the blackening of the paper on a scale from 0-9.

Figure 17. Exhaust gas temperature



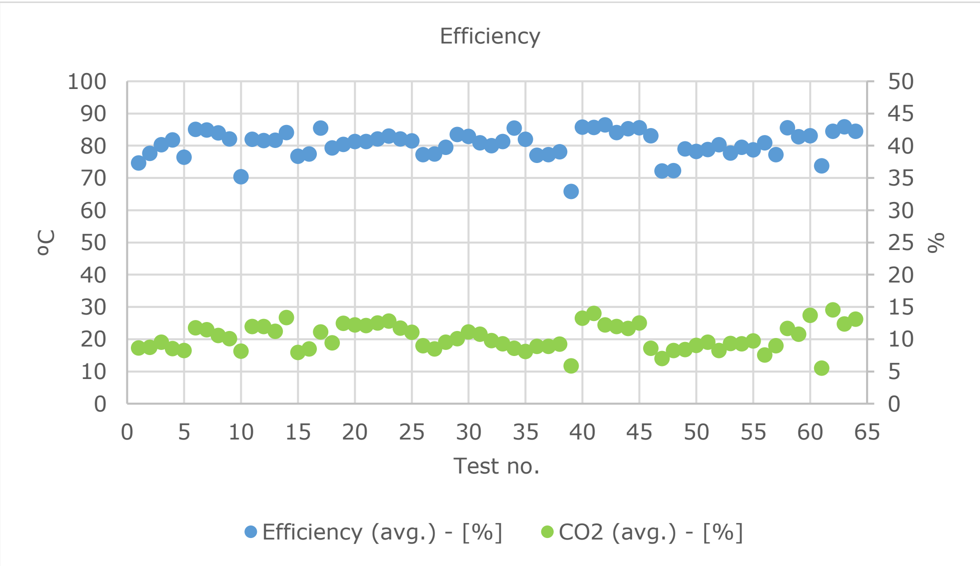
The exhaust temperature is generally very high, which indicates that most of the heaters need cleaning. Experience suggests that exhaust gas temperature should be below 350ºC on a well serviced, clean and efficient heater.

4.8. Combustion efficiency

As mentioned, combustion efficiency primarily depends on exhaust gas temperature and air amount / CO_2 level. High combustion efficiency comes with high CO_2 and low exhaust gas temperature.

Below, combustion efficiency is shown along with CO_2.

Figure 18. Combustion efficiency



There is some correlation between exhaust gas temperature and CO_2. The higher CO_2, the higher combustion efficiency, but due to the combustion quality and emission of combustible gasses as CO, HC and particles, the CO_2 should not be higher than 11% as mentioned in paragraph 4.1. The rest of the combustion efficiency optimization must come from cleaning the convection part in the heater.

The difference in efficiency between the best and the poorest performing heater, roughly gives a difference in fuel consumption around 25% or 1 litre pr. hour.

4.9. Heater performance and Heavy -Duty Euro VI limits

Below, emission-levels from the heaters are compared to the Heavy-Duty Euro VI limits. The average and peak emissions from the measured heaters are averaged and compared to the Euro VI limit for each parameter. Note that calculated peak values may only be seen as indications and tendencies, since the calculations have significant uncertainty.

The first column shows the number and the second column shows the percentage of heaters below the limits. Note that 56 heaters are tested regarding PM and PN, while 64 heaters are tested regarding the other parameters.

Table 2. Heater emission levels vs. Euro VI limits

Parameter	Euro VI limit	Heaters tested	Heaters below Euro VI limit			
			stable phase		peak / ignition phase	
			no	%	no	%
CO	1,5 g/kWh	64	60	94	6	9
HC	0,13 g/kWh	-	not measured			
NO_x	0,4 g/kWh	64	64	100	29	45
PM	0,01 g/kWh	56	50	89	21	38
PN	8×10^{11} #/kWh	56	26	46	1	2

Most of the heaters, 60 of 64 (94%) are below the CO limits at the stable phase. At ignition, however, only 6 (9%) of the heaters are below the limit.

All the heaters are below the NO_x limit at stable conditions, and 29 (45%) are below at ignition.

App. 9 of 10 are below the PM limit at stable conditions. App. 2/5 are below at ignition phase.

Regarding PN, the picture is a bit different. Here, only half of the heaters are below the limits at the stable phase and only one heater is below at ignition.

4.10. Operator maintenance service plan

Two operators (operators 5 and 6) have informed that they have a maintenance service plan. They both replace nozzle, igniter and filter and clean the convection part according to a maintenance service plan. Operator 6 also informs that they adjust the heaters at service.

The other operators do not have a maintenance service plan – they repair the heaters when they break down.

4.11. Environmental Test Manual limits

Measurement results from two Danish surveys of heater performances are shown below. Together with the measurement results from this project, they are used as guidelines to suggest limits for the Environmental Test Manual for future heater tests.

Results for CO_2, CO, soot number and exhaust gas temperature are selected and compared.

These parameters are considered the most relevant to make a simple and effective test of the heater's performance. They are good indicators on the heater's condition, and the measurements can be performed with relatively simple and cheap equipment both by the PTOs' mechanics and by independent measuring bodies.

The measurement results are shown below. In appendix 2, more measurement results from other projects are shown.

Table 3. Measurement results from other projects

Project	Fuel	CO_2	CO			Soot number	Exhaust gas
		%	ppm (avg.)	ppm (max)	mg/Nm³ at 10% CO_2	-	ºC
(I) Technological Institute, "Biodiesel DK – Demonstration Project, TP7, bus heaters, 2009-2010"	B30	10,1	-	-	-	-	289
	Fossil diesel	10,1	-	-	-	-	296
	B30	9,1	93	-	-	0,3	332
	Fossil diesel	8,4	56	-	-	0,5	331
	B10	11,1	93	-	-	1,5	426
(II) Force Technology, "Measurement of emissions from diesel fired heaters for buses", report no. 118-22672.02, April 2018	B7	8,9	-	-	98	-	-
	HVO	9,2	-	-	93	-	-
	B7	11,1	-	-	111	-	-
	HVO	11,6	-	-	121	-	-
Average I and II	-	10,0	81	-	106	0,8	335
Average this project	-	10,2	210	1575	260	1,1	396

The measured results from the two surveys are significantly better than the results from this project.

The results cover a wide range of test methods, heater models, fuels, etc. However, it is evaluated that they are usable as guidelines for future tests limits.

Below, limits are suggested for the Environmental Test Manual.

Table 4. Suggested Environmental Test Manual limits

Parameter	Suggested ETM limits	
CO_2	> 9	%
CO (avg.)	< 150	ppm
CO (max)	< 1500	ppm
Soot number	1	Bacarach
Exhaust gas temperature	< 350	ºC

The CO_2 limit assures that the combustion does not get too much air. This is preferable both regarding combustion quality and combustion efficiency.

The CO avg. limit assures that the combustion is good at stable conditions, and the CO max limit assures a good combustion at ignition.

The soot limit assures, together with CO, a good combustion at stable conditions. As earlier mentioned, both CO and soot need to be low to assure a good combustion.

The CO and soot limits apply to the measured values and not to a fixed reference condition.

The CO_2 limit (>9%) prevents dilution, and it is easier to handle measured values limits at the bus workshops than having to calculate to reference condition.

Furthermore, the *concentration* of CO and soot is evaluated to be more important than the *amount*, since the heaters often operate near people, either in the streets, at the bus stops or at the PTOs' bus depots.

The limit for exhaust gas temperature assures, together with the CO_2 limit, a high combustion efficiency.

4.12. **Data overview**

See more measurement results in appendix 1.

5. Correlation survey

Below the heaters are compared across operators, age of heaters, heater models and fuels. The parameters that are compared are gas emissions, CO and NO_x, particle emissions, exhaust gas temperatures and combustion efficiency.

The parameters are averaged at each comparison.

Bus model, heater setting (CO_2), service, and heater model all effects how the heaters perform. This must be considered when comparing the results. The parameters affect each other so this survey will not give a precise picture of the effect of each parameter, but an overall indication.

5.1. **Operator**

7 operators have participated in the project with a varying number of buses/heaters.

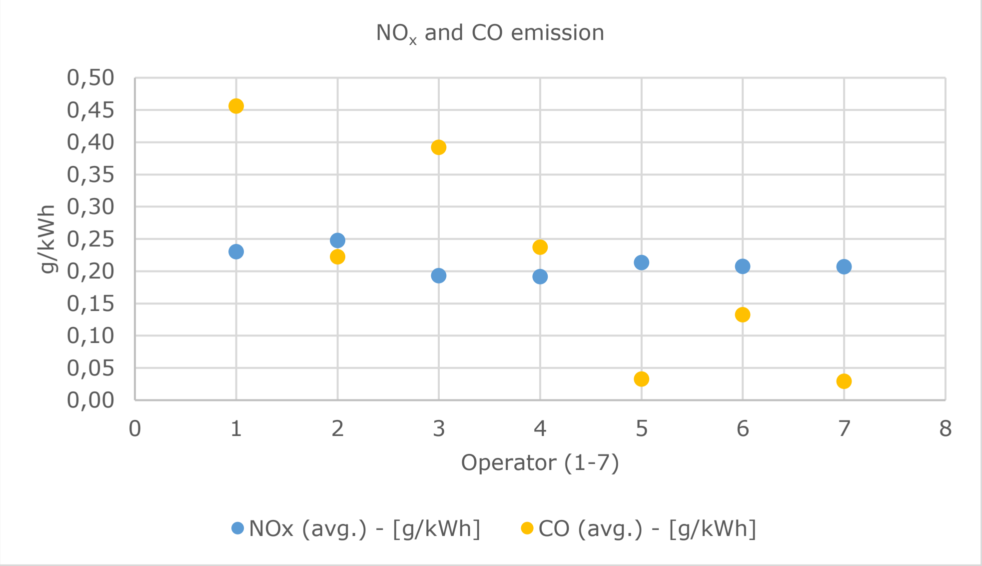
The operators have been promised anonymity; therefore, the parameters are averaged without showing the number of buses/heaters in the project. The number varies from 2 to 22 pr. operator.

This must be considered when evaluating the data. It should also be considered that the buses and heaters are different from operator to operator. This could also affect the results.

Gas emissions

Below, gas emissions, NO_x and CO, are compared across operators.

Figure 19. NO_x- and CO emission



NO_x emissions are very similar across the operators. It varies between 0,19 and 0,25 g/kWh from the lowest to the highest.

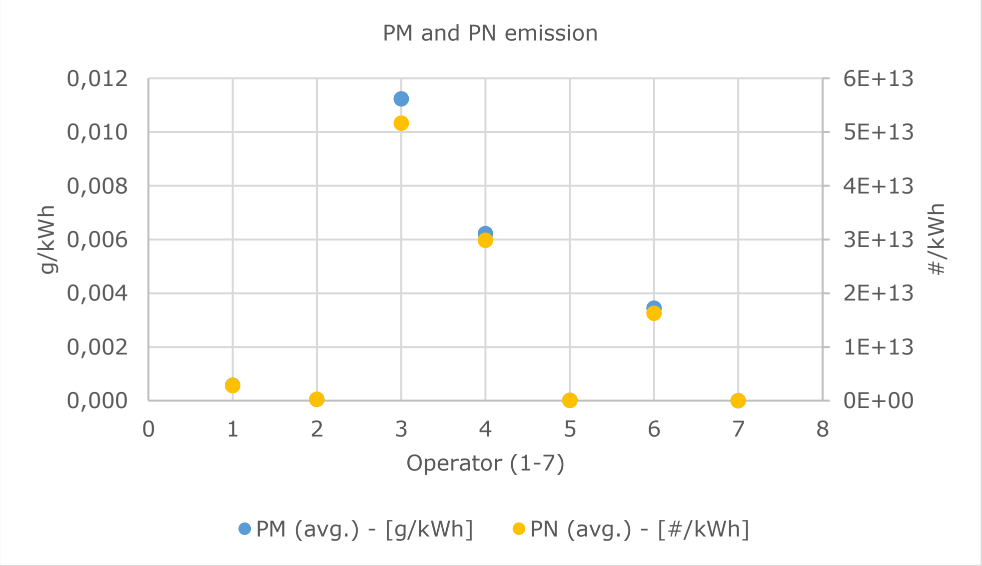
CO on the other hand varies significantly. Heaters from operator 5 and 7 have by far the lowest CO emission. Operator 5 is one of the two operators who have a service maintenance plan while operator 7 does not. The other operator with a service maintenance plan is operator 6, whose heaters have the third lowest average CO level.

The span from the lowest to the highest CO level is 0,03 to 0,46 g/kWh.

PM and PN

Below, PM and PN emissions are compared across operators.

Figure 20. PM and PN emission



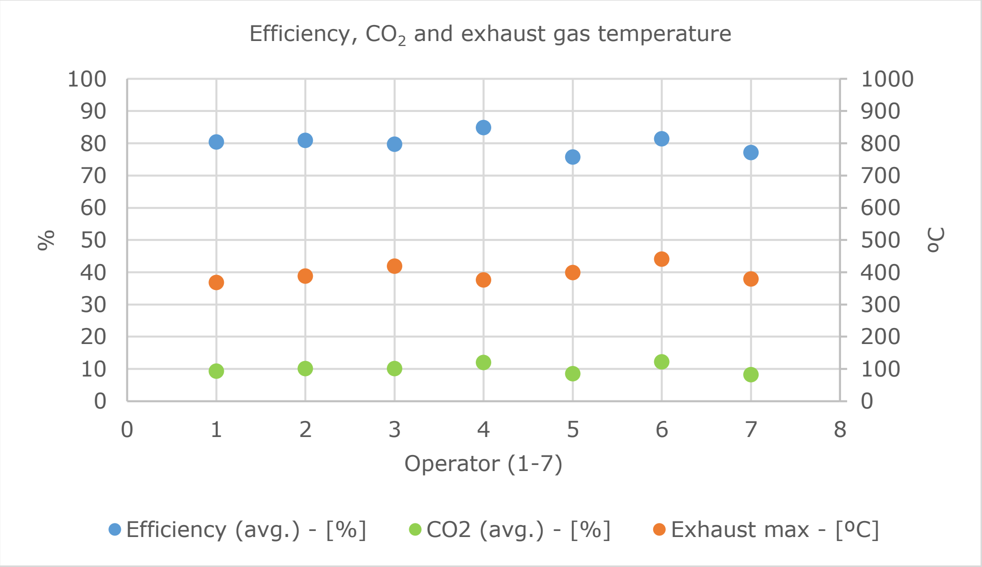
Both PM and PN vary significantly across the operators. Heaters from operator 5 and 7 have the lowest PM and PN emission. Heaters from operator 1 and 2 also have very low particle emission. Except from operator 1 and 2, the picture is much the same as with CO.

The very low particle emission for heaters from operator 1 is remarkable since the CO was very high for heaters from this operator. Data has been checked, but no immediate explanation has been found.

Combustion efficiency, CO_2 and exhaust gas temperature

Below, exhaust gas temperature and combustion efficiency across operators are shown. As earlier described, the exhaust gas loss depends partly on the exhaust gas temperature and partly on the CO_2.

Figure 21. Combustion efficiency, CO_2 and exhaust gas temperature



The max exhaust gas temperature varies from 368ºC to 441ºC from the lowest to the highest level.

This alone equals app. 5% point in combustion efficiency difference.

Combustion efficiency varies between 76% and 85% across the operators. App 5% is explained in the variation in exhaust gas temperature; the rest is explained in difference in CO_2 levels.

5.2. Age

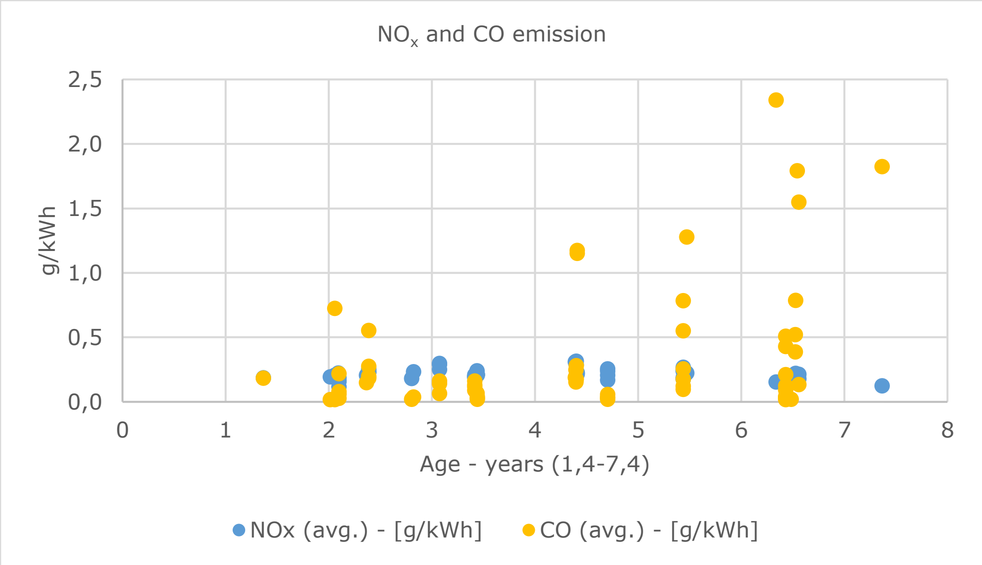
In the project, 64 different buses have been measured. The oldest from 2013 and the newest from 2019. The heaters are presumed to have the same age as the buses.

In the following, emissions, exhaust gas temperature and combustion efficiency are compared across age of bus and heater.

Gas emissions

Below, gas emissions, CO and NO_x, are compared across age.

Figure 22. NO_x- and CO emission



The NO_x emission is close to constant through all the heaters, independent on the heater's age.

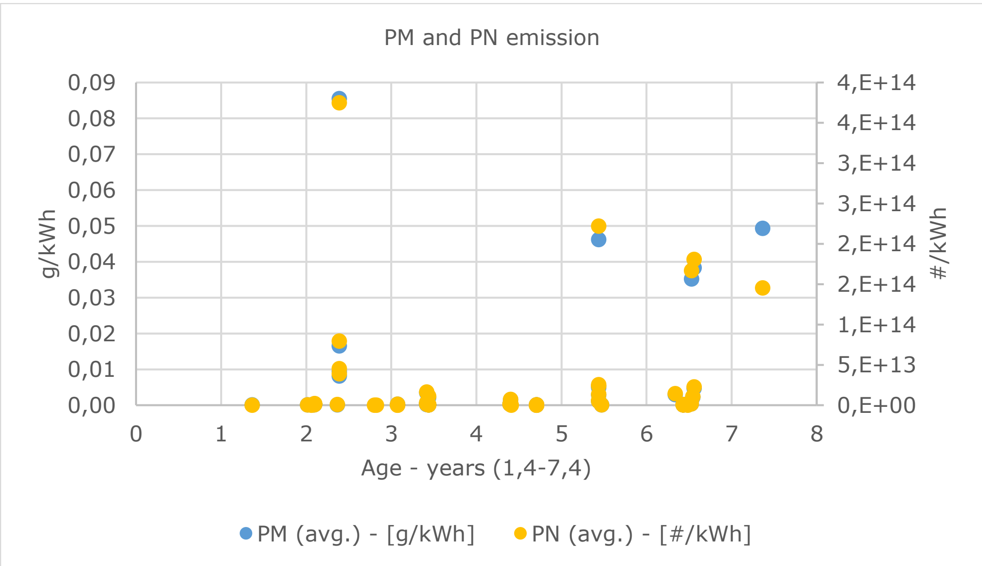
CO emissions on the other hand have a dependence of the age. Many of the older heaters have app. same level of CO as the newer heaters but a relatively big number of the older heaters have relative high CO emissions compared to the newest.

This could be because of development to better heaters or just that the newer heaters are not as dirty and worn as the older.

PM and PN

Below, PM and PN emissions are compared across age of the heater.

Figure 23. PM and PN emission



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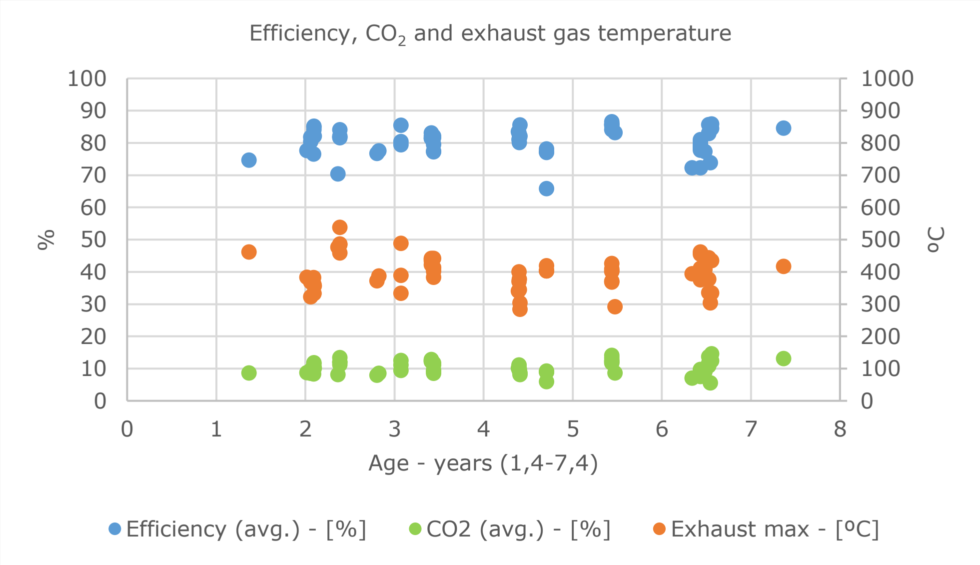
With few exceptions, a tendency of increases in particle emissions as the heaters get older is seen. As with CO, this can be due to development or lack of sufficient service – or both.

Combustion efficiency, CO_2 and exhaust gas temperature

Below, exhaust gas temperature and exhaust gas loss across heater age are shown.

Figure 24. Combustion efficiency, CO_2 and exhaust gas temperature



No correlation between age and exhaust gas temperature or combustion efficiency is shown. The average values are almost constant for both parameters throughout the 7-8 years range.

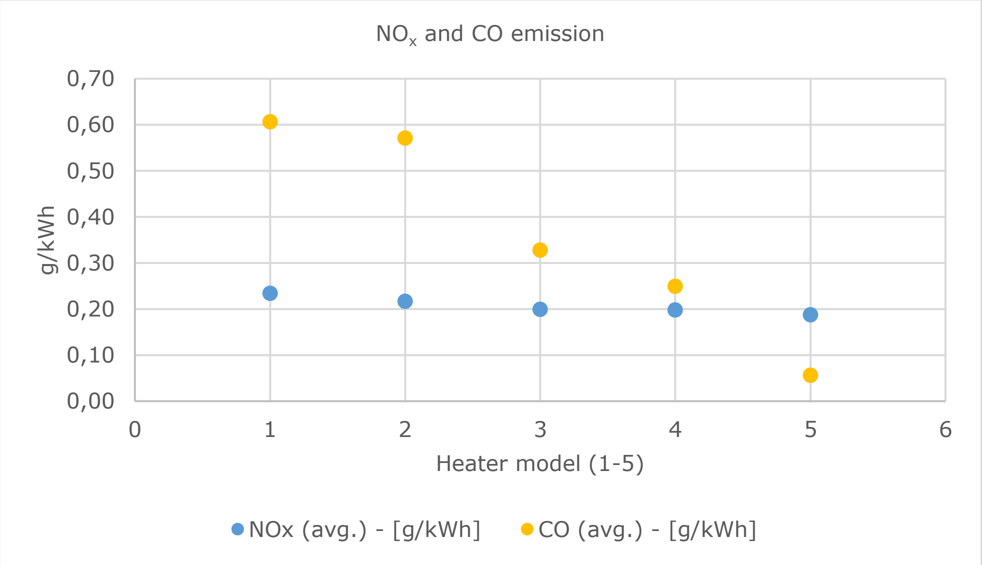
5.3. Heater model

Five different heater models have been tested. Varying from 1 to 34 in number for each model. This variation must be considered when evaluating the data.

Gas emissions

Below, gas emissions, CO and NO_x, are compared across heater models.

Figure 25. NO_x- and CO emission



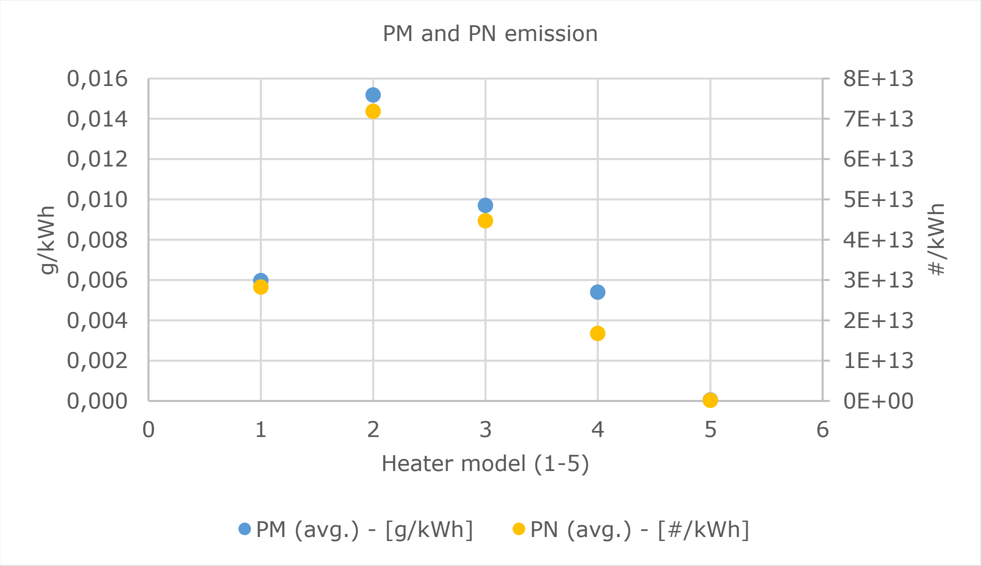
The NO_x emission is roughly constant through all the heaters, independent of the heater model.

CO is on the other hand very different between the heater models, varying from 0,1 to 0,6 g/kWh. Just keep in mind that other things can affect this variation.

PM and PN

Below, PM and PN emissions are compared across heater model.

Figure 26. PM and PN emission

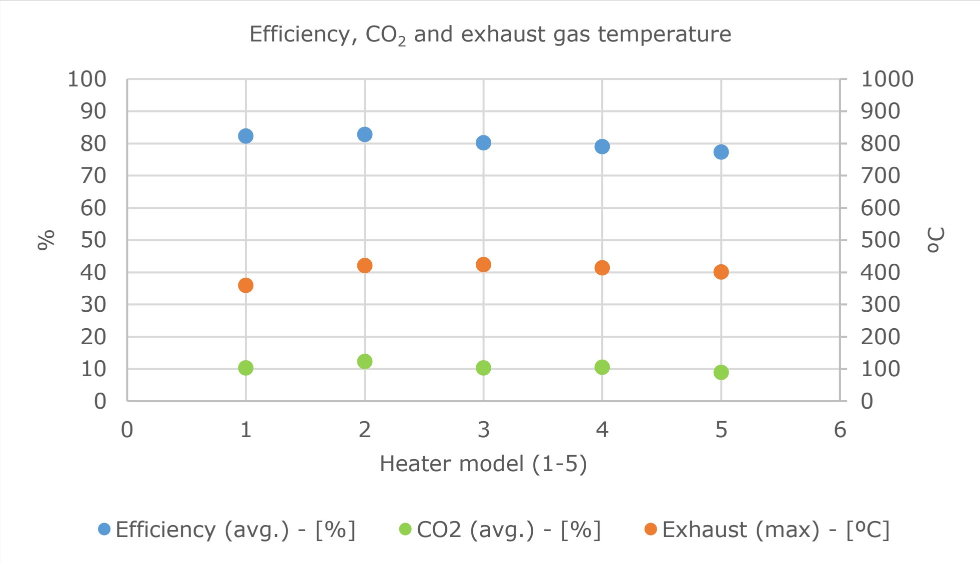


This is pretty much same picture as with CO. Only heater model one has moved from the highest level for CO to the middle regarding particles.

Combustion efficiency, CO_2 and exhaust gas temperature

Below, combustion efficiency and exhaust gas temperature across heater models are shown.

Figure 27. Combustion efficiency, CO_2 and exhaust gas temperature



Overall, the best performance regarding combustion efficiency is delivered by model 1. It has the lowest exhaust gas temperature in combination with a CO_2 level almost in the middle of the recommended range, at 10,4% $_{vol}$. Have in mind that this could cover a variation from too high to too low CO_2.

Model 2 has a slightly higher combustion efficiency, but it is because of a too high average CO_2 and not a low exhaust gas temperature.

The lowest combustion efficiency is at model 5. It is primarily due to the relative low CO_2 level and not due to a special high exhaust gas temperature.

5.4. **Fuel**

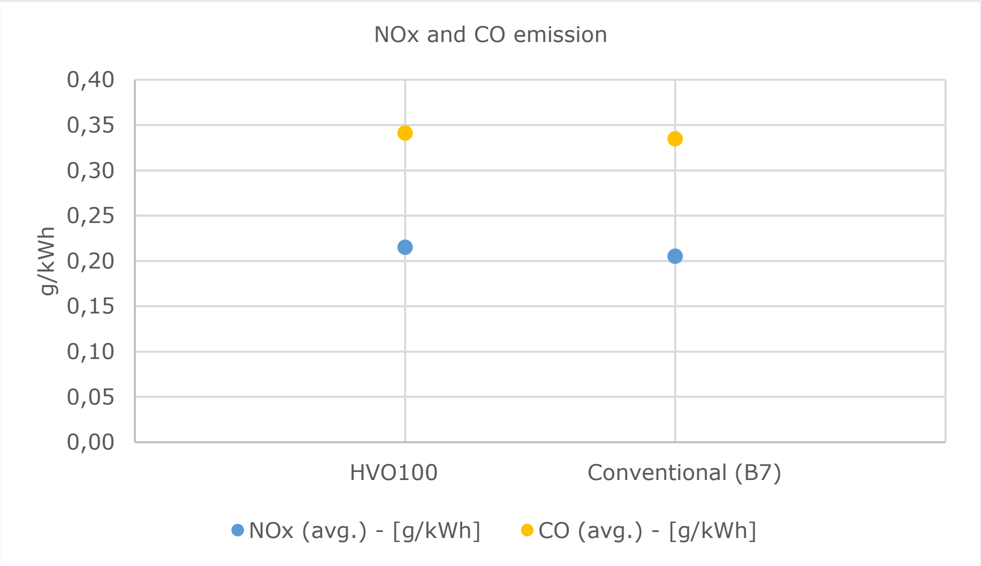
Two different fuels have been used in the heaters: conventional diesel (B7) and HVO biodiesel (HVO100). 11 buses/heaters have used HVO100, and 53 have used conventional diesel.

The two fuels are compared in the following section.

Gas emissions

Below, gas emissions, CO and NO_x, are compared between the two fuels.

Figure 28. NO_x- and CO emission

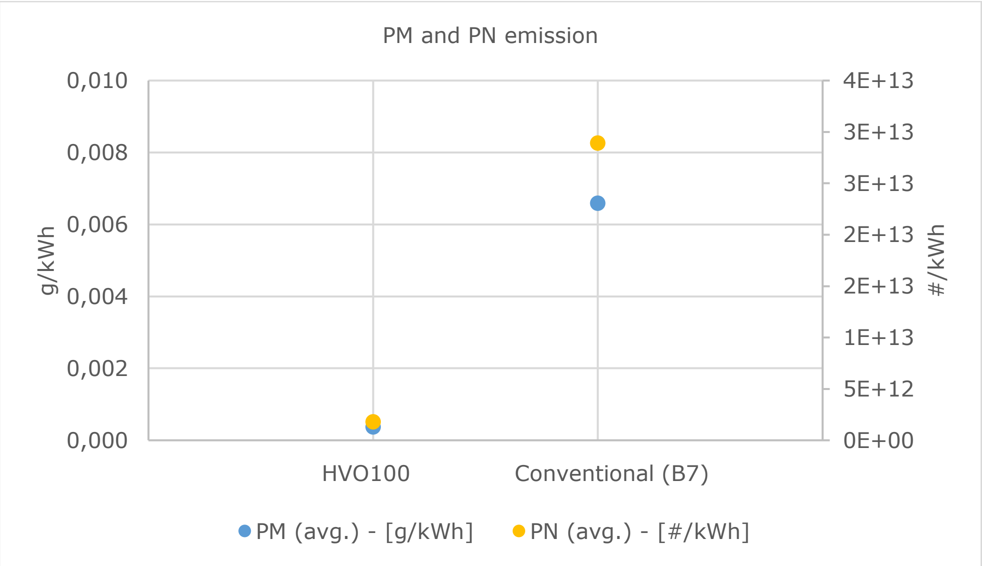


CO and NO_x are almost identical for the two fuels. No significant difference is observed.

PM and PN

Below, PM and PN emissions are compared across the two fuel types.

Figure 29. PM and PN emission



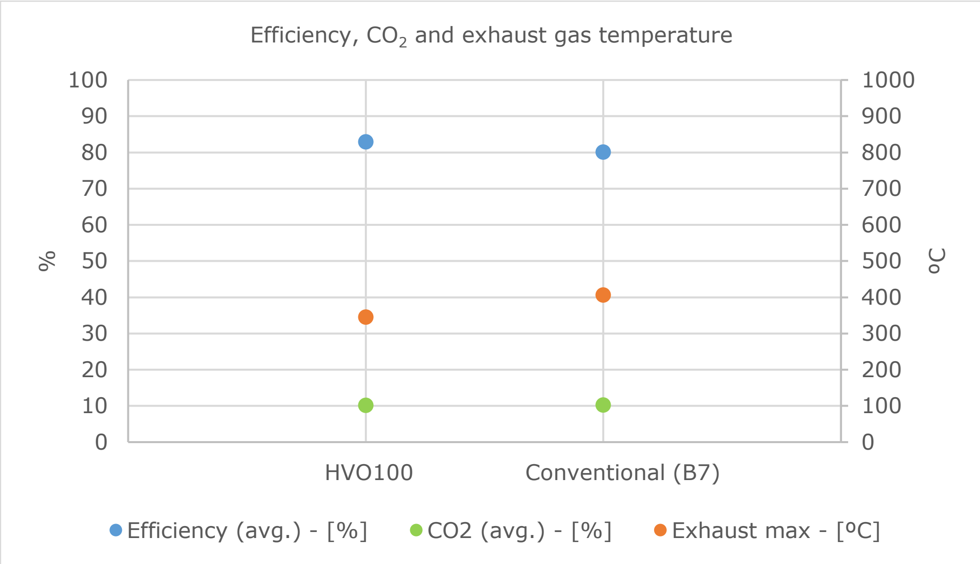
Regarding the particle emission, there is a very significant difference. As mentioned above, the heaters have been set and serviced app. to same level, so this is most likely 100% fuel depending[6].

[6] This result is in accordance with a study from 2018 performed by FORCE Technology for Movia on emissions from diesel heaters powered by respectively conventional diesel (B7), HVO100 and FAME100. Measurement of emissions from diesel fired heaters for buses, FORCE Technology, 2018.

Combustion efficiency, CO_2 and exhaust gas temperature

Below, efficiency, CO_2 and exhaust gas temperature are compared across the two fuels.

Figure 30. Combustion efficiency, CO_2 and exhaust gas temperature



It appears that HVO100 has a slightly higher average combustion efficiency compared to conventional diesel (B7). The average CO_2 is almost the same for the two fuels, so the difference in combustion efficiency all comes from the lower exhaust gas temperature.

6. Appendices

Appendix 1: Data overview

Appendix 2: Data from other projects

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Appendix 1: Data overview

Table 5. Temperatures, number of ignitions, CO_2, O_2, CO and soot [7]

Test index no.	Fuel	Ambient	Bus cabin	Coolant	Exhaust	Ignitions	Combustion efficiency	CO_2	O2	CO														Soot no.
		ºC	ºC	ºC	ºC	-	%	$\%_{vol}$	$\%_{vol}$	ppm measured		ppm at 10% CO_2		g/m^3		g/Nm^3		g/Nm^3 at 10% CO_2		g/kWh		g/kg fuel		
		avg.	avg.	max	max	-	avg.	avg.	avg.	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.
1	Diesel (B7)	8	13	76	462	5	75	8,7	9,5	98	2.029	113	2.532	0,04	1,35	0,12	2,54	0,14	3,17	0,18	4,02	2,26	50	-
2	Diesel (B7)	2	15	73	383	1	78	8,7	9,0	10	1.259	11	2.089	0,01	1,36	0,01	1,57	0,01	2,61	0,02	3,33	0,23	41	-
3	Diesel (B7)	4	34	51	368	1	80	9,5	8,7	10	1.678	10	2.880	0,01	1,47	0,01	2,10	0,01	3,60	0,02	4,56	0,21	56	-
4	Diesel (B7)	9	21	73	322	3	82	8,5	9,5	382	1.014	448	1.302	0,21	0,72	0,48	1,27	0,56	1,63	0,73	2,09	8,97	26	-
5	Diesel (B7)	2	20	48	382	1	76	8,3	9,5	18	1.588	21	2.380	0,01	1,70	0,02	1,99	0,03	2,98	0,03	3,78	0,43	47	-
6	HVO100	-1	16	51	333	2	85	11,8	5,6	158	279	134	691	0,09	0,17	0,20	0,35	0,17	0,86	0,22	1,12	2,68	14	-
7	HVO100	3	19	57	361	3	85	11,5	5,7	42	2.005	37	3.265	0,02	2,21	0,05	2,51	0,05	4,08	0,06	5,15	0,74	64	-
8	HVO100	6	19	60	334	2	84	10,6	6,7	51	1.845	48	3.003	0,03	1,64	0,06	2,31	0,06	3,75	0,08	4,75	0,97	59	-
9	HVO100	3	18	58	356	3	82	10,1	7,4	17	1.972	16	5.113	0,01	2,16	0,02	2,47	0,02	6,39	0,03	7,92	0,33	98	-
10	Diesel (B7)	4	16	65	476	1	70	8,1	15,4	75	814	92	1.011	0,03	0,99	0,09	1,02	0,12	1,26	0,15	1,63	1,85	20	-
11	Diesel (B7)	2	19	77	538	11	82	12,0	4,8	204	1.075	170	1.667	0,09	0,73	0,25	1,34	0,21	2,08	0,28	2,67	3,42	33	-
12	Diesel (B7)	2	19	78	458	10	82	12,0	5,0	135	780	113	2.784	0,06	0,61	0,17	0,98	0,14	3,48	0,18	4,41	2,27	54	-
13	Diesel (B7)	3	19	73	484	11	82	11,2	5,9	138	599	123	3.633	0,06	0,43	0,17	0,75	0,15	4,54	0,20	5,71	2,47	71	-
14	Diesel (B7)	3	20	79	486	7	84	13,3	3,2	456	1.391	342	2.514	0,21	0,97	0,57	1,74	0,43	3,14	0,55	3,99	6,85	49	-
15	Diesel (B7)	11	18	81	372	1	77	8,0	9,9	10	2.227	13	3.841	0,01	2,13	0,01	2,78	0,02	4,80	0,02	6,02	0,26	74	-
16	Diesel (B7)	10	17	79	387	2	77	8,5	9,3	19	2.449	23	4.434	0,01	2,23	0,02	3,14	0,03	5,54	0,04	6,91	0,46	85	-
17	Diesel (B7)	9	19	71	333	8	85	11,1	5,9	44	282	40	442	0,02	0,25	0,06	0,35	0,05	0,55	0,06	0,72	0,80	9	-
18	Diesel (B7)	8	17	73	389	5	79	9,4	8,4	83	529	88	700	0,04	0,34	0,10	0,66	0,11	0,88	0,14	1,13	1,76	14	-
19	Diesel (B7)	8	20	72	488	3	80	12,5	4,3	124	756	99	6.936	0,05	0,41	0,15	0,95	0,12	8,67	0,16	10,56	1,99	130	-
20	Diesel (B7)	11	10	50	441	4	81	12,2	4,4	99	1.747	81	5.198	0,05	3,02	0,12	7,42	0,10	6,50	0,13	8,04	1,63	99	3,3

[7] Note that calculated max/peak values may only be seen as indications and tendencies since the calculations have significant uncertainty.

Test index no.	Fuel	Ambient	Bus cabin	Coolant	Exhaust	Ignitions	Combustion efficiency	CO_2	O2	CO														Soot no.
		ºC	ºC	ºC	ºC	-	%	$\%_{vol}$	$\%_{vol}$	ppm measured		ppm at 10% CO_2		g/m^3		g/Nm^3		g/Nm^3 at 10% CO_2		g/kWh		g/kg fuel		
		avg.	avg.	max	max	-	avg.	avg.	avg.	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.
21	Diesel (B7)	12	13	57	439	4	81	12,2	4,6	67	383	55	908	0,03	0,41	0,08	0,75	0,07	1,13	0,09	1,46	1,11	18	0,5
22	Diesel (B7)	13	15	66	434	4	82	12,5	4,2	125	306	100	1.164	0,06	0,27	0,16	0,49	0,12	1,45	0,16	1,87	2,00	23	1,8
23	Diesel (B7)	14	14	54	422	4	83	12,8	3,8	93	268	72	460	0,04	0,35	0,12	0,50	0,09	0,57	0,12	0,75	1,46	9	1,0
24	Diesel (B7)	6	14	12	441	5	82	11,7	5,2	46	930	39	1.808	0,02	0,82	0,06	1,16	0,05	2,26	0,06	2,89	0,78	36	-
25	Diesel (B7)	7	16	63	413	9	82	11,1	6,1	46	2.063	42	2.362	0,02	1,21	0,06	2,58	0,05	2,95	0,07	3,76	0,84	46	-
26	Diesel (B7)	12	22	58	412	1	77	9,0	9,2	21	880	24	1.356	0,01	0,71	0,03	1,10	0,03	1,69	0,04	2,18	0,48	27	-
27	Diesel (B7)	6	25	33	383	1	77	8,5	9,5	11	1.248	13	2.063	0,01	0,97	0,01	1,56	0,02	2,58	0,02	3,29	0,26	41	-
28	Diesel (B7)	1	23	79	402	2	80	9,5	8,8	15	1.948	16	3.084	0,01	1,60	0,02	2,44	0,02	3,85	0,03	4,87	0,32	60	-
29	HVO100	-2	9	32	341	11	83	10,1	7,0	117	402	115	1.245	0,07	0,30	0,15	0,50	0,14	1,56	0,19	2,00	2,32	25	-
30	HVO100	-2	15	51	370	4	83	11,1	5,5	106	517	95	1.218	0,06	0,37	0,13	0,65	0,12	1,52	0,15	1,96	1,91	24	-
31	HVO100	7	11	48	400	4	81	10,8	6,1	165	639	153	1.398	0,08	0,59	0,21	1,23	0,19	1,75	0,25	2,24	3,06	28	0,0
32	HVO100	-2	14	40	377	1	80	9,8	7,5	106	733	108	700	0,06	0,47	0,13	0,92	0,13	0,88	0,18	1,13	2,17	14	-
33	HVO100	7	9	46	344	5	81	9,3	8,2	160	394	172	1.125	0,09	0,34	0,20	0,62	0,22	1,41	0,28	1,81	3,46	22	1,5
34	HVO100	-3	3	35	283	4	86	8,6	8,9	612	778	712	933	0,38	0,56	0,76	0,97	0,89	1,17	1,15	1,50	14,23	19	-
35	HVO100	6	5	38	304	6	82	8,1	9,6	589	649	726	3.567	0,35	0,54	0,74	1,05	0,91	4,46	1,17	5,61	14,50	69	0,3
36	Diesel (B7)	2	23	65	404	2	77	8,9	9,1	31	1.703	35	2.677	0,02	1,36	0,04	2,13	0,04	3,35	0,06	4,24	0,70	52	-
37	Diesel (B7)	5	24	75	403	3	77	8,9	9,5	11	1.600	13	2.434	0,01	1,26	0,01	2,00	0,02	3,04	0,02	3,87	0,26	48	-
38	Diesel (B7)	5	27	62	402	3	78	9,3	9,1	20	2.362	22	4.490	0,01	1,79	0,03	2,95	0,03	5,61	0,04	6,99	0,44	86	-
39	Diesel (B7)	5	13	67	419	2	66	5,9	13,5	12	2.338	20	3.036	0,01	2,68	0,01	2,92	0,03	3,79	0,03	4,80	0,41	59	-
40	Diesel (B7)	-1	8	66	409	13	86	13,3	3,1	209	3.360	158	2.260	0,10	1,71	0,26	4,20	0,20	2,82	0,26	3,60	3,17	44	-
41	Diesel (B7)	-1	10	66	401	10	86	14,0	2,2	477	2.086	340	2.727	0,24	1,25	0,60	2,61	0,42	3,41	0,55	4,32	6,81	53	-
42	Diesel (B7)	-1	7	68	403	14	87	12,2	4,6	73	1.044	60	1.631	0,04	1,15	0,09	1,31	0,07	2,04	0,10	2,61	1,20	32	-

Test index no.	Fuel	Ambient	Bus cabin	Coolant	Exhaust	Ignitions	Combustion efficiency	CO_2	O2	CO														Soot no.
		ºC	ºC	ºC	ºC	-	%	$\%_{vol}$	$\%_{vol}$	ppm measured		ppm at 10% CO_2		g/m³		g/Nm³		g/Nm³ at 10% CO_2		g/kWh		g/kg fuel		
		avg.	avg.	max	max	-	avg.	avg.	avg.	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.
43	Diesel (B7)	0	11	74	426	11	84	12,0	5,0	131	524	109	1.557	0,06	0,47	0,16	0,66	0,14	1,95	0,18	2,50	2,19	31	-
44	Diesel (B7)	-1	9	68	371	15	85	11,7	5,4	566	3.498	484	3.447	0,30	2,36	0,71	4,37	0,61	4,31	0,78	5,42	9,70	67	-
45	Diesel (B7)	0	8	64	368	9	86	12,5	4,2	93	6.690	74	16.421	0,05	4,09	0,12	8,36	0,09	20,53	0,12	22,96	1,50	284	-
46	Diesel (B7)	7	15	9	292	1	83	8,6	9,3	679	837	791	1.027	0,41	0,89	0,85	1,05	0,99	1,28	1,28	1,65	15,79	20	-
47	Diesel (B7)	2	18	69	394	1	72	7,0	11,5	1.024	3.437	1.458	5.497	0,52	3,21	1,28	4,30	1,82	6,87	2,34	8,48	28,92	105	-
48	Diesel (B7)	3	21	69	454	1	72	8,3	9,9	46	2.953	56	8.410	0,02	2,99	0,06	3,69	0,07	10,51	0,09	12,63	1,13	156	-
49	Diesel (B7)	2	16	79	385	8	79	8,4	9,8	263	2.425	313	5.298	0,14	2,01	0,33	3,03	0,39	6,62	0,51	8,19	6,28	101	-
50	Diesel (B7)	2	18	79	397	6	78	9,0	9,1	22	2.203	25	5.940	0,01	1,72	0,03	2,75	0,03	7,43	0,04	9,13	0,50	113	-
51	Diesel (B7)	5	9	59	395	4	79	9,5	7,8	73	2.502	77	7.311	0,04	2,36	0,09	3,42	0,10	9,14	0,12	11,09	1,54	137	0,0
52	Diesel (B7)	7	7	70	394	4	80	8,3	9,7	107	2.056	129	4.691	0,06	2,29	0,13	2,75	0,16	5,86	0,21	7,29	2,60	90	1,0
53	Diesel (B7)	8	10	72	411	4	78	9,3	8,3	23	1.846	24	5.150	0,01	1,74	0,03	2,94	0,03	6,44	0,04	7,97	0,49	99	0,0
54	Diesel (B7)	2	20	61	375	1	80	9,3	8,7	9	2.411	10	5.620	0,00	2,13	0,01	3,01	0,01	7,03	0,02	8,66	0,20	107	-
55	Diesel (B7)	5	9	53	405	4	79	9,7	7,7	18	1.729	18	4.882	0,01	1,98	0,02	2,97	0,02	6,10	0,03	7,58	0,37	94	0,3
56	Diesel (B7)	-1	8	82	461	9	81	7,6	10,8	200	2.921	265	7.302	0,09	3,17	0,25	3,65	0,33	9,13	0,43	11,08	5,31	137	-
57	Diesel (B7)	9	19	78	407	1	77	9,0	8,9	10	1.742	12	3.291	0,01	1,35	0,01	2,18	0,01	4,11	0,02	5,19	0,23	64	-
58	Diesel (B7)	-2	11	60	335	5	86	11,7	5,2	376	871	322	3.242	0,21	0,63	0,47	1,09	0,40	4,05	0,52	5,11	6,45	63	-
59	Diesel (B7)	0	17	71	377	5	83	10,8	6,9	257	1.039	239	1.575	0,13	0,72	0,32	1,30	0,30	1,97	0,39	2,52	4,80	31	-
60	Diesel (B7)	-1	10	72	443	4	83	13,7	2,8	666	1.334	486	4.594	0,32	0,73	0,83	1,67	0,61	5,74	0,79	7,15	9,73	88	-
61	Diesel (B7)	3	11	51	303	1	74	5,5	14,0	614	865	1.114	1.490	0,36	0,61	0,77	1,08	1,39	1,86	1,79	2,39	22,16	30	-
62	Diesel (B7)	0	14	70	434	2	84	14,5	2,4	1.397	3.278	961	4.150	0,67	1,63	1,75	4,10	1,20	5,19	1,55	6,48	19,15	80	-
63	Diesel (B7)	-1	12	70	334	4	86	12,4	4,6	101	561	82	1.342	0,06	0,41	0,13	0,70	0,10	1,68	0,13	2,16	1,65	27	-
64	Diesel (B7)	9	12	62	417	5	85	13,1	3,7	1.486	2.132	1.134	7.108	0,72	4,01	1,86	8,59	1,42	8,88	1,82	10,80	22,56	134	3,0

Table 6. PM and PN

Test index no.	Fuel	PM										PN									
		mg/m³		mg/Nm³		mg/Nm³ at 10% CO_2		mg/kWh		mg/kg fuel		#/m³		#/Nm³		#/Nm³ at 10% CO_2		#/kWh		#/kg fuel	
		avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max
1	Diesel (B7)	0,003	2,3	0,01	4,7	0,01	5,7	0,01	7,8	0,18	96	6,3E+09	1,1E+13	1,6E+10	2,3E+13	1,9E+10	2,7E+13	2,7E+10	3,8E+13	3,3E+11	4,6E+14
2	Diesel (B7)	0,016	0,44	0,04	0,74	0,04	0,86	0,06	1,2	0,75	15	7,1E+10	2,0E+12	1,7E+11	3,3E+12	2,0E+11	3,8E+12	2,8E+11	5,3E+12	3,4E+12	6,6E+13
3	Diesel (B7)	< 0,001	4,0	< 0,01	6,9	< 0,01	6,4	< 0,01	9,2	< 0,01	113	2,4E+09	2,0E+13	5,7E+09	3,4E+13	5,9E+09	3,1E+13	8,5E+09	4,5E+13	1,0E+11	5,6E+14
4	Diesel (B7)	0,005	0,76	0,01	1,7	0,01	1,9	0,02	2,7	0,20	34	1,2E+10	3,7E+12	2,6E+10	8,3E+12	3,0E+10	9,6E+12	4,2E+10	1,3E+13	5,2E+11	1,7E+14
5	Diesel (B7)	0,016	6,5	0,04	7,1	0,05	15	0,06	20	0,80	245	7,3E+10	3,1E+13	1,7E+11	3,4E+13	2,1E+11	6,9E+13	3,0E+11	9,4E+13	3,7E+12	1,2E+15
6	HVO100	0,134	1,4	0,30	3,1	0,25	2,4	0,36	3,5	4,5	43	6,3E+11	7,9E+12	1,4E+12	1,7E+13	1,2E+12	1,3E+13	1,7E+12	1,9E+13	2,1E+13	2,4E+14
7	HVO100	0,047	20	0,10	26	0,09	23	0,13	32	1,6	398	2,2E+11	9,5E+13	4,9E+11	1,2E+14	4,3E+11	1,1E+14	6,2E+11	1,5E+14	7,7E+12	1,9E+15
8	HVO100	0,065	6,3	0,14	10	0,13	11	0,19	16	2,4	192	3,1E+11	3,0E+13	6,8E+11	5,0E+13	6,4E+11	5,3E+13	9,2E+11	7,4E+13	1,1E+13	9,2E+14
9	HVO100	0,061	7,7	0,14	9,8	0,14	9,2	0,20	13	2,5	162	2,9E+11	3,7E+13	6,7E+11	4,8E+13	6,6E+11	4,5E+13	9,5E+11	6,4E+13	1,2E+13	7,9E+14
10	Diesel (B7)	0,021	13	0,06	13	0,07	16	0,10	22	1,2	277	9,7E+10	6,1E+13	2,7E+11	6,2E+13	3,3E+11	7,7E+13	4,6E+11	1,1E+14	5,7E+12	1,3E+15
11	Diesel (B7)	5,5	13	14	29	11,38	46	17	61	204	755	2,6E+13	6,4E+13	6,5E+13	1,4E+14	5,5E+13	2,2E+14	7,9E+13	3,0E+14	9,8E+14	3,7E+15
12	Diesel (B7)	3,1	7,3	7,7	15	6,5	56	9,4	72	116	893	1,5E+13	3,5E+13	3,7E+13	7,5E+13	3,1E+13	2,7E+14	4,5E+13	3,5E+14	5,6E+14	4,3E+15
13	Diesel (B7)	2,6	6,6	6,3	14	5,6	62	8,1	80	100	989	1,2E+13	3,1E+13	3,0E+13	6,8E+13	2,7E+13	2,9E+14	3,9E+13	3,8E+14	4,8E+14	4,6E+15
14	Diesel (B7)	32	100	78	227	58	173	85	252	1.056	3.111	1,4E+14	1,5E+14	3,4E+14	4,2E+14	2,6E+14	4,1E+14	3,7E+14	5,5E+14	4,6E+15	6,8E+15
15	Diesel (B7)	< 0,001	0,62	< 0,01	0,70	< 0,01	1,5	< 0,01	2,0	< 0,01	24	5,4E+08	2,8E+12	1,3E+09	3,2E+12	1,6E+09	6,6E+12	2,2E+09	8,9E+12	2,8E+10	1,1E+14
16	Diesel (B7)	< 0,001	3,41	< 0,01	5,4	< 0,01	7,6	< 0,01	10	< 0,01	126	6,9E+08	1,6E+13	1,7E+09	2,6E+13	1,9E+09	3,6E+13	2,7E+09	4,8E+13	3,4E+10	6,0E+14
17	Diesel (B7)	0,004	0,08	0,01	0,16	0,01	0,29	0,01	0,4	0,12	4,8	6,5E+09	3,4E+11	1,4E+10	7,2E+11	1,3E+10	1,3E+12	1,8E+10	1,8E+12	2,2E+11	2,2E+13
18	Diesel (B7)	0,003	0,12	0,01	0,29	0,01	0,30	0,01	0,4	0,15	5,3	7,1E+09	5,6E+11	1,7E+10	1,4E+12	1,8E+10	1,5E+12	2,6E+10	2,0E+12	3,2E+11	2,5E+13
19	Diesel (B7)	0,072	11	0,19	29	0,16	46	0,23	61	2,8	750	3,4E+11	5,4E+13	9,2E+11	1,4E+14	7,4E+11	2,2E+14	1,1E+12	2,9E+14	1,3E+13	3,5E+15
20	Diesel (B7)	1,1	100	2,9	240	2,4	260	3,4	356	43	4.406	5,2E+12	1,5E+14	1,4E+13	4,0E+14	1,1E+13	4,1E+14	1,6E+13	5,7E+14	2,0E+14	7,0E+15

Test index no.	Fuel	PM										PN									
		mg/m^3		mg/Nm^3		mg/Nm^3 at 10% CO_2		mg/kWh		mg/kg fuel		#/m^3		#/Nm^3		#/Nm^3 at 10% CO_2		#/kWh		#/kg fuel	
		avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max
21	Diesel (B7)	0,116	3,8	0,30	6,5	0,25	10	0,36	13	4,5	165	5,6E+11	1,7E+13	1,5E+12	2,8E+13	1,2E+12	4,3E+13	1,7E+12	5,9E+13	2,2E+13	7,2E+14
22	Diesel (B7)	0,207	1,2	0,54	2,7	0,43	4,9	0,62	6,5	7,7	80	9,9E+11	5,9E+12	2,6E+12	1,3E+13	2,0E+12	2,3E+13	3,0E+12	3,1E+13	3,7E+13	3,8E+14
23	Diesel (B7)	0,060	10	0,15	25	0,12	21	0,17	30	2,2	370	3,0E+11	4,9E+13	7,5E+11	1,2E+14	5,9E+11	9,9E+13	8,6E+11	1,4E+14	1,1E+13	1,8E+15
24	Diesel (B7)	0,006	1,9	0,01	4,2	0,01	3,4	0,02	5,0	0,22	62	1,9E+10	9,2E+12	4,7E+10	2,0E+13	4,0E+10	1,6E+13	5,8E+10	2,4E+13	7,1E+11	2,9E+14
25	Diesel (B7)	0,661	20	1,6	49	1,5	45	2,1	64	26	796	3,4E+12	9,0E+13	8,4E+12	2,2E+14	7,6E+12	2,0E+14	1,1E+13	2,9E+14	1,4E+14	3,6E+15
26	Diesel (B7)	0,043	3,1	0,11	3,9	0,12	6,0	0,17	8,2	2,1	101	2,1E+11	1,5E+13	5,1E+11	1,8E+13	5,7E+11	2,8E+13	8,1E+11	3,9E+13	1,0E+13	4,8E+14
27	Diesel (B7)	0,007	0,86	0,02	1,2	0,02	2,6	0,03	3,5	0,37	43	2,3E+10	3,9E+12	5,4E+10	5,7E+12	6,3E+10	1,2E+13	9,0E+10	1,6E+13	1,1E+12	1,9E+14
28	Diesel (B7)	0,018	13	0,04	23	0,04	23	0,06	32	0,78	400	9,2E+10	6,3E+13	2,2E+11	1,1E+14	2,3E+11	1,1E+14	3,3E+11	1,6E+14	4,1E+12	2,0E+15
29	HVO100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	HVO100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	HVO100	0,077	7,5	0,19	11	0,18	30	0,25	40	3,1	495	3,7E+11	3,6E+13	9,1E+11	5,2E+13	8,5E+11	1,4E+14	1,2E+12	1,9E+14	1,5E+13	2,3E+15
32	HVO100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	HVO100	0,423	3,6	0,95	5,5	1,0	7,9	1,5	11	18	135	2,0E+12	1,8E+13	4,6E+12	2,8E+13	4,9E+12	3,9E+13	7,0E+12	5,5E+13	8,6E+13	6,7E+14
34	HVO100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35	HVO100	< 0,001	0,00	< 0,01	0,01	< 0,01	0,07	< 0,01	0,1	< 0,01	1,0	1,9E+09	1,1E+10	3,9E+09	2,3E+10	4,9E+09	1,7E+11	6,8E+09	2,2E+11	8,4E+10	2,7E+12
36	Diesel (B7)	0,019	24	0,05	47	0,05	40	0,07	57	0,90	704	8,0E+10	1,2E+14	2,0E+11	2,3E+14	2,2E+11	1,9E+14	3,1E+11	2,8E+14	3,9E+12	3,4E+15
37	Diesel (B7)	0,001	1,1	< 0,01	1,8	< 0,01	2,3	0,01	3,1	0,07	39	4,3E+09	5,3E+12	1,1E+10	8,7E+12	1,2E+10	1,1E+13	1,7E+10	1,5E+13	2,1E+11	1,9E+14
38	Diesel (B7)	< 0,001	5,8	< 0,01	11	< 0,01	11	< 0,01	15	< 0,01	189	2,6E+09	2,8E+13	6,4E+09	5,4E+13	6,9E+09	5,2E+13	9,9E+09	7,4E+13	1,2E+11	9,2E+14
39	Diesel (B7)	0,006	5,0	0,01	5,8	0,02	5,9	0,03	8,1	0,41	100	1,7E+10	2,4E+13	4,2E+10	2,8E+13	7,1E+10	2,9E+13	9,8E+10	3,9E+13	1,2E+12	4,9E+14
40	Diesel (B7)	1,9	82	4,4	202	3,3	137	4,9	200	61	2.478	9,3E+12	1,5E+14	2,1E+13	3,8E+14	1,6E+13	2,6E+14	2,4E+13	3,8E+14	2,9E+14	4,7E+15
41	Diesel (B7)	19	47	44	80	31	146	46	193	570	2.387	8,9E+13	1,5E+14	2,1E+14	2,9E+14	1,5E+14	6,9E+14	2,2E+14	9,1E+14	2,7E+15	1,1E+16
42	Diesel (B7)	0,476	28	1,0	31	0,83	31	1,2	43	15	535	2,3E+12	1,3E+14	4,9E+12	1,4E+14	4,0E+12	1,5E+14	5,8E+12	2,1E+14	7,2E+13	2,6E+15

Test index no.	Fuel	PM										PN									
		mg/m³		mg/Nm³		mg/Nm³ at 10% CO_2		mg/kWh		mg/kg fuel		#/m³		#/Nm³		#/Nm³ at 10% CO_2		#/kWh		#/kg fuel	
		avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max
43	Diesel (B7)	1,0	2,6	2,3	5,4	1,9	10	2,8	14	35	172	4,8E+12	1,3E+13	1,1E+13	2,6E+13	9,3E+12	4,6E+13	1,3E+13	6,1E+13	1,7E+14	7,5E+14
44	Diesel (B7)	2,0	14	4,3	25	3,7	54	5,3	70	66	870	9,4E+12	6,5E+13	2,1E+13	1,2E+14	1,8E+13	2,6E+14	2,5E+13	3,4E+14	3,1E+14	4,2E+15
45	Diesel (B7)	0,382	100	0,86	221	0,68	523	1,0	635	12	7.855	1,8E+12	1,5E+14	4,1E+12	3,5E+14	3,3E+12	7,8E+14	4,8E+12	9,8E+14	5,9E+13	1,2E+16
46	Diesel (B7)	0,008	1,8	0,02	2,4	0,02	3,2	0,03	4,3	0,32	53	2,5E+10	3,5E+13	5,1E+10	7,3E+13	5,9E+10	8,5E+13	8,3E+10	1,2E+14	1,0E+12	1,5E+15
47	Diesel (B7)	0,611	100	1,5	105	2,1	261	2,9	346	36	4.278	2,9E+12	1,5E+14	7,2E+12	1,6E+14	1,0E+13	3,9E+14	1,4E+13	5,2E+14	1,7E+14	6,4E+15
48	Diesel (B7)	0,011	7,4	0,03	14	0,04	18	0,05	23	0,61	290	3,4E+10	3,6E+13	9,0E+10	6,6E+13	1,1E+11	8,9E+13	1,5E+11	1,1E+14	1,9E+12	1,4E+15
49	Diesel (B7)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	Diesel (B7)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	Diesel (B7)	0,018	11	0,05	17	0,05	102	0,07	134	0,83	1.657	1,1E+11	5,1E+13	2,8E+11	8,3E+13	2,9E+11	4,4E+14	4,1E+11	5,8E+14	5,1E+12	7,1E+15
52	Diesel (B7)	0,031	16	0,07	41	0,08	48	0,12	68	1,4	837	1,5E+11	7,8E+13	3,3E+11	1,9E+14	4,0E+11	2,3E+14	5,6E+11	3,2E+14	6,9E+12	4,0E+15
53	Diesel (B7)	< 0,001	3,4	< 0,01	7,1	< 0,01	7,00	< 0,01	9,9	< 0,01	123	1,1E+10	1,6E+13	2,7E+10	3,4E+13	2,9E+10	3,3E+13	4,1E+10	4,7E+13	5,1E+11	5,9E+14
54	Diesel (B7)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55	Diesel (B7)	0,003	7,4	0,01	14	0,01	14	0,01	20	0,14	241	1,6E+10	3,6E+13	4,0E+10	6,7E+13	4,1E+10	6,6E+13	5,9E+10	9,3E+13	7,3E+11	1,2E+15
56	Diesel (B7)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
57	Diesel (B7)	0,003	0,12	0,01	0,31	0,01	0,33	0,01	0,5	0,16	5,8	5,7E+09	5,4E+11	1,4E+10	1,4E+12	1,6E+10	1,4E+12	2,2E+10	2,1E+12	2,7E+11	2,5E+13
58	Diesel (B7)	0,340	1,8	0,73	3,2	0,63	3,1	0,91	4,4	11	54	1,6E+12	9,0E+12	3,5E+12	1,5E+13	3,0E+12	1,5E+13	4,4E+12	2,1E+13	5,4E+13	2,7E+14
59	Diesel (B7)	0,099	0,35	0,23	0,60	0,21	1,1	0,30	1,5	3,7	18	4,7E+11	1,6E+12	1,1E+12	2,9E+12	1,0E+12	5,2E+12	1,4E+12	6,9E+12	1,8E+13	8,6E+13
60	Diesel (B7)	13	94	33	234	24	171	35	251	435	3.097	6,0E+13	1,5E+14	1,6E+14	3,8E+14	1,1E+14	2,7E+14	1,7E+14	4,0E+14	2,1E+15	5,0E+15
61	Diesel (B7)	0,431	1,6	0,90	2,2	1,6	6,1	2,2	8,1	27	100	2,1E+12	7,7E+12	4,3E+12	1,1E+13	7,8E+12	2,9E+13	1,1E+13	3,9E+13	1,3E+14	4,8E+14
62	Diesel (B7)	15	100	38	206	26	153	38	224	473	2.765	7,0E+13	1,5E+14	1,8E+14	3,9E+14	1,2E+14	2,6E+14	1,8E+14	3,9E+14	2,2E+15	4,8E+15
63	Diesel (B7)	1,8	92	4,0	202	3,3	156	4,7	227	59	2.806	8,7E+12	1,5E+14	1,9E+13	3,3E+14	1,6E+13	2,6E+14	2,3E+13	3,7E+14	2,8E+14	4,6E+15
64	Diesel (B7)	18	100	44	258	34	191	49	280	610	3.456	5,4E+13	1,5E+14	1,3E+14	3,9E+14	1,0E+14	3,4E+14	1,5E+14	4,8E+14	1,8E+15	5,9E+15

Table 7. NO_x

Test index no.	Fuel	NO_x													
		ppm measured		ppm at 10% CO_2		g/m^3		g/Nm^3		g/Nm^3 at 10% CO_2		g/kWh		g/kg fuel	
		avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max
1	Diesel (B7)	60	87	70	112	0,05	0,07	0,12	0,18	0,14	0,23	0,19	0,30	2,29	3,66
2	Diesel (B7)	63	69	72	144	0,05	0,09	0,13	0,14	0,15	0,30	0,19	0,39	2,38	4,76
3	Diesel (B7)	71	78	74	76	0,06	0,07	0,15	0,16	0,15	0,16	0,20	0,20	2,45	2,51
4	Diesel (B7)	66	75	78	122	0,06	0,07	0,14	0,15	0,16	0,25	0,21	0,32	2,55	3,98
5	Diesel (B7)	70	70	84	344	0,06	0,08	0,14	0,14	0,17	0,70	0,22	0,92	2,77	11,33
6	HVO100	59	70	50	219	0,05	0,10	0,10	0,14	0,09	0,45	0,12	0,58	1,43	7,18
7	HVO100	80	83	70	150	0,06	0,11	0,14	0,17	0,12	0,31	0,16	0,40	2,00	4,95
8	HVO100	72	68	68	105	0,06	0,08	0,13	0,14	0,12	0,22	0,16	0,28	1,95	3,47
9	HVO100	81	74	80	155	0,06	0,11	0,14	0,15	0,14	0,32	0,19	0,41	2,30	5,10
10	Diesel (B7)	63	126	77	109	0,05	0,16	0,13	0,26	0,16	0,22	0,21	0,29	2,55	3,60
11	Diesel (B7)	102	132	85	321	0,07	0,21	0,21	0,27	0,18	0,66	0,23	0,85	2,81	10,47
12	Diesel (B7)	109	132	91	469	0,08	0,10	0,22	0,27	0,19	0,96	0,24	1,22	3,00	15,04
13	Diesel (B7)	96	123	85	521	0,07	0,09	0,20	0,25	0,18	1,07	0,23	1,35	2,82	16,74
14	Diesel (B7)	128	171	96	308	0,09	0,15	0,26	0,35	0,20	0,63	0,25	0,80	3,15	9,93
15	Diesel (B7)	54	61	68	118	0,05	0,07	0,11	0,13	0,14	0,24	0,18	0,31	2,24	3,88
16	Diesel (B7)	74	103	87	233	0,06	0,12	0,15	0,21	0,18	0,48	0,23	0,62	2,88	7,68
17	Diesel (B7)	108	135	97	327	0,11	0,13	0,25	0,28	0,23	0,67	0,30	0,87	3,67	10,74
18	Diesel (B7)	89	101	94	147	0,07	0,08	0,18	0,21	0,19	0,30	0,25	0,39	3,10	4,85
19	Diesel (B7)	135	154	109	676	0,10	0,12	0,28	0,31	0,22	1,39	0,29	1,79	3,58	22,19
20	Diesel (B7)	95	99	78	159	0,07	0,08	0,19	0,20	0,16	0,33	0,21	0,42	2,57	5,19

Test index no.	Fuel	NOx													
		ppm measured		ppm at 10% CO_2		g/m^3		g/Nm^3		g/Nm^3 at 10% CO_2		g/kWh		g/kg fuel	
		avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max
21	Diesel (B7)	85	88	70	103	0,07	0,07	0,17	0,18	0,14	0,21	0,19	0,27	2,30	3,39
22	Diesel (B7)	92	100	73	220	0,07	0,08	0,19	0,20	0,15	0,45	0,19	0,58	2,41	7,18
23	Diesel (B7)	95	100	74	150	0,07	0,08	0,20	0,21	0,15	0,31	0,20	0,40	2,44	4,92
24	Diesel (B7)	103	119	88	211	0,08	0,10	0,21	0,24	0,18	0,43	0,23	0,56	2,90	6,94
25	Diesel (B7)	100	111	90	389	0,08	0,09	0,20	0,23	0,18	0,80	0,24	1,02	2,97	12,67
26	Diesel (B7)	70	78	78	80	0,06	0,07	0,14	0,16	0,16	0,16	0,21	0,21	2,59	2,66
27	Diesel (B7)	67	77	78	81	0,06	0,08	0,14	0,16	0,16	0,17	0,21	0,22	2,58	2,67
28	Diesel (B7)	76	86	80	252	0,06	0,09	0,16	0,18	0,16	0,52	0,21	0,67	2,65	8,29
29	HVO100	135	127	133	525	0,11	0,12	0,24	0,26	0,24	1,08	0,31	1,38	3,82	17,09
30	HVO100	93	84	84	140	0,07	0,07	0,17	0,17	0,15	0,29	0,19	0,37	2,40	4,56
31	HVO100	92	82	85	276	0,07	0,07	0,16	0,17	0,15	0,57	0,20	0,73	2,44	8,97
32	HVO100	133	120	136	121	0,10	0,10	0,24	0,25	0,24	0,25	0,32	0,32	3,90	4,00
33	HVO100	116	106	125	272	0,09	0,10	0,21	0,22	0,22	0,56	0,29	0,72	3,57	8,88
34	HVO100	84	92	98	117	0,07	0,09	0,15	0,19	0,17	0,24	0,23	0,31	2,78	3,85
35	HVO100	76	79	94	171	0,06	0,08	0,14	0,16	0,17	0,35	0,22	0,44	2,67	5,45
36	Diesel (B7)	86	131	96	258	0,07	0,12	0,18	0,27	0,20	0,53	0,26	0,69	3,17	8,52
37	Diesel (B7)	68	76	77	146	0,06	0,08	0,14	0,16	0,16	0,30	0,20	0,39	2,53	4,81
38	Diesel (B7)	59	70	64	113	0,05	0,07	0,12	0,14	0,13	0,23	0,17	0,30	2,10	3,72
39	Diesel (B7)	53	101	89	106	0,04	0,13	0,11	0,21	0,18	0,22	0,24	0,28	2,95	3,49
40	Diesel (B7)	120	149	91	360	0,10	0,13	0,25	0,31	0,19	0,74	0,24	0,95	2,99	11,68
41	Diesel (B7)	142	182	101	510	0,12	0,15	0,29	0,37	0,21	1,04	0,27	1,32	3,32	16,37
42	Diesel (B7)	87	110	71	267	0,07	0,13	0,18	0,22	0,15	0,55	0,19	0,70	2,34	8,69

Test index no.	Fuel	NO_x													
		ppm measured		ppm at 10% CO_2		g/m^3		g/Nm^3		g/Nm^3 at 10% CO_2		g/kWh		g/kg fuel	
		avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max	avg.	max
43	Diesel (B7)	81	96	67	238	0,06	0,08	0,17	0,20	0,14	0,49	0,18	0,63	2,22	7,79
44	Diesel (B7)	78	105	66	238	0,07	0,09	0,16	0,21	0,14	0,49	0,18	0,61	2,18	7,59
45	Diesel (B7)	112	152	89	256	0,10	0,13	0,23	0,31	0,18	0,52	0,24	0,68	2,95	8,36
46	Diesel (B7)	72	77	84	88	0,07	0,10	0,15	0,16	0,17	0,18	0,22	0,23	2,75	2,87
47	Diesel (B7)	41	48	58	69	0,03	0,05	0,08	0,10	0,12	0,14	0,15	0,18	1,89	2,17
48	Diesel (B7)	41	57	49	62	0,03	0,06	0,08	0,12	0,10	0,13	0,13	0,17	1,63	2,06
49	Diesel (B7)	55	61	66	248	0,05	0,07	0,11	0,13	0,13	0,51	0,18	0,65	2,16	8,04
50	Diesel (B7)	66	70	72	242	0,06	0,07	0,13	0,14	0,15	0,50	0,19	0,64	2,39	7,94
51	Diesel (B7)	58	91	61	110	0,05	0,08	0,12	0,19	0,12	0,23	0,16	0,29	2,00	3,62
52	Diesel (B7)	58	61	70	106	0,05	0,10	0,12	0,12	0,14	0,22	0,19	0,28	2,31	3,48
53	Diesel (B7)	64	74	69	119	0,05	0,07	0,13	0,15	0,14	0,24	0,18	0,32	2,27	3,93
54	Diesel (B7)	63	66	67	69	0,05	0,07	0,13	0,13	0,14	0,14	0,18	0,18	2,22	2,26
55	Diesel (B7)	57	71	58	98	0,05	0,07	0,12	0,15	0,12	0,20	0,16	0,26	1,92	3,23
56	Diesel (B7)	37	62	49	131	0,03	0,11	0,08	0,13	0,10	0,27	0,13	0,35	1,63	4,33
57	Diesel (B7)	65	77	72	155	0,05	0,06	0,13	0,16	0,15	0,32	0,19	0,41	2,38	5,10
58	Diesel (B7)	83	98	71	204	0,08	0,09	0,17	0,20	0,15	0,42	0,19	0,54	2,33	6,65
59	Diesel (B7)	85	96	79	149	0,07	0,09	0,18	0,20	0,16	0,31	0,21	0,39	2,61	4,86
60	Diesel (B7)	114	132	83	176	0,09	0,12	0,23	0,27	0,17	0,36	0,22	0,46	2,72	5,68
61	Diesel (B7)	40	43	72	76	0,04	0,04	0,08	0,09	0,15	0,16	0,19	0,20	2,36	2,47
62	Diesel (B7)	98	132	67	238	0,08	0,12	0,20	0,27	0,14	0,49	0,18	0,63	2,20	7,84
63	Diesel (B7)	99	117	80	500	0,09	0,11	0,20	0,24	0,16	1,03	0,21	1,32	2,65	16,28
64	Diesel (B7)	62	69	47	252	0,05	0,07	0,13	0,14	0,10	0,52	0,12	0,67	1,53	8,25

Appendix 2: Data from other projects

Table 8. Measurement data from other projects

Report	Heater	Measured by	Procedure	Fuel	Heat output	CO_2	CO		NO_x			PM		PN			Soot no.	Exhaust
					kW	%	ppm measured	mg/Nm^3 at 10% CO_2	ppm	mg/Nm^3 at 10% CO_2	g/kg	mg/Nm^3 at 10% CO_2	g/kg	#/m^3	#/Nm^3 at 10% CO_2	#/kg	-	ºC
Technological Institute, "Biodiesel DK – Demonstration Project, TP7, bus heaters, 2009-2010"	Stroco	Manufacturer	Measurement on test Bench at manufacturer	B30	-	10,1	-	-	90	-	-	-	-	-	-	-	-	289
				Fossil diesel	-	10,1	-	-	83	-	-	-	-	-	-	-	-	296
		Technological Institute	Measurement on test bench at Technological Institute	B30	23	9,1	93	-	93	-	-	-	-	-	-	-	0,3	332
				Fossil diesel	23	8,4	56	-	83	-	-	-	-	-	-	-	0,5	331
			Measurement on heater installed in bus	B10	-	11,1	93	-	102	-	-	-	-	-	-	-	1,5	426
Force Technology, "Measurement of emissions from diesel fired heaters for buses", report no. 118-22672.02, April 2018	Stroco 3500	Force Technology	Measurement on test bench at Force Technology after 45 min preheating	B7	-	8,9	-	98	-	196	-	0,87	-	-	4,1E+12	-	-	-
				HVO	-	9,2	-	93	-	201	-	0,044	-	-	2,2E+11	-	-	-
				FAME	-	8,5	-	92	-	166	-	0,081	-	-	3,9E+11	-	-	-
	Spheros Thermo 300			B7	-	11,1	-	111	-	148	-	0,022	-	-	1,4E+11	-	-	-
				HVO	-	11,6	-	121	-	183	-	0,0044	-	-	6,2E+10	-	-	-
				FAME	-	12,3	-	142	-	190	-	0,019	-	-	1,3E+11	-	-	-
Technological Institute for Movia, "Diesel fired bus heaters", report no. 2016-1032147	NN	Technological Institute	Measurement on heater installed in bus	Fossil diesel	-	-	-	-	70	-	-	-	-	2,0E+12	-	-	-	-
IVL Svenska Miljöinstitutet 2018, "En kunskapsinventering om utsläpp från bränslevärmare i elbussar", report no. U 6048.	Spheros 230	IVL (2018)	Measurement on heater installed in bus	Fossil diesel	-	-	-	-	-	-	1,7	-	0,20	-	-	-	-	-
	NN	Vojtisek-Lom et al (2015)	Measurement on test bench	Fossil diesel	-	-	-	-	-	-	4,5	-	-	-	-	1,7E+12	-	-
Average measurements above	-	-	-	-	-	10,0	81	110	87	181	3,1	0,17	0,20	2,0E+12	8,4E+11	1,7E+12	0,8	335
Average this project	-	-	-	-	-	10,2	210	260	82	159	2,5	3,48	0,07	9,4E+12	1,5E+13	3,2E+14	1,1	396