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Measurement of Carbon Monoxide Emissions from Domestic Gas Appliances at Low Ventilation Rates

CBRU/2015/080/R

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HSL Project Number:	**PE01871**

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EXECUTIVE SUMMARY

Objectives

To investigate the potential concentration of carbon monoxide due to emissions from gas appliances in domestic buildings with low ventilation rates.

Method

Four different domestic gas appliances were chosen for testing. These were:

- a four ring hob single oven gas cooker,
- a wall-mounted flue-less gas fire,
- a portable cabinet heater,
- a standard gas fire requiring a flue.

A bespoke test room was designed and built, which incorporated mechanical ventilation. The mechanically driven ventilation rates used for testing were 1.00, 0.50, 0.25, 0.125 h^{-1}, these rates are typical of naturally ventilated spaces, i.e. no mechanical ventilation. A minimum ventilation rate of <0.02 h^{-1} i.e. ≈0.00 h^{-1} was also used that was achieved by switching off the extraction fan, therefore providing no mechanical ventilation. However, this rate is determined by temperature and pressure variances across the building envelope which can vary from day to day.

The concentrations of carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) were measured in the test room at four different positions using MultiRAE PLUS real-time gas monitors.

Main Findings

- Concentrations of CO did not exceed the 15 minute Short Term Exposure Limit (STEL) value of 200 ppm at any time during the test.
- A gas cooker with all four gas hob rings at maximum could be capable of emitting enough CO to exceed the 8-hour Workplace Exposure Limit (WEL) of 30 ppm, although this would be extremely unlikely in practice as this raised the ambient temperature in the test room above approximately 40 °C, which would not be comfortable for an occupant.
- Operating the gas oven alone at its maximum setting resulted in a maximum CO concentration of 9.2 ppm and typically had an equilibrium value of 6 to 7 ppm.
- With the flue-less gas fire operating at maximum, the concentration of CO never exceeded 7.2 ppm and could therefore be operated without risk of harmful exposure to CO.
- When using a portable cabinet heater at a ventilation rate of ≈0.00 h^{-1}, a CO concentration of 33.4 ppm was detected, which was the highest recorded concentration during any test.

- A portable cabinet heater could emit enough CO to cause exposures of approximately 30 ppm if operated in a room with a ventilation rate of less than 0.25 h^{-1}.
- It should be noted that the cabinet heater was tested in conditions outside of the manufacturer's recommendations, i.e. lower that the recommended room ventilation rate.
- A properly installed flue can provide a natural ventilation rate to a room exceeding 1.00 h^{-1}.
- A gas fire in good working order when connected to a properly installed flue can be operated indefinitely without emitting any harmful concentrations of either CO or CO_2. Tests carried out using the gas fire with a flue produced peak CO concentrations of less than 5 ppm.
- Although none of the appliances tested produced harmful levels of CO, ventilation rates of <0.5 h^{-1} to 1.0 h^{-1} were less efficient at removing CO.
- Oxygen levels in the room remained above 20% v/v when the oven alone and fire with flue were in use. All other appliances resulted in oxygen levels ranging 17.8 - 19.9% v/v. The minimum oxygen level measured was 17.8% v/v during use of the hob rings with no mechanical ventilation.
- For all appliances except the gas fire with a flue, the STEL for CO_2 was exceeded at least once during testing. The highest concentration of CO_2 was 1.93% v/v, measured during use of the hob rings with no mechanical ventilation. Similarly, for all appliances except the gas fire with flue the concentration for the 8-hour WEL was exceeded but for considerably shorter periods than 8 h.
- A functioning ASD fitted to the cabinet heater should have activated once the CO_2 concentration exceeded 0.8 v/v. Although the air in the test room was considered to be relatively well mixed there was no measurement position at the exact location of the heater so it is not known what the CO_2 concentration was here.

CONTENTS

1 INTRODUCTION

This is a reissued version of the original report CBRU/2015/080. The revisions include editorial changes to the chapter numbering and some clarifying comments regarding operation of the cabinet heater outside of the manufacturer's recommendations.

There is a trend to increase the energy efficiency of homes by increasing insulation and air tightness, subsequently reducing the ventilation or air change rates (ACR) of the housing stock in the United Kingdom (UK). This could cause increased concentrations of carbon monoxide (CO) in dwellings and potential chronic exposure to low concentrations of CO.

The Health and Safety Laboratory (HSL) was contracted by the Institution of Gas Engineers and Managers (IGEM) to investigate the potential concentration of carbon monoxide in domestic buildings with low ventilation rates due to emissions from gas appliances. The work was completed in two parts; the first being a focused literature review and the second being experimental work to measure CO concentrations from gas appliances under controlled conditions.

The literature review (Baldwin, 2014) concluded that there are likely to be a significant number of dwellings with ventilation rates below 0.2 air changes per hour (ach or h^{-1}) in the UK's older housing stock, as older houses are being retrospectively fitted with ways to increase the existing energy efficiency e.g. sealed unit double glazing. Baldwin also found that exposure to CO can have health effects at concentrations as low as 17 parts per million (ppm) in susceptible individuals such as pregnant women or the elderly and at 70 ppm in non-susceptible populations.

Existing studies had been performed at higher ventilation rates than found in current dwellings, which could under-estimate the actual CO concentrations at lower ventilation rates. A recommendation to test at controlled ventilation rates $<0.5\ h^{-1}$ was made in order to better model the current housing stock and provide valuable additional information to the industry.

Previous work also reportedly measured concentrations of other combustion gases, such as carbon dioxide (CO_2), above the corresponding HSE workplace exposure limits. Therefore, CO_2 and Oxygen (O_2) concentrations were measured in this study to provide a more complete picture.

Considering the findings of the literature review, experimental work was planned to measure CO emissions from a range of domestic gas appliances at low ventilation rates. This report presents and discusses the findings of the experimental work.

2 METHODS

2.1 TEST ROOM

A bespoke test room (Figure 2) was designed and built with dimensions 4.0 x 4.0 x 2.7 m (length x width x height), a typical representative size for rooms in domestic properties. The walls and ceiling were built from Knauf Fire Panels supported by an exterior wooden frame. Gaps between the panels and between the walls and the concrete floor were sealed in order to control air infiltration through planned gaps only. A standard domestic interior door was included for access.

A thin slit (0.50 length × 0.01 m height) was cut in to the right-hand wall to allow air to enter the room to simulate trickle vents found in modern double glazed window units. Air was extracted from the room through a grille on the opposite wall, which was connected to ducting and a fan to mechanically ventilate the room (Section 2.3).

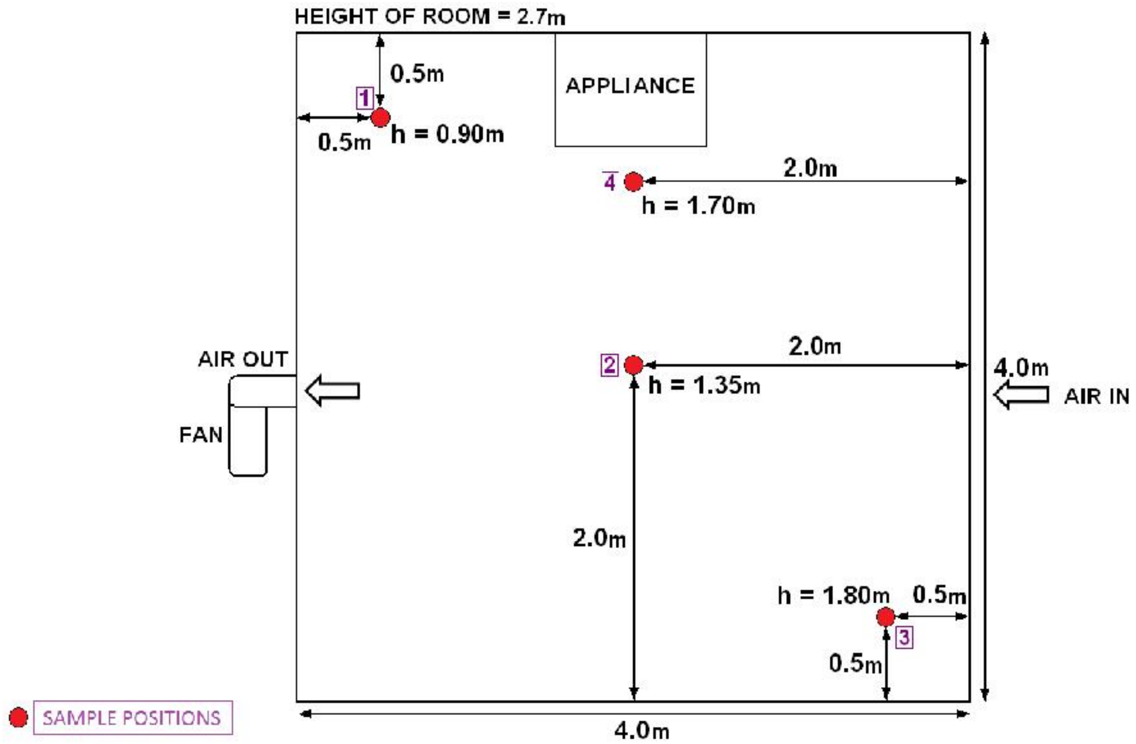

Figure 2.1 Test room layout, dimensions and sample positions

A flue was installed for testing of the gas fire, the opening of which was sealed during tests where it wasn't required. The flue was installed by registered gas safe engineers and exhausted outside of the building containing the test room shown in Figure 2.2.

Figure 2.2 Flue discharging outside of the building containing the test room

2.2 APPLIANCES

Four different domestic gas appliances were chosen for testing. These are described in Table 2.1.

Table 2.1 The four appliances used for testing for this research.

Description	Rating / kW	Inlet pressure / mbar	Fuel type	Image
Four ring hob single oven gas cooker	Oven: 2.8 Burners: 2 x 1.9 1 x 1.0 1 x 3.0	20 – 2	Natural gas	
Wall-mounted flue-less gas fire	1.5 - 2.6	20 – 2	Natural gas	

Description	Rating / kW	Inlet pressure / mbar	Fuel type	Image
Portable cabinet heater	4.2	28 – 2	Commercially available butane	
Standard gas fire requiring a flue	3.5 - 6.2	20 – 2	Natural gas	

All appliances were in the lower to mid-price range and properly functioning, as the purpose of this study was to determine the performance of appliances during normal use. Data was only collected for one example of each appliance; however these examples were chosen to be representative of appliances found commonly installed in domestic buildings. All appliances were installed and commissioned by a qualified Gas Safe registered engineer. A fixed manometer was connected to the natural gas supply to allow a tightness test and working pressure check before each test to ensure the fixed appliances were safe and working at a pressure representative of a domestic setting i.e. approximately 21 mbar. The portable cabinet heater used a commercially available cylinder of butane. The gross inlet pressure stated for this appliance was 28 – 2 mbar.

2.3 VENTILATION

The ventilation was set to ensure low ventilation rates in the room to represent modern housing, or housing which has been retrospectively fitted with ‘energy-saving improvements’. The maximum mechanically driven ventilation rate used for testing was 1.00 h^{-1} for the gas cooker. The lower ventilation rates used for testing the other appliances were: 0.50 h^{-1}, 0.25 h^{-1}, 0.125 h^{-1} and ≈0.00 h^{-1}. A ventilation rate of ≈0.00 h^{-1} was achieved by switching off the extraction fan and therefore providing no mechanical ventilation. When measured, the actual ventilation rate under these conditions was found to be <0.02 h^{-1}. However, this rate is determined by temperature and pressure variances across the building envelope which can vary from day to day.

A differential pressure flow measurement device was installed as part of the ductwork carrying the air, which was extracted from the room. The pressure across this device was measured and monitored using a calibrated micro-manometer to allow the operator to set and maintain a consistent ventilation rate in the room during testing.

The volume flow rate was altered by means of a variable speed fan and a valve on the outlet of the fan. A combination of these two controls determined the ventilation rate in the room. The extracted air was then exhausted outside of the building containing the test room in order to prevent re-entrainment of any extracted combustion products back into the test room.

2.4 MEASURING GAS CONCENTRATIONS

Four MultiRAE PLUS real-time gas monitors were used to monitor and record the data within the test chamber. Each instrument was set to log gas concentrations every 60 s and output the peak value from this time period. The instruments have a detection range of 0 - 500 ppm for CO, a limit of detection of 1 ppm, and a resolution of 1 ppm.

The instruments were functionally checked before each day of testing. All underwent a ‘fresh air check’, four were checked against CO, three for CO_2 and one for methane as a precaution to monitor for a potential gas leak.

A plan view of the sample positions can be seen at Figure 2.1. Sample positions 1, 2, and 3 were a lower corner, geometric centre, and upper corner of the room respectively. Sample position 4 was selected to be head height (1.7 m) of a person standing in front of the appliance. The real-time instruments were positioned outside the test chamber and connected to sample lines which terminated at the sample positions within the room (Figures 2.1 and 2.3). The sample lines were constructed from 6.0 mm outer diameter, 4 mm inner diameter nylon tubing 6.5 m in length and passed through small holes in the wall to the instruments (Figure 2.4). The volume flow rate of the samplers was 0.2 L/min, this meant that there was a delay of approximately 55 s from sample position to instrument; this time delay was insignificant compared with the test duration and the rate at which gas concentrations were anticipated to be changing.

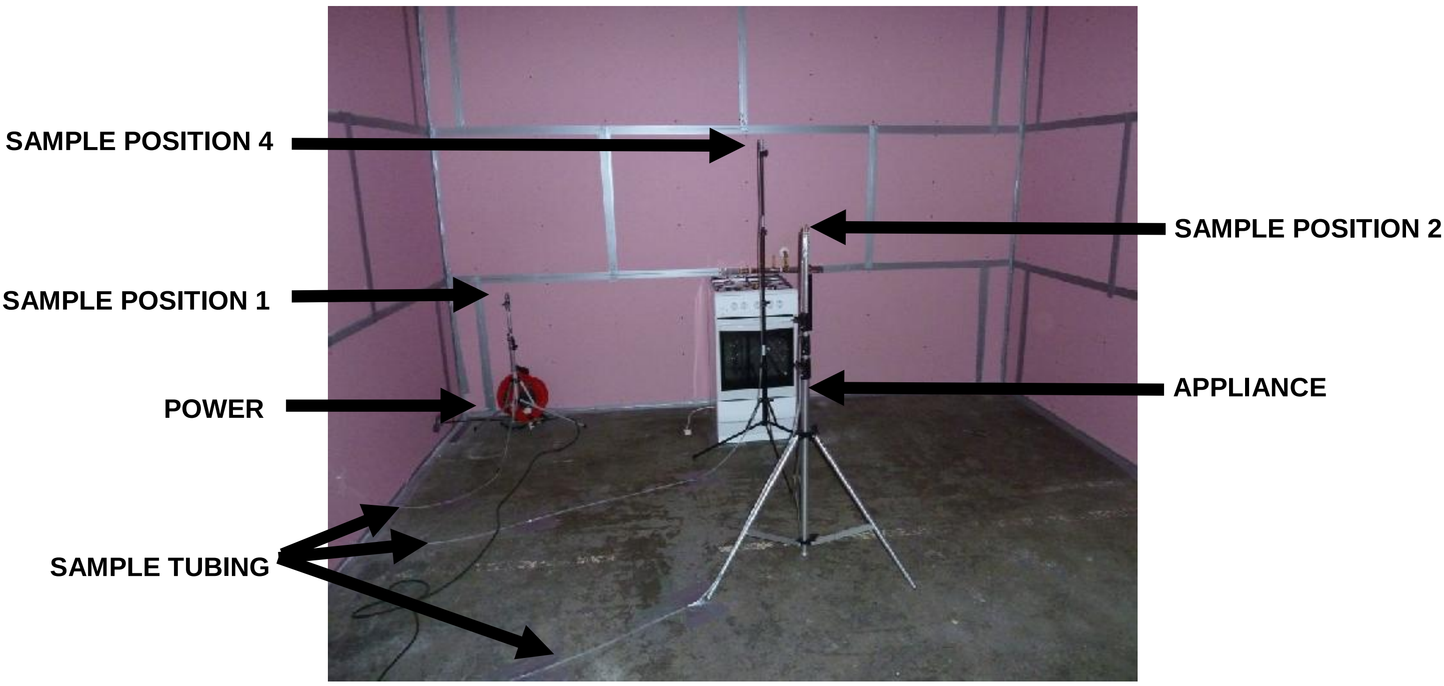

Figure 2.3 Photograph of experimental set-up including the locations of sample positions 1, 2 and 4 in relation to the position of the appliance.

Figure 2.4 Photograph of the sample lines exiting the test room attached to the MultiRAE real time instruments.

The concentration of CO produced when the appliances were running, at a range of ventilation rates, was monitored over realistic time frames to simulate the normal domestic use of the appliance. These planned tests are shown in Table 2.2. Some of the tests did not run for the planned duration, due to the CO concentration reaching equilibrium and remaining unchanged for an extended period of time. Some of the ventilation rates included in the test plan were not included in the experimental work. This was because the CO concentrations measured at lower ventilation rates were found to be extremely low and higher ventilation rates would therefore result in concentrations that would remain at even lower levels.

It was decided that if the temperature were to rise to approximately 40 °C then the test would also be stopped, as it was considered that this would represent conditions which were extremely unlikely to occur in a domestic setting due to the appliance being switched off by the user.

Table 2.2 Plan for Testing

Test No.	Appliance	Test conditions	Ventilation rate / h^{-1}	Test Duration / h
1	Cooker	Oven maximum, all hob rings maximum	1.00	1
2			0.25	
3			≈0.00	
4		Oven maximum, no hob rings	1.00	3
5			0.25	
6			≈0.00	
7		Oven off, all hob rings maximum	1.00	8
8			0.25	
9			≈0.00	
10	Flue-less fire	Fire maximum	1.00	12
11			0.50	
12			0.25	
13			≈0.00	
14	Portable cabinet heater	Heater maximum	1.00	12
15			0.50	
16			0.25	
17			≈0.00	
18	Fire with flue	Fire maximum	1.00	12
19			0.25	
20			0.10	
21			≈0.00	

3 RESULTS

3.1 GAS COOKER

3.1.1 General

The concentration of CO at each position was measured for each ventilation rate during different test conditions. The peak concentration for each test is shown in Table 3.1. The table also shows the peak percentage of CO_2 and minimum O_2 percentage recorded during each test. The duration of the tests stated in Table 3.1 may differ from the planned duration of the tests stated in Table 2.2. This was due either to the CO level reaching equilibrium and remaining constant for a number of hours; or for safety reasons, explanations for which are given in Table 3.1 for any tests where this was the case.

With the oven and all four gas hob rings at maximum, the highest peak CO concentration was 29.5 ppm at a ventilation rate of ≈0.00 h^{-1}; the lowest was 15.2 ppm at 1.00 h^{-1}. The highest peak concentration of CO_2 was 1.63% v/v at a ventilation rate of ≈0.00 h^{-1}; the lowest was 0.82% v/v at rate of 0.25 h^{-1}. The minimum recorded O_2 concentrations were 18.5% v/v, 19.9% v/v, and 18.4% v/v.

With only the oven on, set to maximum, the highest peak CO concentration was 9.2 ppm at a ventilation rate of ≈0.00 h^{-1}; the lowest was 6.3 ppm at 1.00 h^{-1}. The highest peak concentration of CO_2 was 0.68% v/v at a ventilation rate of ≈0.00 h^{-1}; the lowest was 0.39% v/v at 1.00 h^{-1}. The minimum recorded O_2 concentrations were 20.3% v/v, 20.4% v/v and 20.9% v/v.

With the four hob rings on only (i.e. the oven was not switched on) at maximum setting, the highest peak CO concentration was 20.4 ppm at a ventilation rate of ≈0.00 h^{-1}; and the lowest was 14.7 ppm at 1.00 h^{-1}. The highest peak concentration of CO_2 was 1.93% v/v at a ventilation rate of ≈0.00 h^{-1}; the lowest concentration was 1.19% v/v at 1.00 h^{-1}. The minimum recorded O_2 concentrations at ≈0.00, 0.25, and 1.00 h^{-1} were 17.8% v/v, 17.9% v/v, and 19.1% v/v respectively.

Table 3.1 CO concentrations measured in the room due to the cooker, across all 4 measurement positions

Test Conditions	Ventilation rate h^{-1}	CO Concentration ppm	CO_2 concentration % v/v	O_2 Concentration % v/v (– 0.1)
		Peak	Peak	Minimum
Oven maximum, all hob rings maximum 60 minutes[1]	1.00	15.2 – 1.5	0.91 – 0.15	18.4
	0.25	26.9 –2.7	0.82 – 0.13	19.9
	≈0.00	29.5 – 3.0	1.63 – 0.26	18.5
Oven maximum, no hob rings 180 minutes	1.00	6.3 – 0.6	0.39 – 0.06	20.9
	0.25	6.4 – 0.6	0.66 – 0.11	20.3
	≈0.00	9.2 – 0.9	0.68 – 0.11	20.4
Oven off, all hob rings maximum 180 minutes[2]	1.00	14.7 – 1.5	1.19 – 0.19	19.1
	0.25	19.2 – 1.9	1.90 – 0.30	17.9
	≈0.00	20.4 – 2.0	1.93 – 0.31	17.8

1. The test at ≈0.00 h^{-1} was stopped at 57 minutes due to the hob rings going out.

2. The test at ≈0.00 h^{-1} was stopped at 140 minutes due to the hob rings going out and the temperature exceeding approximately 40 ℃.

3.1.2 Oven and all four gas hob rings at maximum

Figure 3.1 shows the CO concentration at all four sample positions during the test at a ventilation rate of 0.25 h^{-1}. This pattern showed that the CO concentration was relatively well mixed between positions 1, 2 and 4, but less so at position 3, which was furthest away from the oven and had lower CO concentrations. This pattern was also observed at the other ventilation rates. Figure 3.2 shows the concentration of CO at sample position 2 for all three ventilation rates. This shows that at the two lower ventilation rates the concentration of CO was still rising after one hour but at the highest rate of 1.00 h^{-1} the concentration had reached equilibrium. At the two lower ventilation rates, ≈0.00 h^{-1} and 0.25 h^{-1} the concentration of CO appeared to be approaching equilibrium and then began to increase again, possible reasons for this are discussed in Section 4.2.1.

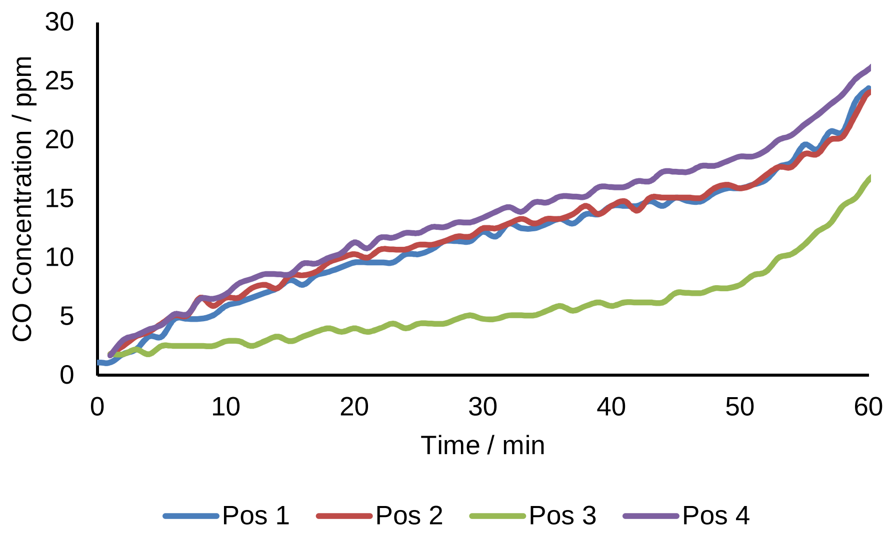

Figure 3.1 CO concentrations at all four sample positions at a ventilation rate of 0.25 h^{-1} with the oven and all four gas hob rings at maximum

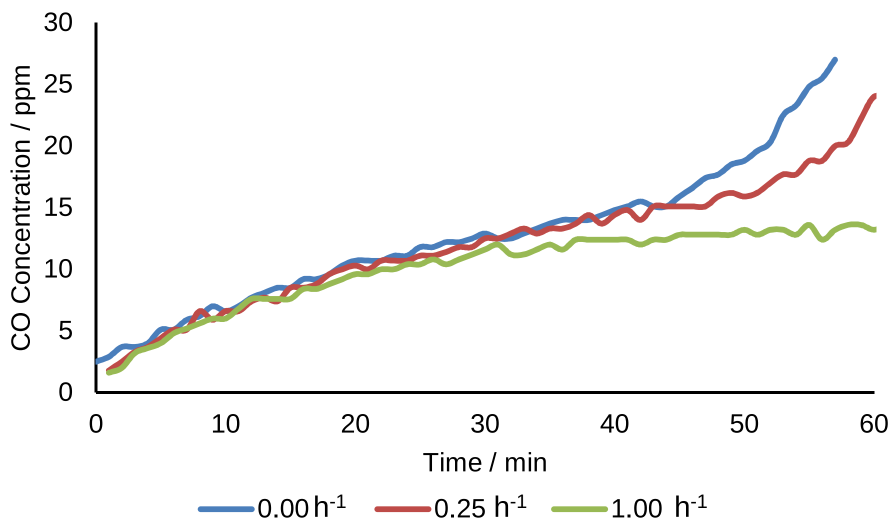

Figure 3.2 CO concentrations at sample position 2 for each of the three ventilation rates tested with the oven and all four gas hob rings at maximum

3.1.3 Oven only at maximum

Figure 3.3 shows the CO concentration at all four sample positions during the test at a ventilation rate of 0.25 h^{-1}. This pattern showed that CO concentration was relatively well mixed between positions 1, 2, and 4, but less so at position 3, which was furthest away from the oven and had lower CO concentrations. This pattern was also observed at the two other ventilation rates of ≈0.00 h^{-1} and 1.00 h^{-1}.

Figure 3.4 shows the concentration of CO at sample position 2 for all three ventilation rates.

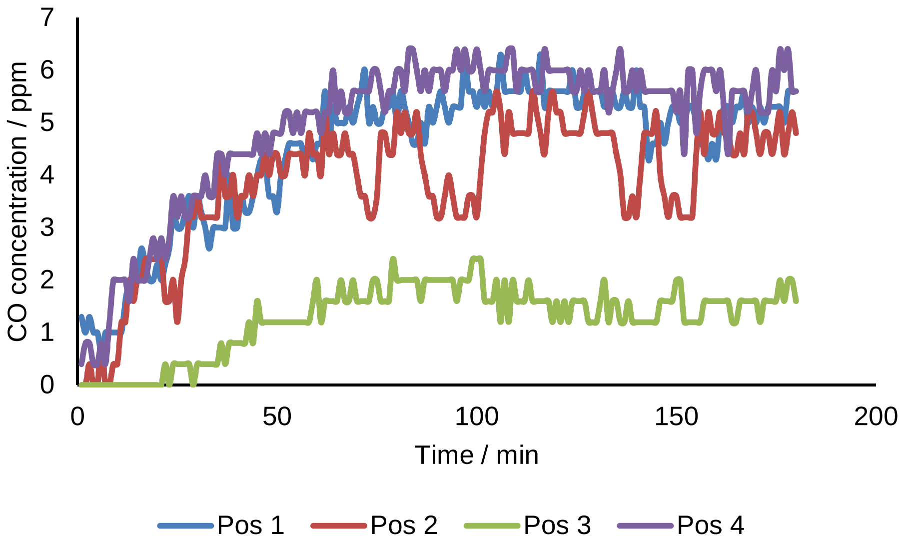

Figure 3.3 CO concentrations at all four sample positions at a ventilation rate of 0.25 h^{-1} with the oven at maximum

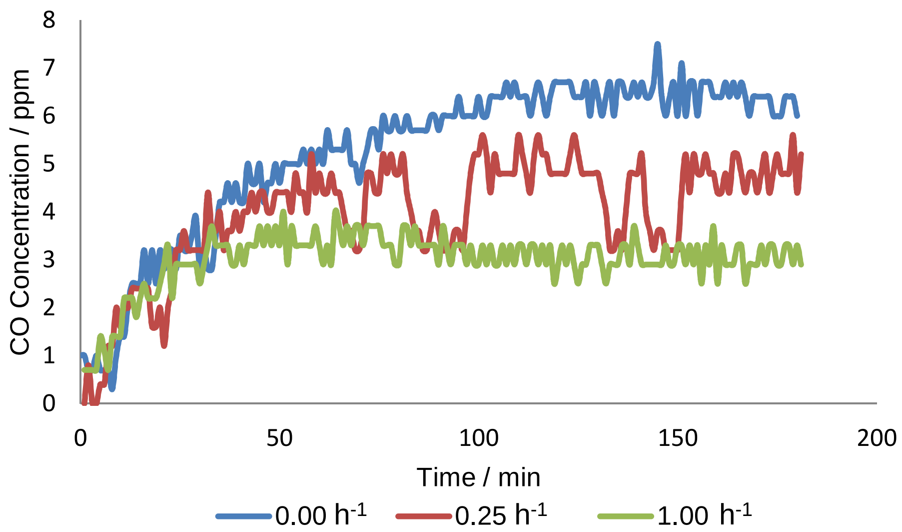

Figure 3.4 CO concentrations at sample position 2 for each of the three ventilation rates tested with the oven at maximum

3.1.4 All four hob rings only (oven not on) at maximum

Figure 3.5 shows the CO concentration at all four sample positions during the test at a ventilation rate of 0.25 h^{-1}. This pattern showed that CO concentration was relatively well mixed between positions 1, 2, and 4, but less so at position 3, which was furthest away from the oven and had lower CO concentrations. This pattern was also observed at the two other ventilation rates of ≈0.00 h^{-1} and 1.00 h^{-1}. Figure 3.6 shows the concentration of CO at sample position 2 for all three ventilation rates. The test carried out at ≈0.00 h^{-1} was halted at 140 minutes due to the hob rings being extinguished and the ambient room temperature exceeding approximately 40 °C.

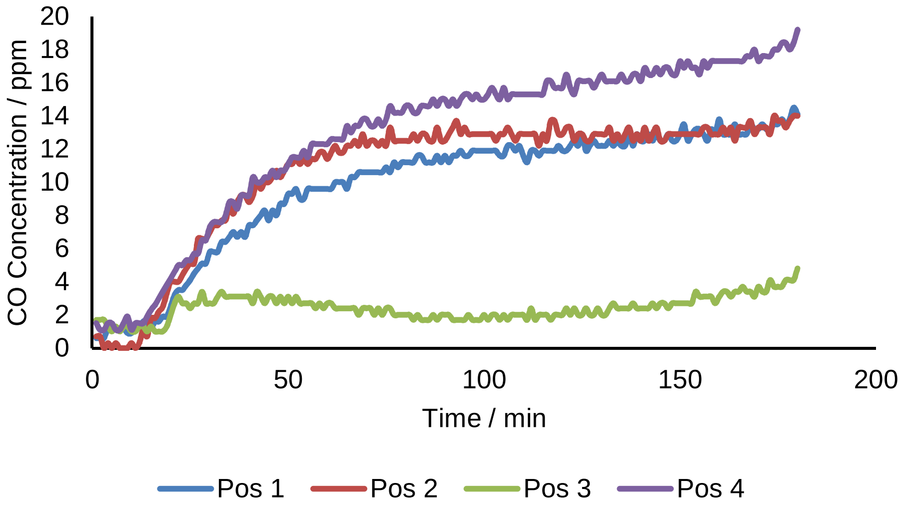

Figure 3.5 CO concentrations at all four sample positions at a ventilation rate of 0.25 h^{-1} with all four hob rings at maximum

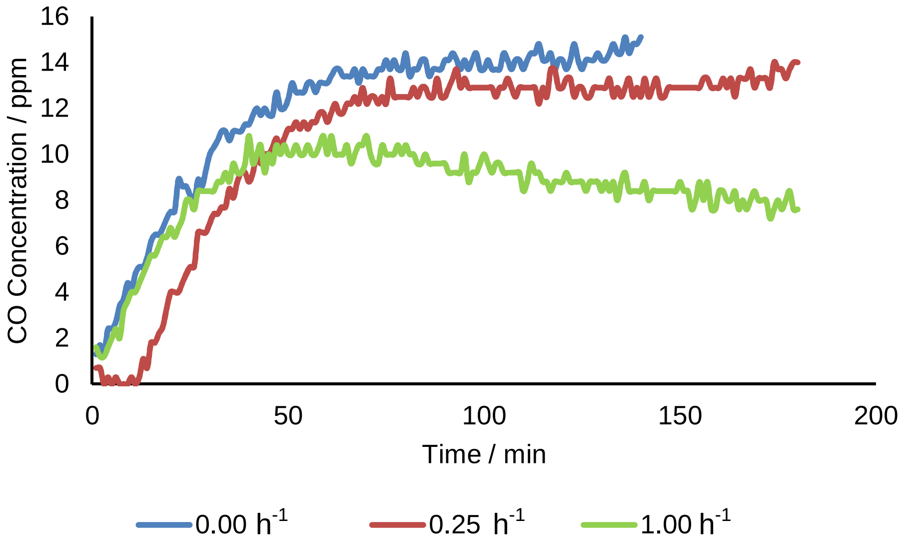

Figure 3.6 CO concentrations at sample position 2 at all three ventilation rates tested with all four hob rings at maximum[1]

3.2 FLUE-LESS FIRE

The concentration of CO at each position was measured for each ventilation rate with the fire set to maximum for each test. The peak concentration for each test is shown in Table 3.2. The table

[1] *Test at ≈0.00 h^{-1} was halted at 140 minutes due one of the hob rings being extinguished and the indicative temperature exceeding approximately 40 ℃.*

also shows the peak percentage of CO_2 and minimum O_2 percentage recorded during each test. Initially, the test was carried out with no mechanical ventilation and stopped after 5 hours and 40 minutes due to the CO reaching equilibrium and remaining constant over a number of hours. Using the information gathered from this initial test, the tests at the higher ventilation rates were shortened to three hours. Data for the full length of the ≈0.00 h^{-1} test is shown in Figure 3.7, however, the data presented in Table 3.2 and Figure 3.8 is taken from the first three hours of this test in order to make a direct comparison with tests at the other ventilation rates.

With the flue-less gas fire set to maximum, the highest peak CO concentration was 7.2 ppm at a ventilation rate of 0.5 h^{-1} and the lowest was 5.3 ppm at a rate of 0.25 h^{-1}. There was little significant difference between CO concentrations at the varying ventilation rates. The highest peak concentration of CO_2 was 1.02% v/v at a ventilation rate of 0.25 h^{-1} and the lowest was 0.71% v/v at a rate of 0.50 h^{-1}. The concentration of CO_2 was at or was close to the equilibrium concentration for each ventilation rate after 180 minutes. The minimum recorded O_2 concentrations at ventilation rates of ≈0.00, 0.125, 0.25, and 0.5 h^{-1} were 19.5% v/v, 18.9% v/v, 18.4% v/v, and 19.1% v/v respectively.

Table 3.2 CO concentrations measured in the room due to the flue-less fire, across all 4 measurement positions

Test Conditions	Ventilation rate h^{-1}	CO Concentration ppm	CO_2 Concentration % v/v	O_2 Concentration % v/v (– 0.1)
		Peak	Peak	Minimum
Fire maximum 180 minutes	0.50	7.2 – 0.7	0.71 – 0.11	19.1
	0.25	5.3 – 0.5	0.81 – 0.13	18.4
	0.125	5.8 – 0.6	1.02 – 0.16	18.9
	≈0.00	6.5 – 0.7	0.94 – 0.14	19.5

Figure 3.7 shows the CO concentration at all four sample positions during the test at a ventilation rate of ≈0.00 h^{-1} with the flue-less gas fire at its maximum setting. Figure 3.8 shows the concentration of CO at sample position 2 for all four ventilation rates with the flue-less gas fire at maximum.

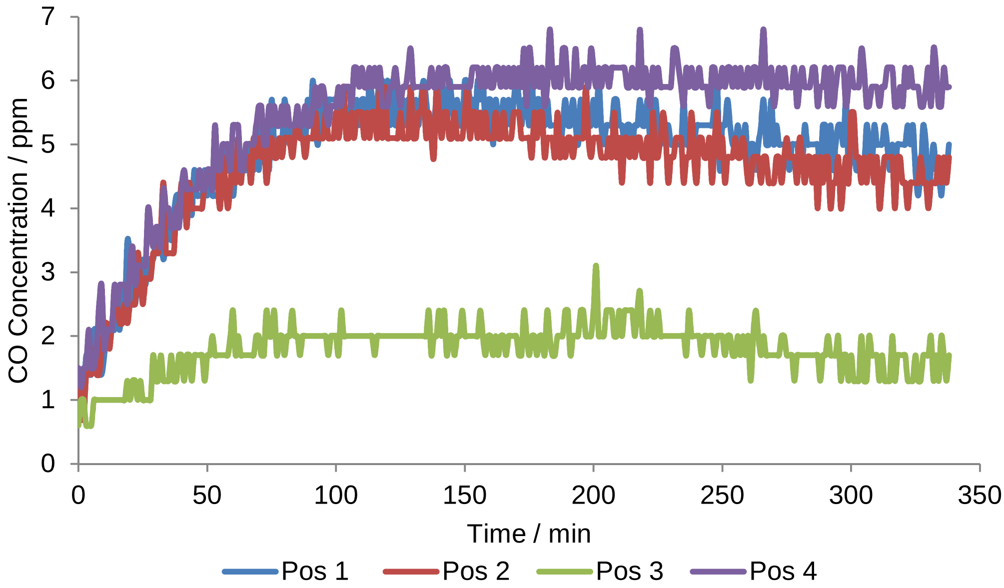

Figure 3.7 CO concentrations at all four sample positions at a ventilation rate of »0.00 h^{-1} with the flue-less gas fire at maximum

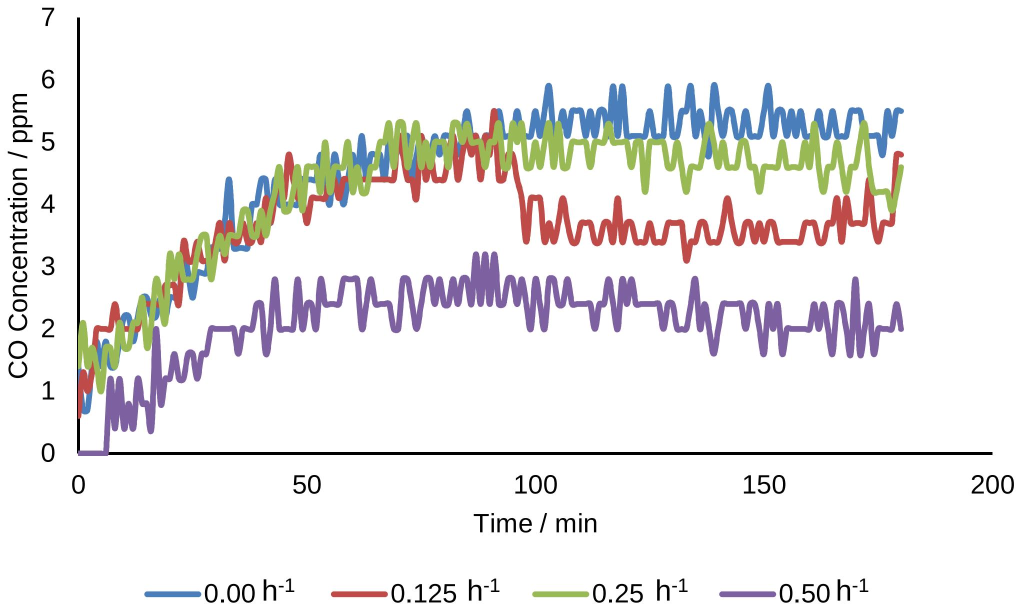

Figure 3.8 CO concentrations at sample position 2 for each of the four ventilation rates tested with the flue-less gas fire at maximum. For the ≈0.00 h^{-1} test, the first three hours are displayed.

3.3 PORTABLE CABINET HEATER

The concentration of CO at each position was measured for each ventilation rate with the portable cabinet heater set to maximum for each test. The peak concentration for each test is shown in Table 3.3.This table also shows the peak percentage of CO_2 and minimum O_2 percentage recorded during each test. The test at 0.125 h^{-1} had a duration of 179 minutes and the pump of the instrument at position 3 failed at approximately 145 minutes due to a twisted inlet air-line. Initially, the test was run with no mechanical ventilation and stopped after four hours due to the CO reaching equilibrium and remaining constant over a number of hours. Using the information gathered from this initial test, the tests at the higher ventilation rates were shortened to three hours. Data for the full length of the ≈0.00 h^{-1} test is shown in Figure 3.9, however, the data presented in Table 3.3 and Figure 3.10 is taken from the first three hours of this test in order to make a direct comparison with tests at the other ventilation rates. It should be noted that for some tests the heater was operated outside of the manufacturer's recommended operating conditions.

With the portable cabinet heater at maximum, the highest peak CO concentration was 33.4 ppm at a ventilation rate of ≈0.00 h^{-1} and the lowest was 24.3 ppm at a rate of 0.50 h^{-1}. The highest peak concentration of CO_2 was 1.77% v/v at a ventilation rate of ≈0.00 h^{-1} and the lowest was 1.15% v/v at a rate of 0.50 h^{-1}. The concentration of CO_2 was at or was close to the equilibrium concentration for each ventilation rate after 180 minutes. The minimum recorded O_2 concentrations at ventilation rates of ≈0.00, 0.125, 0.25, and 0.5 h^{-1} were 18.5% v/v, 18.3% v/v, 18.5% v/v, and 19.1% v/v respectively.

Table 3.3 CO concentrations measured in the room due to the portable cabinet heater, across all 4 measurement positions

Test Conditions	**Ventilation rate h^{-1}**	**CO Concentration ppm**	**CO_2 Concentration % v/v**	**O_2 Concentration % v/v (– 0.1)**
		Peak	**Peak**	**Minimum**
Heater maximum for 180 minutes	0.50	24.3 – 2.4	1.15 – 0.18	19.1
	0.25	26.9 – 2.7	1.76 – 0.28	18.5
	0.125	29.6 – 3.0	1.63 – 0.26	18.3
	≈0.00	33.4 – 3.3	1.77 – 0.28	18.5

Figure 3.9 shows the CO concentration at all four sample positions during the test at a ventilation rate of ≈0.00 h^{-1} with the portable cabinet heater at maximum. The sharp decrease in CO concentration at approximately 280 minutes was due to the heater self-extinguishing. Figure 3.10 shows the concentration of CO at sample position 2 for all four ventilation rates with the portable cabinet heater at maximum.

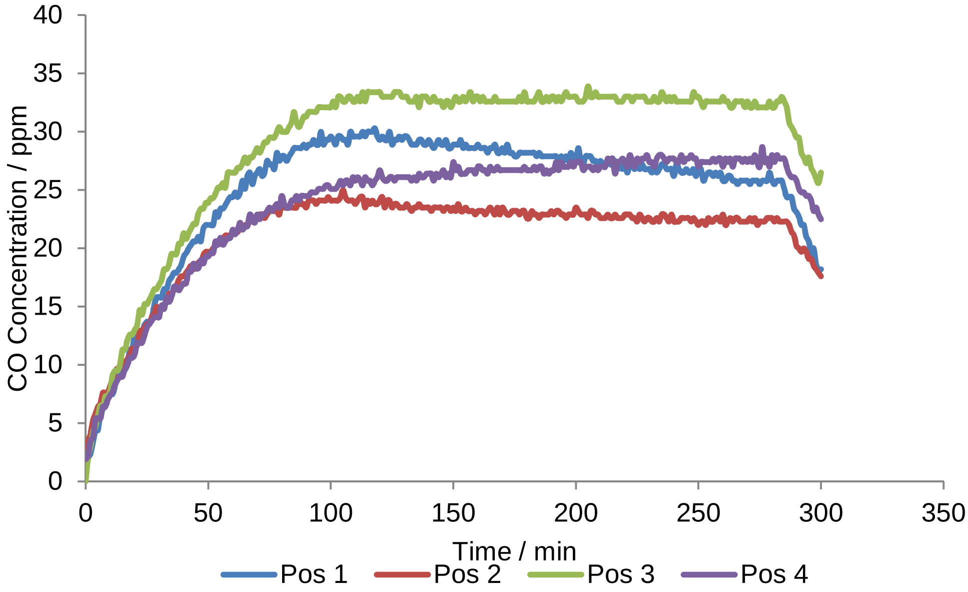

Figure 3.9 CO concentrations at all four sample positions at a ventilation rate of »0.00 h^{-1} with the portable cabinet heater at maximum

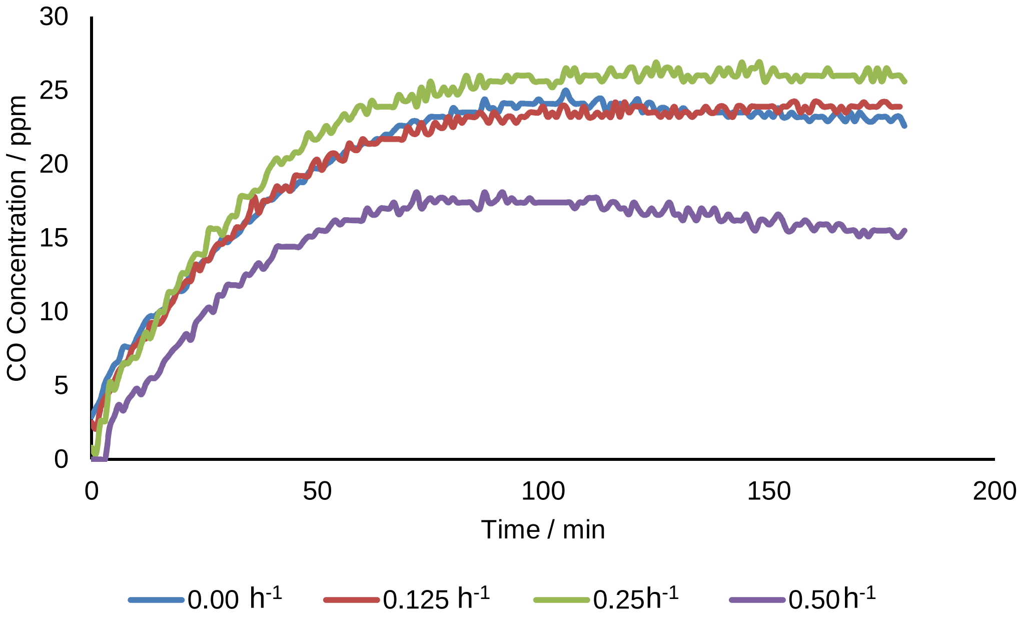

Figure 3.10 CO concentrations at sample position 2 for each of the four ventilation rates tested with the flue-less gas fire at maximum

3.4 FIRE WITH FLUE

The concentration of CO at each position was measured at a ventilation rate of ≈0.00 h^{-1} with the fire set to maximum. The peak concentration for each test is shown in Table 3.4. The table also shows the peak percentage of CO_2 and minimum O_2 percentage recorded during each test With the gas fire set to maximum, the flue fully open and a mechanical ventilation rate of ≈0.00 h^{-1}, the peak concentration of CO recorded over a period of 180 minutes was 3.1 ppm and the mean concentration for all sample positions was 0.2 ppm. The mean concentration is quoted here to highlight the low concentration throughout the test. During this test the peak CO2 concentration was 550 ppm (0.06% v/v) and the mean CO_2 concentration was 468 ppm (0.05% v/v), which is marginally above the mean atmospheric concentration of 400 ppm (0.04% v/v) and remained essentially unchanged throughout the test. The minimum recorded O_2 concentration was 20.9% v/v.

Table 3.4 CO concentrations measured in the room due to the fire with flue, across all four measurement positions

Test Conditions	Ventilation rate h^{-1}	CO Concentration ppm	CO_2 Concentration % v/v	O_2 Concentration % v/v (– 0.1)
		Peak	Peak	Minimum
Fire maximum	≈0.00	3.1 – 0.3	0.06 – 0.01	20.9

Tests at the higher ventilation rates were deemed to be unnecessary because the mean concentration of CO measured across all four sample positions at a ventilation rate of ≈0.00 h^{-1} was 0.2 ppm; which was extremely low. Instead, the real ventilation rate in the test room was determined with the fire connected to the flue in two scenarios: 'fire on' and 'fire off'. Mechanical ventilation was not applied to the room, but the purpose of the flue is to extract air from the room driving a natural ventilation rate that is not found with the other appliances as they did not have flues.

The ventilation rate of the room was determined using a tracer gas method whereby a tracer gas was introduced into the room and mixed with the room air. The concentration of the tracer gas was then monitored as it decays due to the ventilation of the room. The ventilation of the room enabled air, which did not contain tracer gas, to be introduced to the room thus diluting it. The method used was the 'step-down' method described by Etheridge & Sandberg, 1996. The tracer gas used was sulphur hexafluoride (SF_6) and the concentration was monitored using a calibrated infrared spectrometer (Miran 1a, S/N 151586). The experimental method was as follows;

1. For the 'fire on' test, the fire was set to maximum and then allowed to run for a period of 1 hour to allow the temperature in the room to reach equilibrium and then remained on throughout the test. For the 'fire off' test this first step was omitted.
2. Tracer gas was then introduced into the room from a pressurised cylinder and mixed with the room air using an axial mixing fan to ensure that the concentration of tracer gas was the same at all points within the room.
3. Once the concentration of SF_6 had reached a value of approximately 100 ppm, gas flow was halted.
4. The concentration of SF_6 was then logged for a period of three hours at a sample position at the geometric centre of the room.

5. The numerical concentration of SF_6 was then converted to a natural logarithm and plotted against time giving a linear relationship.
6. The ventilation rate of the room was then determined as the gradient of the plotted line.

The results of the two ventilation rate determinations are shown in Table 3.5.

Table 3.5 Determined ventilation rates in room fitted with a flue

Test Conditions	Determined Ventilation rate / h^{-1}
Fire on at maximum	1.54
Fire off	1.42

4 DISCUSSION

4.1 GENERAL

The concentration of CO emitted by a range of gas appliances was measured in a specially designed test room at a range of mechanical ventilation rates from ≈0.00 h^{-1} to 1.00 h^{-1}. The lower value of ≈0.00 h^{-1} was achieved by applying no mechanical ventilation to the room. Natural ventilation occurred due to the inlet in the right-hand wall simulating a trickle vent in a window, the natural gaps around the door and ventilation outlet, which was not sealed. The real ventilation rate was determined using the method described above in Section 3.4; this was found to be 0.015 h^{-1}. However, given the experimental uncertainty in the method it was not possible to accurately determine a rate below 0.02 h^{-1}. Additionally, as this rate is determined by temperature and pressure variances across the building envelope it can vary from day to day. However, this was as low as practically achievable without fully sealing the room, which would have been outside of normal conditions.

All the appliances tested were in good working order and had been installed by a Gas Safe Registered engineer and declared safe for use before testing. Similarly, the flue used with the gas fire had been installed and cleared as safe to use by a Gas Safe Registered engineer. Data was only collected for one example of each appliance; however these examples were chosen to be representative of appliances found commonly installed in domestic buildings.

This research aimed to investigate levels of CO produced by appliances used in rooms with low ventilation rates. The manufacturers' instructions provided with the appliances included requirements for necessary ventilation and room sizes. These recommendations were not necessarily followed during all the tests undertaken for this research as it has been recognised that ventilation rates less than those recommended are found in domestic properties. This was particularly relevant to the testing of the cabinet heater which was tested in conditions outside of the manufacturer's recommended operating conditions.

The highest concentration of CO measured during the stated test periods was 33.4 ppm, which was detected whilst using a portable cabinet heater set to maximum with a ventilation rate of ≈0.00 h^{-1}. Higher concentrations of CO were detected but these occurred outside the range of test conditions deemed suitable. Examples of this included the tests with the gas cooker where the gas hob rings were all at maximum; in both of these tests conducted at ≈0.00 h^{-1} the tests were halted before the end either due to one or more of the hob rings being extinguished or the temperature exceeding approximately 40°C, as discussed in Section 4.2. The lowest concentrations measured were during the operation of a gas fire fitted with a flue where the peak CO concentration was 3.1 ppm over a three hour period and the mean concentration of 0.2 ppm was observed.

There are no proscribed exposure limits for CO or CO_2 in domestic settings. However, there are performance standards in BS EN 50291-1:2010 +A1:2012 (British Standards Institute, 2012) that specifies the CO concentration and times at which domestic CO alarms should activate. Times before which the alarm must not activate are also specified, in addition to alarm activation times, to prevent spurious alarms, e.g. from fuel appliances starting up. These alarm set points are designed to protect vulnerable groups (Table 4.1).

Table 4.1 CO alarm limits (Reproduced from BS EN 50291-1:2000 +A1:2012)

Domestic CO alarm levels and exposure times from BS EN 50291-1 (2010)		
CO alarm level (ppm)	**Must alarm before (ppm)**	**Must not alarm before (min)**
30	-	120
50	90	60
100	40	10
300	3	-

In Great Britain the Health and Safety Executive (HSE) provide a workplace exposure limit (WEL) as an 8-hour Time Weighted Average (TWA) and a short-term exposure limit (STEL) as a 15-minute TWA as part of the Control of Substances Hazardous to Health (COSHH) regulations (HSE Books, 2005). The WEL for CO is 30 ppm and the STEL is 200 ppm. For CO_2 the WEL is 5000 ppm (0.5% v/v) and the STEL is 15000 ppm (1.5% v/v). These are not applicable in domestic settings, but serve as useful references when discussing exposure to hazardous substances.

The Industrial Gases Council (IGC) Document 44/09/E states that a situation becomes hazardous when the percentage of O_2 drops below 18% v/v. The minimum level of O_2 measured during this research was 17.8% v/v. The document describes the effects and symptoms of breathing air with an O_2 level of 11-18% v/v as a reduction of physical and intellectual performance without the sufferer being aware.

Concentrations exceeding the STEL for CO were not detected at any point during any of the tests conducted. Concentrations of CO exceeding 30 ppm were detected during some tests however, if these concentrations were converted to a TWA over the length of the test, they would be below the WEL. When using the portable cabinet heater at the lowest ventilation rate the concentration of CO would have exceeded the 30 ppm for a minimum of 120 minutes. The minimum conditions for a domestic CO alarm to activate shown above would have been met if operated for 200 minutes or more, according to BS 50291. BS7967:2015 states that when CO levels are above 30 ppm the appliance should be classed as "immediately dangerous" and occupants are advised to leave the dwelling immediately with remediation including increasing the ventilation. For this research, the ventilation was set to be deliberately low and below the level stated necessary in manufacturer's information, therefore, higher levels of CO would be expected compared with use of the same appliance in a better ventilated space.

For all appliances except the gas fire with a flue, the STEL for CO_2 was exceeded at least once during testing. Similarly, for all appliances except the gas fire with flue the concentration for the WEL was exceeded but for considerably shorter periods than 8 hours.

Figures 3.1, 3.3, 3.5, and 3.7 all show that the air in the test room was not well mixed with considerable variation between sample positions. The lowest concentrations were consistently recorded at sample position 3 which was located at a high level in a corner of the room opposite the appliance. This is not uncommon in rooms with no artificial mixing. Sample position 2 at the geometric centre of the room generally saw concentrations close to the mean. Sample position 4 was located at the approximate head height of a person standing in front of the gas cooker and was retained for the rest of the appliances for consistency; this position generally saw the highest concentrations, most likely because it was the closest to the appliances.

4.2 GAS COOKER

4.2.1 Oven and all four gas hob rings at maximum

The gas cooker showed a degree of variability in CO emission between using the hob rings and the oven. The cooker was tested with all four hob rings and the oven operating at maximum for a period of 1 hour in order to simulate the time taken to prepare a meal. The maximum ventilation rate investigated was 1.00 h^{-1} unlike the other three appliances where it was 0.50 h^{-1}. This was because kitchens generally have the highest ventilation rates in houses with the exception of bathrooms, and the other appliances tested are more commonly found in living areas of houses. The peak concentrations of CO at ventilation rates of ≈0.00 and 0.25 h^{-1} were similar at 29.5 and 26.9 ppm and lower at 1.00 h^{-1} where it was 15.2 ppm.

Overall, the highest CO concentration from testing of the cooker was recorded with both the oven and all four hob rings set to maximum at ≈0.00 h^{-1}. This was one of the tests that was abandoned before the scheduled end when one of the hob rings was observed to have been extinguished after 57 minutes of the scheduled hour. Examination of Figures 3.1 and 3.2 shows that at the two lower ventilation rates, the concentration of CO had begun to approach equilibrium then after approximately 50 minutes began to increase exponentially again. A possible explanation for this is that the concentration of CO_2 had reached a level where it displaced enough O_2 to reduce the concentration below the level where complete combustion of the natural gas was not possible. This can increase the rate of production of CO and extinguish the flame; this process is known as vitiation (Hazelhurst, 2009). This theory is supported by the evidence shown in Figures 4.1 and 4.2 which show that after 50 minutes the concentration of CO_2 had exceeded 10000 ppm (1% v/v) and that the O_2 concentration had dropped below 19% v/v, this would explain why one of the hob rings was observed to have been extinguished.

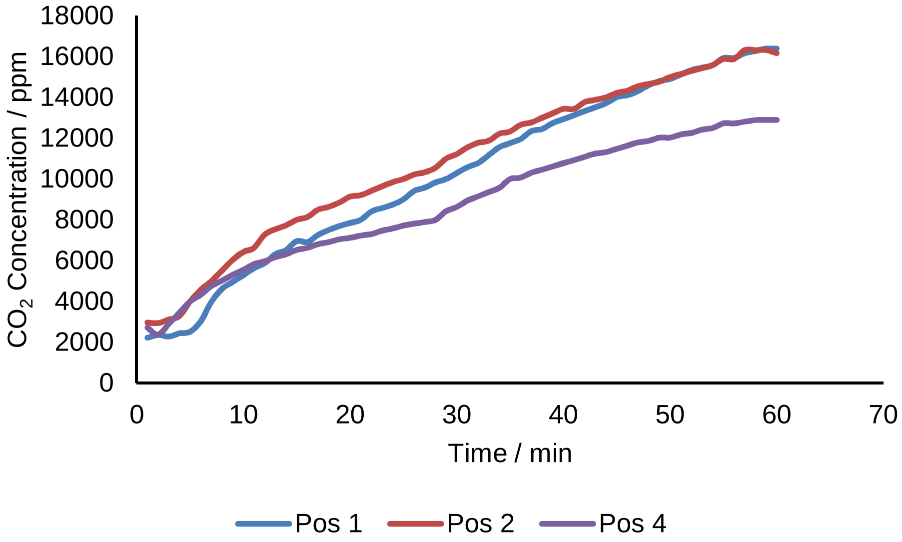

Figure 4.1 CO_2 concentrations at sample positions 1, 2, and 4 during test with all four hob rings and oven at maximum at ≈0.00 h^{-1}

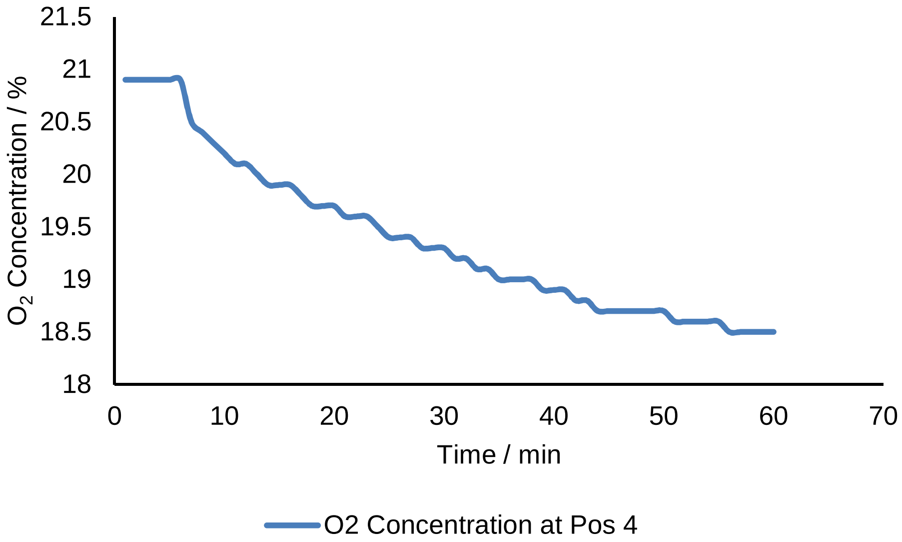

Figure 4.2 O_2 concentrations at sample position 4 during test with all four hob rings and oven at maximum at »0.00 h^{-1}

At a ventilation rate of 1.00 h^{-1}, Figure 3.2 shows that the concentration of CO had reached equilibrium at approximately 15 ppm. These results indicate that if operated in a room with sufficient ventilation, i.e. at least 1.00 h^{-1}, using a gas cooker for a period of an hour will not cause exposure to CO that exceeds the STEL of 200 ppm and even if operated for 8 hours would not cause exposure that exceeds the 8-hour WEL of 30 ppm. If operated in rooms with lower ventilation rates, i.e. 0.25 h^{-1} or less, CO_2 concentrations could approach levels that will cause the cooker to operate in less than ideal conditions and cause elevated CO emissions.

Although CO_2 exceeding the WEL value of 5000 ppm were recorded it would be highly unlikely that anyone would use all four rings and the oven for this length of time so the WEL should not be exceeded in normal use. Likewise, examination of Figure 4.1 shows that given the time it took to reach the STEL value of 15000 ppm it is unlikely that this limit would be exceeded in normal use.

Pans were not added to the hob as part of the testing schedule. Adding pans of water would have meant that there would have been a necessity to enter the room during testing to avoid all the water evaporating and heating a dry pan, consequentially influencing the measurements. It is however, important to note that adding pans to the hob during the test would most likely have produced different results and potentially higher levels of CO due to flame impingement and reduced airflow to the flame.

4.2.2 Oven at maximum

For these tests the oven was operated at the maximum setting for a period of three hours, this was considered to be representative of a typical longer cooking or baking time. Figure 3.4 shows that at all three ventilation rates the concentration of CO had reached an equilibrium value after approximately two hours, so even if it was operated for longer than the test duration the CO concentration would not have changed barring a change in the ventilation rate. Even at the lowest ventilation rate of ≈0.00 h^{-1} this equilibrium value was approximately 6 ppm so it is unlikely that the use of a gas oven, even for periods exceeding 8 hours, would lead to an exposure to levels of CO exceeding the WEL of 30 ppm.

Figure 4.3 below shows that the concentration of CO_2 had exceeded the WEL value of 5000 ppm after approximately 150 minutes and was very close to reaching the equilibrium value. This indicates that if the oven were operated for a further 8 hours i.e. for a total time exceeding 500 minutes then the WEL would have been exceeded however this is unlikely to occur in practice as it would be highly unusual for an oven to be operated at maximum for this amount of time. The STEL value of 15000 ppm was not approached at any time, which means that the STEL could not be exceeded using the oven in this manner.

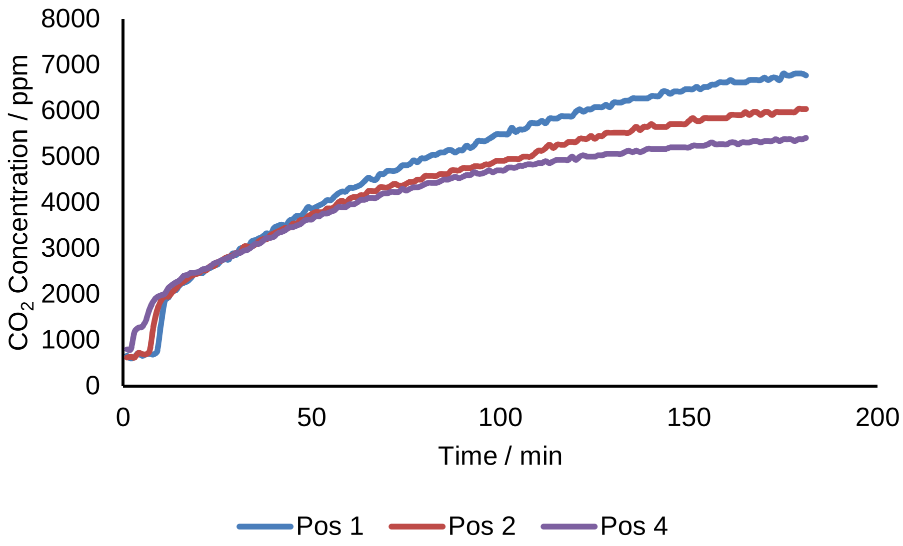

Figure 4.3 CO_2 concentrations at sample positions 1, 2, and 4 for oven at maximum at a ventilation rate of ≈0.00 h^{-1}

4.2.3 All four hob rings at maximum

For these tests all four hob rings were operated at maximum, this was to simulate the use of gas hobs to heat homes. For this reason it was originally intended to run these tests for a period of 8 hours, see Table 2.2. However, when performing the test at a ventilation rate of ≈0.00 h^{-1} it was noted that the concentration of CO was approaching equilibrium after approximately 90 minutes (Figure 3.6), therefore it was decided to reduce the test duration to 3 hours. Furthermore, the test at ≈0.00 h^{-1} was halted after 140 minutes when the indicative temperature in the room exceeded approximately 40 °C and in fact it is likely that the vast majority of people would have turned the hob rings off well before this point.

The peak concentrations of CO were 20.4, 19.2, and 14.7 ppm at ventilation rates of ≈0.00, 0.25, and 1.00 h^{-1} respectively. Figure 3.6 showed that these concentrations had reached equilibrium well before the end of the three hour test. This means that it would not have been possible to exceed either the STEL or WEL for CO. Additionally, at the two lower ventilation rates, the temperature in the test room was such that the hob rings would likely have been switched off.

Figures 4.4 and 4.5 show the concentration of CO_2 at the highest and lowest ventilation rates. They both indicate that the WEL value of 5000 ppm is exceeded within 30 minutes. However, the temperature rise is such that it is extremely unlikely that the hob rings would be used for 8 hours so the WEL considered as the 8-hour TWA is unlikely to be exceeded. Figure 4.4 does show that the STEL value of 15000 ppm had been exceeded at all three sample positions after 120 minutes; this means that it is possible that the STEL could be exceeded. However, it should be noted that this test was halted after 140 minutes due the indicative temperature exceeding approximately 40 °C so, again it is likely that they would have been switched off before this became a problem. These results and those from the earlier tests should be noted in that prolonged use of the gas hob rings creates elevated levels of CO_2, particularly at low ventilation rates, i.e. less than or equal to 0.25 h^{-1}.

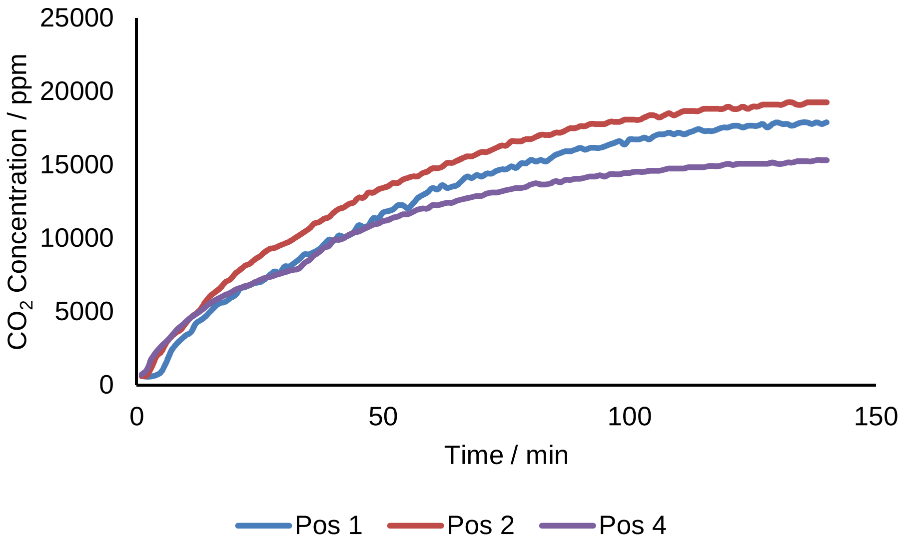

Figure 4.4 CO_2 concentrations at sample positions 1, 2, and 4 at a ventilation rate of ≈0.00 h^{-1} with all four hob rings at maximum

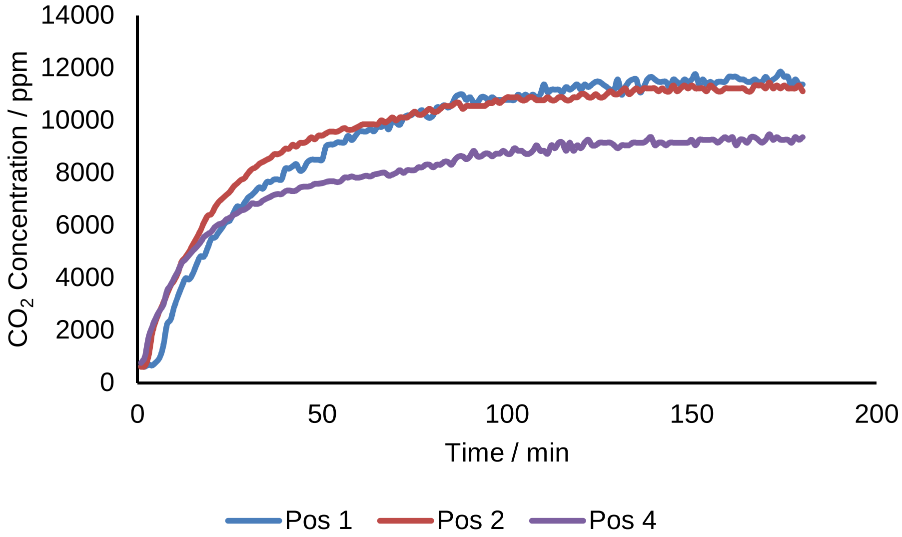

Figure 4.5 CO_2 concentrations at sample positions 1, 2, and 4 at a ventilation rate of 1.00 h^{-1} with all four hob rings at maximum

Although the WEL value for CO of 30 ppm was not exceeded during testing of the cooker the results highlighted in Figures 3.1, 3.2 and 3.5 whilst operating all four hob rings should be noted. The results shown in Figures 3.1 and 3.2 show that the concentration of CO had initially reached equilibrium after approximately 30 – 40 minutes but then began to increase again. This was mentioned earlier in Section 4.2.1, the likely cause for this is the increasing concentration of CO_2 creating unfavourable conditions for combustion and causing vitiation. This phenomenon was investigated in an HSE joint industry project and was reported in an HSE contract research report (HSE, 2001). The findings reported that once the process of vitiation begins the concentration of CO increases rapidly and would cause the STEL of 200 ppm to be exceeded quickly. The purpose of that work was to investigate the performance of gas appliances under fault conditions which differs from this project which is looking at properly functioning appliances under normal operating conditions.

It is possible that if the tests with all four hob rings in use were extended that a similar process could take place leading to considerably higher concentrations of CO. This indicates that the operation of a cooker under these conditions, i.e. using all four hob rings in a room with a ventilation rate of less than 0.25 h^{-1}, can cause elevated CO_2 levels which could in turn cause elevated CO emissions.

4.3 FLUE-LESS GAS FIRE

The flue-less gas fire was tested at its maximum setting. It was originally intended to test the fire for a period of 8 hours (Table 2.2), but after performing the test at the lowest ventilation rate it was noted that the CO concentrations had reached equilibrium after approximately 120 minutes (Figure 3.7). For this reason it was decided to limit the remaining tests at higher ventilation rates to 3 hours, this was because equilibrium concentrations would be reached faster at higher ventilation rates. The peak CO concentrations at ventilation rates of ≈0.00, 0.125, 0.25, and 0.50 h^{-1} were 6.5, 5.8, 5.3, and 7.2 ppm respectively. At the lowest ventilation rate, the mean CO concentration across all four sample positions during the test period was 4.0 ppm. These results mean that when using the flue-less gas fire in the test room it would not be possible to exceed either the STEL or WEL for CO.

Figures 4.6 and 4.7 show the CO_2 concentrations at the highest and lowest ventilation rates. Therefore, the concentration of CO_2 in the test room exceeded the WEL value of 5000 ppm within 90 minutes at both rates, but was approaching equilibrium after 3 hours. These results mean that if the fire were operated at maximum for a period exceeding 9 – 10 hours it would be possible to exceed the CO_2 WEL but concentrations would not approach the STEL value of 15000 ppm.

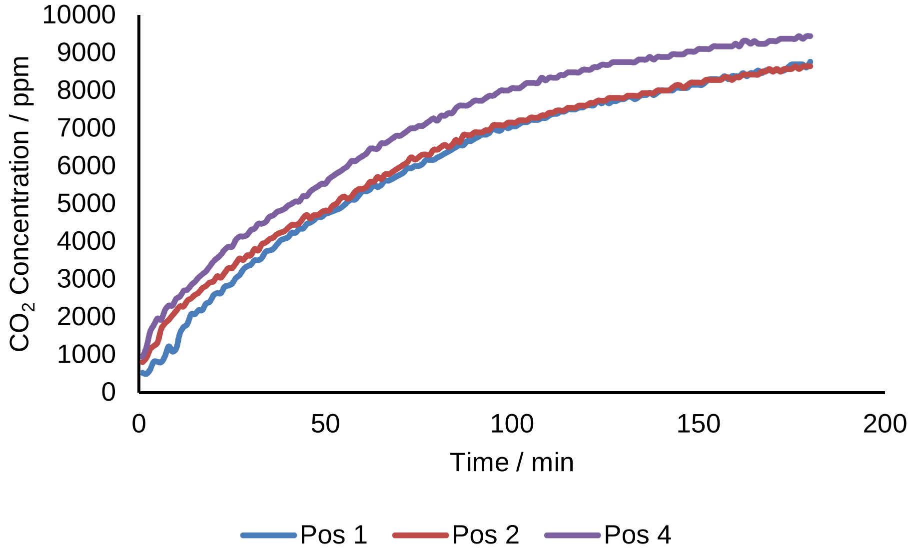

Figure 4.6 CO_2 concentrations at sample positions 1, 2, and 4 at a ventilation rate of ≈0.00 h^{-1} with the flue-less gas fire at maximum

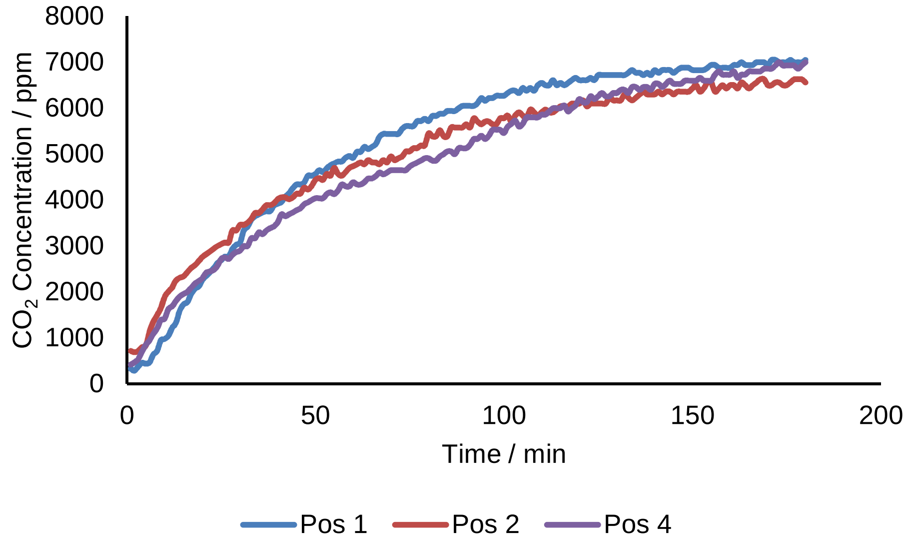

Figure 4.7 CO_2 concentrations at sample positions 1, 2, and 4 at a ventilation rate of 0.50 h^{-1} with the flue-less gas fire at maximum

4.4 PORTABLE CABINET HEATER

The portable cabinet heater was tested at its maximum setting. It was originally intended to test the heater for a period of 12 hours, see Table 2.2, but after performing the test at the lowest ventilation rate it was noted that the CO concentrations had reached equilibrium after approximately 90 minutes (see Figure 3.9). For this reason it was decided to limit the remaining tests at higher ventilation rates to 3 hours, as equilibrium concentrations would be reached faster at higher ventilation rates. It should be noted that the heater was tested in conditions beyond those recommended by the manufacturer. The peak CO concentrations at ventilation rates of ≈0.00, 0.125, 0.25, and 0.50 h^{-1} were 33.4, 29.6, 26.9, and 24.3 ppm respectively. These results mean that if the portable cabinet heater were to be used in the test room for a period of 9-10 hours, anybody that remained in the room for the entire duration would be exposed to a concentration of CO at or close to but not significantly exceeding the WEL of 30 ppm unless the ventilation rate was 0.25 h^{-1} or higher. This again highlights the finding that ventilation rates below 0.5 h^{-1} were less effective at removing CO and CO_2. The concentration of CO did not approach the STEL value of 200 ppm at any time during the test; this indicates that it would not be possible to cause exposures that would exceed the STEL. Figure 4.8 shows the CO_2 concentrations at the lowest ventilation rate of ≈0.00 h^{-1}. The results show that the WEL value of 5000 ppm was exceeded after 30 minutes, that the concentration was approaching equilibrium and that this value would be at or close to the STEL value of 15000 ppm. Figure 4.9 shows the CO_2 concentrations at a ventilation rate of 0.25 h^{-1}, showing that the WEL value of 5000 ppm was again exceeded within 30 minutes and that at 3 hours was approaching equilibrium close to the STEL value of 15000 ppm. Figure 4.10 shows the CO_2 concentrations at a ventilation rate of 0.50 h^{-1}, showing that the WEL value of 5000 ppm was exceeded after 38 minutes but that the equilibrium value was less than the STEL value of 15000 ppm.

On the whole these results indicate that if the portable cabinet heater were to be used at the maximum setting for a period of more than 9 hours the WEL of 5000 ppm would likely be exceeded. In order to ensure that the STEL of 15000 ppm was not to be exceeded it should only be used in rooms with a ventilation rate of 0.50 h^{-1} or greater. It should be noted that use of the cabinet heater for extended periods, i.e. greater than 2 – 3 hours resulted in elevated temperatures beyond the normal comfortable range for humans (approximately 40 ^{o}C) and would likely be switched off under these circumstances.

These types of appliances are generally fitted with an atmospheric sensing device (ASD), which is intended to deactivate the appliance in the event that elevated concentrations of CO_2 are detected. Previous research carried out by HSE and BRE Environment confirmed that the ASD on a similar device operated at CO_2 concentrations between 0.8 and 1.5% v/v (HSE. 2004). There was no measurement position at the exact location of the heater so it is not known what the CO_2 concentration was here. However the rest of the data suggest that although there were some significant differences, particularly at the high and low positons, the atmosphere within the test room was relatively well mixed. Therefore, it is possible that the CO_2 concentration exceeded the 0.8% v/v value required to operate the ASD at this location, but this cannot be confirmed. It is not known why the ASD device did not operate during the testing as in normal operation, with a functioning ASD, it is likely that the device would shut off preventing the generation of these elevated CO_2 concentrations.

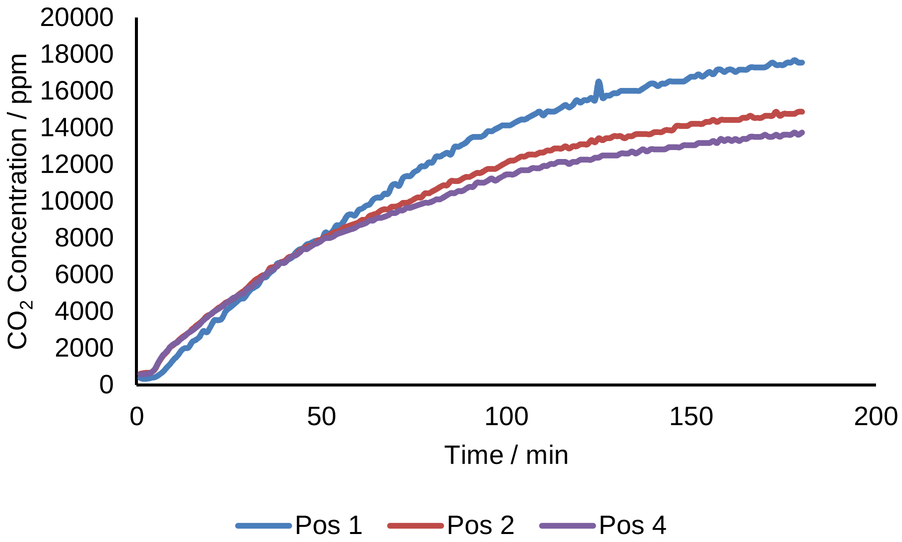

Figure 4.8 CO_2 concentrations at sample positions 1, 2, and 4 at a ventilation rate of »0.00 h^{-1} with the portable cabinet heater at maximum

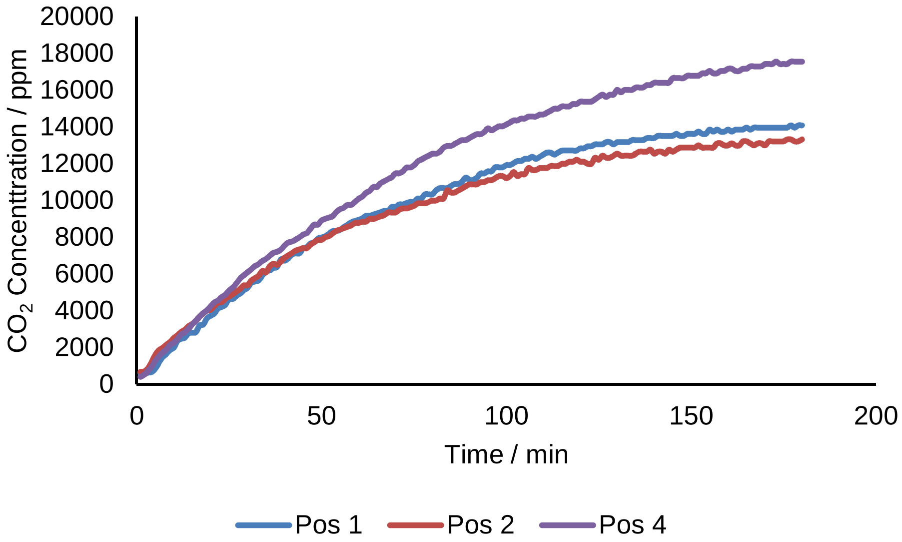

Figure 4.9 CO_2 concentrations at sample positions 1, 2, and 4 at a ventilation rate of 0.25 h^{-1} with the portable cabinet heater at maximum

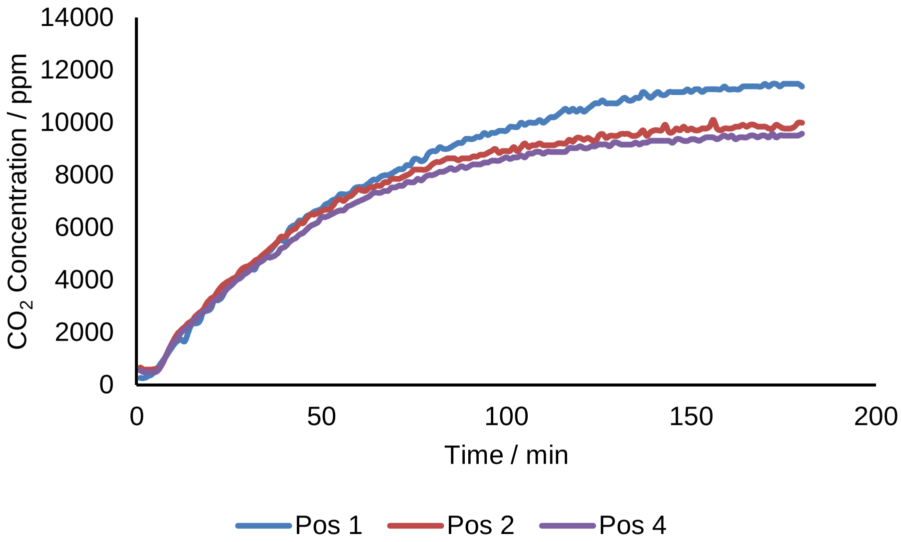

Figure 4.10 CO_2 concentrations at sample positions 1, 2, and 4 at a ventilation rate of 0.50 h^{-1} with the portable cabinet heater at maximum

4.5 GAS FIRE WITH FLUE

The gas fire with flue was tested at its maximum setting. It was originally intended to test the fire for a period of 8 hours, see Table 2.2, but after performing the test at the lowest ventilation rate it was noted that the CO concentrations had reached equilibrium almost immediately and never exceeded 3.1 ppm, see Figure 3.11. For these reasons it was decided to not to test the fire at the higher ventilation rates, this was because it was considered unlikely that higher concentrations of CO would be detected at higher ventilation rates.

The measured concentrations of CO_2 showed similar results, i.e. equilibrium was reached almost immediately and was close to the mean atmospheric concentration of 400 ppm. This indicates that the fire was emitting little if any CO_2 into the room.

Experiments to determine the ventilation rate of the room with the fire on and off and the flue fully open indicated that the ventilation rate was approximately 1.4 – 1.5 h^{-1}.

On the whole these results indicate that if connected to a properly installed flue, the gas fire could be used indefinitely with minimal risk of exposure to either CO or CO_2. Furthermore the results have indicated that the presence of a properly fitted flue provides a level of ventilation to the test room exceeding the maximum tested mechanical ventilation rate of 1.00 h^{-1}.

5 CONCLUSIONS

A range of gas appliances have been tested to determine the concentration of CO that they emit at a range of low ventilation rates. The results of these tests have indicated that:

- At no point during any test did concentrations of CO exceed the 15 minute STEL value of 200 ppm. A gas cooker with all four gas hob rings at maximum would be capable of emitting enough CO so as to exceed the 8 hour WEL of 30 ppm but this would be extremely unlikely in practice as this would raise the temperature above approximately 40 °C.
- Operating the gas oven alone at its maximum setting resulted in a maximum CO concentration of 9.2 ppm and typically had an equilibrium value of 6 -7 ppm.
- With the flue-less gas fire operating at maximum, the concentration of CO never exceeded 7.2 ppm and could therefore be operated without risk of harmful exposure to CO.
- When using a portable cabinet heater at a ventilation rate of approximately 0.00 h^{-1} a CO concentration of 33.4 ppm was detected, which was the highest recorded during any test.
- A portable cabinet heater could emit enough CO to cause exposures of approximately 30 ppm if operated in a room with a ventilation rate of less than 0.25 h^{-1}.
- It should be noted that the cabinet heater was tested in conditions outside of the manufacturer's recommendations, i.e. lower that the recommended room ventilation rate.
- A properly installed flue can provide a natural ventilation rate to a room exceeding 1.00 h^{-1}.
- A gas fire in good working order when connected to a properly installed flue can be operated indefinitely without emitting any harmful concentrations of either CO or CO_2; the gas fire with a flue tested produced peak CO concentrations of less than 5 ppm.
- Although none of the appliances tested produced harmful levels of CO, ventilation rates below 0.5 to 1.0 h^{-1} were less efficient at removing CO.
- An unexpected result was the detection of high levels of CO_2 at several test positions.
- For all appliances except the gas fire with a flue, the STEL for CO_2 was exceeded at least once during testing.
- Oxygen levels in the room remained above 20% v/v when the oven alone and fire with flue were in use. All other appliances resulted in oxygen levels ranging from 17.8 - 19.9% v/v. The minimum oxygen level measured was 17.8% v/v during use of the hob rings with no mechanical ventilation.
- A functioning ASD should have activated once the CO_2 concentration exceeded 0.8 v/v. Although the air in the test room was considered to be relatively well mixed there was no measurement position at the exact location of the heater so it is not known what the CO_2 concentration was here.

Further work that could be undertaken could include the study of poorly maintained appliances or the use of alternative heating fuels such as wood or other solid fuels. The testing of the cooker could be extended to include loading of the hob rings with pans and other uses such as use of a grill. It may also be worthwhile considering further work to consider the issue of elevate CO_2 emissions from gas appliances.

6 REFERENCES

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