Joint Industry Programme on carbon monoxide issues

Experimental work to study the interaction between air extraction equipment and open-flued appliances - Phase 2

Prepared by Advantica Technologies Limited
(formerly BG Technology)
for the Health and Safety Executive

CONTRACT RESEARCH REPORT 381/2001
The work is a continuation of the tests described in Phase 1, but in a different house, with one extra gas appliance (a flame effect gas fire), and one extra type of air extraction. Concentrations of carbon dioxide, carbon monoxide and oxygen monitored in the upstairs rooms of the house, in the extraction system, and close to the boiler. as were the temperatures. Room and boiler temperatures were also measured.

The factors which had caused the most significant build up of carbon monoxide in the first phase of the programme were investigated further. The effect of the conducting tests in a different house was also investigated.

As a result of work in both phases we recommend that:

a) An "additional 50cm² ventilation" is inappropriate in many situations

b) All installers of appliances which use extract fans must be aware of potential conflicts with open flued appliances.

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SUMMARY

INTRODUCTION
The effective removal of combustion products through the flue of an open-flued gas appliance can be affected by a number of processes, e.g. blockage of the flue or inadequate ventilator air provision to the appliance. The operation of air extraction equipment in a property can also cause the combustion products to be inefficiently removed by depressurising the area within which the appliance is located and offering a preferred pathway into the property.

Previous work was reported. This report describes further work carried out to determine what factors contribute to this process in a full-scale domestic property, and produces some guidelines for the installers of gas appliances and extract fans.

METHODOLOGY
A programme of work was carried out in a new full-scale brick built house using 3 types of open-flued gas appliance. Extract rates, gas concentrations, temperatures, and pressures were monitored during the tests.

RESULTS
a) Flue reversal can be obtained in some appliances with extract rates of less than 100m3/hr.

b) The rate of production of carbon monoxide was dependent on the appliance, the extraction rate and the location of the extract.

The Central Heating Boiler at low extraction rates produced little carbon monoxide. Larger quantities were produced at higher (>300m3/hr) extraction rates. Increased amounts were produced in both cases when a low height (rather than located in the top of the window) extract was used.

The Combi Boiler, even at the lowest extraction rates used produced much more carbon monoxide. Again, a low height extract increased the quantity of carbon monoxide produced.

The quantity produced by the Gas Fire was small during each test.

c) The temperature rise in the room, alone, compared to normal operation of the appliances, may warn an occupant of a developing toxic atmosphere.
RECOMMENDATIONS

a) An additional 50cm² has been found to be inappropriate in many situations. Consequently the guidance that “50cm² additional ventilation will generally be sufficient” should be removed from both BS5440¹ and the CORGI handbook², and replaced with “The additional ventilation required can be determined during a spillage test by partially opening a window and measuring the free area of the opening at a point when spillage is no longer evident during the test. The spillage test must be repeated with a cold appliance and flue when the additional permanent ventilation has been fitted.” Similar wording should be added to BS5440 Part 1³

b) Increase public and gas installers awareness of the potential for cooker hoods, room extract fans, tumble driers and similar appliances with fans, to cause spillage. Electrical installers must be made aware of the potential problems. Instructions for such appliances must include a suitable warning.

c) The spillage test is currently the best method available to a service engineer for determining conflicts with air extraction equipment.

¹ BS5440: Part 2: 2000 (Specification for the installation and maintenance of ventilation for gas appliances), Section 6.1
³ BS5440: Part 1: 2000 (Specification for the installation and maintenance of flues), Section 5.3.2.3
1 INTRODUCTION

Open-flued appliances work by taking air for combustion from the volume surrounding the appliance, and venting the combustion products via the flue to the atmosphere. If the process of venting is impeded, e.g. by an adverse flow in the flue, unwanted combustion products can be spilled into the volume around the appliance. Whilst current legislation requires anti-vitiation devices to be fitted to new appliances, a substantial population of older appliances (up to 40 million altogether) currently installed in the UK includes a significant number without such safety features. The anti-vitiation devices fitted to new appliances may also not work effectively under such conditions because they sense parameters other than the carbon monoxide produced.

Open-flued appliances are designed with a draught diverter to cope with intermittent downdraught in the flue (caused generally by wind effects around the flue terminal) to ensure the products of combustion do not directly affect the appliance burners. However, for these normally short periods the combustion products enter the room by the draught diverter, rather than being evacuated by the flue.

A potential way of producing adverse flow in the flue is the operation of an extraction fan near the open-flued appliance. This causes de-pressurisation of the room and consequently air from outside may flow preferentially down the flue into the room, causing combustion products spillage into the room. Examples of appliances with extraction fans are cooker hoods, tumble driers, fan assisted open-flued appliances, as well as wall and window mounted extraction fans themselves.

This report describes work following on from the First Phase, described in reference 1. The experiments were conducted in a recently built test house at Advantica’s Loughborough site (see Section 2 for a more detailed description). Two appliances used in the First Phase of work (the Combi and Central Heating Boilers) were again used, together with a flame effect gas fire. Details of the appliances are given in Section 2. Some of the tests were repeats of tests in Phase 1, to see if a different house would produce similar results. Other tests were designed to investigate the effect of a lower height (tumble drier rather than window mounted) extraction and the effect of a different gas appliance. A window-mounted ventilator (sized to comply with BS5440 minimum requirements on area) was used. At the end of a typical experiment the extract fan was left on and the extra ventilator area necessary to allow normal operation of the flue was determined.
2 EXPERIMENTAL FACILITIES

2.1 THE TEST ENCLOSURE

The programme of experiments was carried out in the Ventilation Test House facility at the Advantica Loughborough Site. This test facility is a purpose-built two-storey detached house of timber frame construction, with a brick cladding for the outside walls and a pitched tiled roof (see Figure 1) built to current building regulations. The layout of the house is shown in Figure 2 and the room dimensions (as stated by the builders) are given in Table 1.

![Elevation of house](image)

<table>
<thead>
<tr>
<th>Ground Floor</th>
<th>First Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchen</td>
<td>Bedroom 1 (max)</td>
</tr>
<tr>
<td>2425mm x 2490mm</td>
<td>4573mm x 2313mm</td>
</tr>
<tr>
<td>Lounge / Dining</td>
<td>Bedroom 2</td>
</tr>
<tr>
<td>4573mm x 4027mm</td>
<td>2313mm x 3872mm</td>
</tr>
<tr>
<td>WC</td>
<td>Bedroom 2 (max)</td>
</tr>
<tr>
<td>911mm x 1500mm</td>
<td>4573mm x 2363mm</td>
</tr>
<tr>
<td></td>
<td>Bathroom</td>
</tr>
<tr>
<td></td>
<td>2620mm x 1800mm</td>
</tr>
</tbody>
</table>

*Height of each room* 2300mm
The experiments were conducted with the gas appliance in Bedroom 2 and the extract in either Bedroom 1 or Bedroom 2, as required by the experimental program. All the internal doors in the house were normally open during the experiments unless specifically required to be closed for the particular experiment. The door to Bedroom 2, when closed, was sealed with tape at the sides and the top but not the bottom. This left a nominal 6mm gap between the door and the floor, a similar configuration to that generally used during Phase 1. The experiments were conducted on the upper floor of the house in this Phase, whereas the tests utilised the ground floor of the house in the tests in Phase 1. Consequently, where the appliance was in one room and the extract in another, the bottom of the stairs was blocked by a wooden board to prevent preferential ventilation via the stair well. The position of ventilators, extract openings, and gas appliances is shown in Figure 3 and their exact location details are given in Table 2. Ventilation for Bedroom 2 was available via an opening of adjustable area located centrally in one of the windows, 1.76m from the floor, as shown in Figure 3.

2.2 GAS APPLIANCES

The gas appliances used were a wall-mounted central heating boiler, a wall-mounted combi-boiler, and a coal effect gas fire for which details are listed below. The locations of the appliances are shown in Figure 2, and photographs in Figure 4.

To make the flue pull less susceptible to the effects of wind conditions, the flue was terminated in the loft space. There was no evidence of any combustion product build up in the loft space influencing the experiments.
Figure 3 Layout of appliances, ventilators, and extraction units

Table 2 Measurements in Bedroom 2

<table>
<thead>
<tr>
<th></th>
<th>$x_{ex}$</th>
<th>$y_{ex}$</th>
<th>$z_{ex}$</th>
<th>$x_{ex}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low height extract</td>
<td>1.44m</td>
<td>0.36m</td>
<td>0.33m</td>
<td>1.44m</td>
</tr>
<tr>
<td>High level extract</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y_{ex}$</td>
<td>In window</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z_{ex}$</td>
<td>1.86m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_{v}$</td>
<td>1.22m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilator</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y_{v}$</td>
<td>In window</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z_{v}$</td>
<td>1.76m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_{b}$</td>
<td>1.68m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Fire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y_{f}$</td>
<td>0.64m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z_{b}$</td>
<td>0.07m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_{b}$</td>
<td>1.75m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Heating Boiler</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y_{b}$</td>
<td>0.27m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z_{b}$</td>
<td>1.02m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$x_{b}$</td>
<td>1.67m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combi Boiler</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y_{b}$</td>
<td>0.26m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z_{b}$</td>
<td>1.12m</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurements are as shown on Figure 3
$z_{ex}$ and $z_{b}$ are from the floor to the centre of the opening
$z_{b}$ is from the floor to the base of the appliance
$z_f$ is from the floor to the base of the internal firebox
2.2.1 Central Heating Boiler

The wall-mounted central heating boiler was a Myson Apollo 40C model with a maximum heat input of 15.4kW (52,600Btu/hr). It was supported on a trolley and located at a height of 1.02m from the floor, with the back of the boiler approximately 0.27m from the wall. The appliance was flued by 100mm diameter twin walled flue which terminated in the loft space, and had a length of 1.5 m.

2.2.2 Combi-Boiler

The wall-mounted combi-boiler was a Vaillant VCW GB 280H model with a maximum heat input of 35.4kW (120,800Btu/hr). The appliance was supported on a trolley and was located at a height of 1.12m from the floor, with the back of the boiler approximately 0.26m from the wall. The appliance was flued by 125mm diameter twin walled flue which terminated in the loft space, and had a length of 1 metre.

2.2.3 Gas Fire

This floor standing appliance was a Royal Cozyfires “The Royal Chichester” with a maximum heat input of 6.6kW. The fire was mounted in a Firebox and flued by 125mm diameter twin walled flue. The flue was terminated in the loft space, and had a length of 2.6 metres.

2.2.4 Operating Arrangements

The Gas Fire did not have a thermostat installed and, following ignition, was operated continuously at the maximum heat output setting.

The Combi-Boiler, and Central Heating Boiler were operated continuously (at maximum heat output) by using an external radiator to dispose of excess heat. In this way, the water outlet temperature was prevented from becoming high enough to cause the appliance to turn off or cycle.
2.3 GAS SUPPLY

Natural gas was supplied to the appliances from the main supply at Advantica. The pressure was reduced by the meter governor to approximately 20mbar, which is typical of a domestic system.

2.4 AIR EXTRACTION EQUIPMENT

A schematic diagram of the air extraction system is shown in Figure 5. The air extraction system consisted of 2 Xpelair Centrifugal Duct fans, type XID 150, a flow measurement section using a Trox VMR125 with a Furness Controls micromanometer, type FCS510, and 150mm diameter flexible ducting. The outlet from the system was positioned so that combustion products did not re-enter the house. The high level inlet from the room was via an adapter plate which was fitted in place of the top section of one of the windows of the house as shown in Figure 5. The low height extract was made by connecting an extra length of flexible ducting to the adaptor plate in the window so that the extract opening was closer to the floor. This is shown in Figure 3 and Figure 5, with details of the location in Table 2.

Flow was measured via the Trox VMR125, and could be adjusted by using a Variac to control the speed of the fans.

![Figure 5 Schematic diagram of extraction system](image-url)
2.5 EXPERIMENTAL MEASUREMENTS

During each experiment, measurements were made to monitor the following parameters: - 

a) Concentration of carbon monoxide, carbon dioxide and oxygen present within the test enclosure, in the combustion air supply to the appliance, at the draught diverter, in the flue, and in the extract system;  
b) Temperature within the test enclosure, the draught diverter, and the flue;  
c) Pressure in the test enclosure and the flue;  
d) Prevailing weather conditions outside the Test House.

Details of these measurements are outlined below.

2.5.1 Infrared Analysers

The concentration of carbon monoxide, carbon dioxide, and oxygen within the rooms of the test enclosure was monitored by means of sample probes attached to a sample stand. These stands were located approximately in the centre of Bedrooms 1 and 2 and supported seven probes positioned to provide measurements of gas concentration on a vertical axis over essentially the full height of the room between floor and ceiling level. In addition, sample probes were located in the path of the combustion air supply to the appliance, at the draught diverter, in the flue, and in the ductwork from the extract fan. The heights of the sample probes above the ground floor are given in Table 3.

<table>
<thead>
<tr>
<th>Sample probe</th>
<th>On Sample Stands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample probe</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>Height above floor metres</td>
<td>2.25 1.85 1.50 1.20 0.85 0.45 0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Combi Boiler</th>
<th>Central Heating Boiler</th>
<th>Gas Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height above floor metres</td>
<td>1.4</td>
<td>1.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Combi Boiler</th>
<th>Central Heating Boiler</th>
<th>Gas Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height above floor metres</td>
<td>1.9</td>
<td>1.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Combi Boiler</th>
<th>Central Heating Boiler</th>
<th>Gas Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height above floor metres</td>
<td>2.1</td>
<td>1.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>
The probes were sampled in sequence using a stream selection unit controlled by the data logging/analysis system connected to four analysers. Details of the sample probe sequence are shown in Table 4. The build-up of carbon monoxide within each room was monitored by means of graphical displays of the concentration-height profiles measured at the sample stand location via a video display unit which formed part of the data logging/analysis system.

Table 4  Sample probe sequence

<table>
<thead>
<tr>
<th>Appliance combustion air and combustion product streams</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sequence:</strong>  Combustion air supply → Draught diverter → Flue</td>
</tr>
<tr>
<td><strong>Time taken</strong> - 2¼ minutes</td>
</tr>
<tr>
<td><strong>In centre of bedrooms</strong></td>
</tr>
<tr>
<td><strong>Sequence</strong></td>
</tr>
<tr>
<td><strong>Time taken</strong> - 5¼ minutes</td>
</tr>
</tbody>
</table>

All samples withdrawn during the course of an experiment for analysis were analysed by instruments located inside an instrument kiosk situated to the side of the Test House and dried prior to analysis using dedicated Perma Pure drying columns. These columns exchanged water vapour through capillary tubes with walls made from semi-permeable material with a dry stream of air circulating around them. Such a technique ensured there was no adsorption of combustion products onto the surface of any solid drying agents which would have rendered the resulting gas concentration measurements inaccurate.

Each of the probes used to measure the concentration of carbon monoxide, carbon dioxide and oxygen was sampled for a 45 second period to ensure the line had been purged completely and the analyser, a Siemens Ultramat 22 + O2 or Siemens Ultramat 23 + O2, provided an accurate measurement of concentration at the moment a data point was logged.

2.5.2 Temperatures

Temperatures were measured at 3 heights (near the ceiling, mid height, and close to the floor) on the sample stands in Bedroom 1 and Bedroom 2. In addition, temperatures were measured in or close to the draught diverter, and in the flue. The position of the sensor in the flue is shown in Figure 6.

![Figure 6 Position of probes in the flue](image)
2.5.3 **Pressures**

Furness Controls micromanometers, type FCO16, were used to measure the differential pressures:

- a) Between outside the property and the room;
- b) Between the room and the flue;
- c) The pressure between the “upstream” and “downstream” probes in the flue.

In addition, as mentioned in Section 2.4 the pressure due to flow through the Trox VMR125 in the extraction system was also measured.

2.5.4 **Ambient Weather Conditions**

The prevailing weather conditions were monitored during each experiment using instrumentation local to the test enclosure. Air temperature and relative humidity were measured using a Vaisala HMD70Y, and the atmospheric pressure using a PTB100A barometer. The wind speed was monitored together with the wind direction using a Gill Instruments Ultrasonic Anemometer. The sensing elements for this instrument were positioned at a height of 6 metres and attached to a supporting mast approximately 6 metres north of the Test House.

2.5.5 **Recording of data**

The logging system was controlled by a PC in the control room, and used InstruNet modules (manufactured by GW Instruments inc.) located much closer to the instruments to record the data. In this way, the noise on the signals was kept as low as possible.

The InstruNet modules were also used to control the stream selection boxes for the gas sample probes with data points recorded every 45 seconds. The data was transferred straight into an Excel spreadsheet so that real time displays could be obtained of, for example, gas concentration profiles, temperatures, weather conditions, etc. during the test. In addition, the spreadsheet itself could be examined while the test was in progress.
3 EXPERIMENTAL PROGRAMME

The experimental programme consisted of 10 tests, details of which are shown in Table 5.

Three different types of gas appliance, as described in Section 2.2, and two types of air extraction, as described in Section 2.4, were used. These were located as shown in Figure 3 and Table 5. A ventilator was provided to comply with the minimum ventilation requirements of BS5440 Part 2, 20002, and its position is shown in Figure 3 and Table 2.

Some tests were performed with the gas appliance and the extract fan in the same room, whilst in others the gas appliance and extract fan were in different rooms.

Table 5  Experimental programme

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Appliance type</th>
<th>Area of vent (cm²)</th>
<th>Extract in room</th>
<th>Doors closed (other doors are open)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CHB</td>
<td>Bedroom 2</td>
<td>Bedroom 2</td>
<td>Bedroom 2 door closed</td>
</tr>
<tr>
<td>2</td>
<td>CHB</td>
<td>Bedroom 2</td>
<td>Bedroom 1</td>
<td>Bedroom 2 door closed, bathroom door closed, stairs blocked at bottom</td>
</tr>
<tr>
<td>3</td>
<td>CHB</td>
<td>Bedroom 2</td>
<td>Bedroom 1</td>
<td>Bedroom 1 door closed, bathroom door closed, stairs blocked at bottom</td>
</tr>
<tr>
<td>3a</td>
<td>CHB</td>
<td>Bedroom 2</td>
<td>Bedroom 1</td>
<td>Both bedroom doors open, bathroom door closed, stairs blocked at bottom</td>
</tr>
<tr>
<td>4</td>
<td>CHB</td>
<td>Bedroom 2</td>
<td>Bedroom 2</td>
<td>Bedroom 2 door closed</td>
</tr>
<tr>
<td>5</td>
<td>CB</td>
<td>Bedroom 2</td>
<td>Bedroom 2</td>
<td>Bedroom 2 door closed, bathroom door closed, stairs blocked at bottom</td>
</tr>
<tr>
<td>6</td>
<td>CB</td>
<td>Bedroom 2</td>
<td>Bedroom 1</td>
<td>Bedroom 1 door closed, bathroom door closed, stairs blocked at bottom</td>
</tr>
<tr>
<td>7</td>
<td>CB</td>
<td>Bedroom 2</td>
<td>Bedroom 1</td>
<td>Both bedroom doors open, bathroom door closed, stairs blocked at bottom</td>
</tr>
<tr>
<td>7a</td>
<td>CB</td>
<td>Bedroom 2</td>
<td>Bedroom 1</td>
<td>Both bedroom doors open, bathroom door closed, stairs blocked at bottom</td>
</tr>
<tr>
<td>8</td>
<td>CB</td>
<td>Bedroom 2</td>
<td>Bedroom 2</td>
<td>Bedroom 2 door closed</td>
</tr>
<tr>
<td>9</td>
<td>GF</td>
<td>Bedroom 2</td>
<td>Bedroom 2</td>
<td>Bedroom 2 door closed</td>
</tr>
<tr>
<td>10</td>
<td>GF</td>
<td>Bedroom 2</td>
<td>Bedroom 2</td>
<td>Bedroom 2 door closed</td>
</tr>
</tbody>
</table>

CHB = Central Heating Boiler  
CB = Combi Boiler  
GF = Gas Fire
4 EXPERIMENTAL PROCEDURE

To start each experiment, the extract fan was run at a high rate and the gas appliance lit. The flow in the flue was monitored by the differential pressure due to flow and also by the temperatures in the flue and at the draught diverter. The level of extraction was reduced until the flue started to pull in order that the flow rate required to just reverse the flue could be determined. The appliance was then extinguished and the extract rate increased. The flue was allowed to cool before the gas appliance was re-lit. This time the flow rate in the extract was only reduced to a level where flow reversal in the flue could be maintained in spite of variations in ambient conditions, such as fluctuations in wind speed and direction. This demanded care - too low a flow rate resulted in the flue spontaneously pulling normally, and too high a rate would distort the experimental results. In practice, the flow rate used was increased from a low level until spontaneous flue pulling was not observed.

In some experiments the extraction fan was run at one rate until steady state conditions were achieved or the flue started to pull spontaneously, and then the extract rate was increased so that the effect could be observed. This flow rate was maintained for the rest of the test.

The phase of the test where reversed flow was maintained was continued until one of the following conditions had been reached:

- a steady-state concentration of carbon monoxide had been measured within the room containing the appliance;
- ½ hour had elapsed (using the Combi Boiler);
  1 hour had elapsed (using the Central Heating Boiler);
  3 hours had elapsed (using the Gas Fire).

The final phase of the experiment determined the extra ventilator area required to cause the flow in the flue to revert to normal. The extraction rate was maintained while the ventilator(s) were gradually opened. “Normal” flow in the flue was deemed to have been produced when the flue products were again passing up the flue and a steady flow had been re-established.

The sequence is summarised in Figure 7.
Start extract system on a high setting, and light the appliance

Reduce extract until flue pulls
(*This gives the flowrate required to just reverse the flue*)

Extinguish the appliance and increase extraction rate. Allow flue to cool

Reduce extraction rate to required level. Re-light appliance

Run the test for the required time

Use a different extract rate and run the test again for the required time

Determine extra ventilator area needed to make flue pull

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**Figure 7** Sequence diagram for conducting a test
5 RESULTS

The Appendix to this report contains details of the measurements made during the tests. Each test has associated data which includes:

1. Details of the room configuration, average wind speed/direction and general test conditions in Table 5 and Table 6
2. The prevailing weather conditions (wind speed/direction, temperature, humidity, pressure).
3. The variation in carbon monoxide, carbon dioxide and oxygen concentrations with time in the combustion air supply, at the draught diverter, and in the flue to the appliance.
4. The variation in carbon monoxide, carbon dioxide and oxygen concentrations with time in the rooms of the house. This information is presented as concentration-height profiles.
5. The variation in carbon monoxide, carbon dioxide and oxygen concentrations with time in the extraction system.
6. Flow through the extraction system.
7. Extra ventilator area needed to make the flue revert to normal operation.
8. Temperatures inside the house.

The results obtained are discussed in detail below.

5.1 CENTRAL HEATING BOILER

When the extract and the boiler were in the same room it was found that an extract rate of 90 – 135m³/hr was sufficient to maintain flue reversal for a short period. The rate of extraction determined above was not sufficient to maintain flue reversal during the steady state phase of the test. This may have been due to small pressure perturbations in the flue caused by external wind conditions, or variations in the “drive” of combustion products at the base of the flue. Thus for the steady state phase, rates of 260 - 290m³/hr were used.

This “excess” flow rate in the extraction system is defined as:

\[
\text{flow rate used} - \text{flow rate required to just reverse the cold flue}
\]

The extraction rates measured in each test are shown in Table 6.

Carbon monoxide and carbon dioxide spilled into the room as soon as the flue was reversed. The profiles for tests 1 and 4 are shown in Figure 8, and the concentrations at the highest sample point on the stand are shown in Figure 9. A summary of the concentrations of carbon monoxide, carbon dioxide, and oxygen measured during each test is shown in Table 7. The amount of carbon monoxide produced by this boiler was significantly less than that produced by the Combi Boiler. However, higher extraction rates did produce more carbon monoxide than tests using low extraction rates. As can be seen, much more carbon monoxide was produced in the tests where the extract was at a low height rather than mounted through the window.

The spillage of combustion products also raised the temperature in the room. The rise in temperature measured during each test (see Section 5.1) is given in Table 8.

In the final part of the test, the external ventilator area was increased until the flue started to pull normally. The results obtained are given in Table 6.

When the boiler and extract were in different rooms (Tests 2, 3, and 3a) it did not prove possible to reverse (and maintain) the flow in the flow in the flue, even at the highest extract rates available (~350m³/hr).
| Test No | Appliance | Extraction rate required to just reverse flue | Extraction rate used in test | Average area needed to get flue to pull | Atmospheric pressure | Outside temperature | Relative humidity | Wind speed | Wind direction
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>m³/hr</td>
<td>m³/hr</td>
<td>cm²</td>
<td>mbar</td>
<td>Celsius</td>
<td>%</td>
<td>metres / second</td>
<td>degrees relative to North</td>
</tr>
<tr>
<td>1</td>
<td>CHB</td>
<td>134</td>
<td>285</td>
<td>-</td>
<td>990</td>
<td>9</td>
<td>91</td>
<td>3.8 ± 1.2</td>
<td>191 ± 26</td>
</tr>
<tr>
<td>1</td>
<td>CHB †</td>
<td>134</td>
<td>342</td>
<td>&gt;250ᵃ</td>
<td>989</td>
<td>9.2</td>
<td>91</td>
<td>3.4 ± 1.1</td>
<td>200 ± 39</td>
</tr>
<tr>
<td>2</td>
<td>CHB</td>
<td>‡</td>
<td>-</td>
<td>-</td>
<td>13</td>
<td>8</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CHB</td>
<td>‡</td>
<td>-</td>
<td>-</td>
<td>13</td>
<td>8</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>CHB</td>
<td>‡</td>
<td>-</td>
<td>-</td>
<td>13</td>
<td>8</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>CHB</td>
<td>91</td>
<td>262</td>
<td>-</td>
<td>988</td>
<td>9.7</td>
<td>93</td>
<td>3.6 ± 1.2</td>
<td>169 ± 78</td>
</tr>
<tr>
<td>4</td>
<td>CHB †</td>
<td>91</td>
<td>320</td>
<td>&gt;250ᵇ</td>
<td>987</td>
<td>10</td>
<td>91</td>
<td>4 ± 1</td>
<td>145 ± 28</td>
</tr>
<tr>
<td>5</td>
<td>CB</td>
<td>205</td>
<td>284</td>
<td>0</td>
<td>990</td>
<td>6</td>
<td>90</td>
<td>1.4 ± 0.8</td>
<td>274 ± 47</td>
</tr>
<tr>
<td>6</td>
<td>CB</td>
<td>‡</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>1</td>
<td>315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>CB</td>
<td>‡</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>1</td>
<td>315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7a</td>
<td>CB</td>
<td>‡</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>1</td>
<td>315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>CB</td>
<td>165</td>
<td>271</td>
<td>87</td>
<td>987</td>
<td>6.1</td>
<td>95</td>
<td>1.9 ± 0.9</td>
<td>208 ± 31</td>
</tr>
<tr>
<td>9</td>
<td>GF</td>
<td>94</td>
<td>174</td>
<td>-</td>
<td>977</td>
<td>14.2</td>
<td>87</td>
<td>4.4 ± 1.5</td>
<td>184 ± 36</td>
</tr>
<tr>
<td>9</td>
<td>GF †</td>
<td>94</td>
<td>202</td>
<td>100</td>
<td>978</td>
<td>13.9</td>
<td>87</td>
<td>4.2 ± 1.3</td>
<td>205 ± 44</td>
</tr>
<tr>
<td>10</td>
<td>GF</td>
<td>90</td>
<td>202</td>
<td>-</td>
<td>988</td>
<td>11.1</td>
<td>85</td>
<td>4.2 ± 1.7</td>
<td>168 ± 41</td>
</tr>
<tr>
<td>10</td>
<td>GF †</td>
<td>90</td>
<td>254</td>
<td>&gt;290ᶜ</td>
<td>987</td>
<td>11.2</td>
<td>85</td>
<td>4.2 ± 1.5</td>
<td>152 ± 26</td>
</tr>
</tbody>
</table>

ᵃ Unable to maintain reversal ᵇ Higher extract rate
ᶜ Extract reduced until flue pulled normally, at (a) 270m³/hr, (b) 260m³/hr, (c) 150m³/hr
CHB = Central Heating Boiler  CB = Combi Boiler  GF = Gas Fire
<table>
<thead>
<tr>
<th>Test No</th>
<th>Carbon Dioxide concentration in Bedroom 2</th>
<th>Carbon Dioxide concentration in extract</th>
<th>Oxygen concentration in Bedroom 2</th>
<th>Carbon Monoxide concentration produced</th>
<th>Carbon Monoxide concentration in extract</th>
<th>Carbon Dioxide concentration produced</th>
<th>Carbon Dioxide concentration in feed</th>
<th>Oxygen concentration in feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm</td>
<td>%</td>
<td>%</td>
<td>ppm</td>
<td>m³/hr</td>
<td>%</td>
<td>m³/hr</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>1</td>
<td>144</td>
<td>0.041</td>
<td>144</td>
<td>0.59</td>
<td>1.665</td>
<td>0.48</td>
<td>20.2</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>297</td>
<td>0.102</td>
<td>297</td>
<td>0.42</td>
<td>1.421</td>
<td>0.58</td>
<td>20</td>
<td>18.9</td>
</tr>
<tr>
<td>2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3a</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>rising to 880</td>
<td>rising to 1.4</td>
<td>falling to 18.6</td>
<td>311</td>
<td>0.082</td>
<td>0.54</td>
<td>1.426</td>
<td>1.22</td>
</tr>
<tr>
<td>4</td>
<td>falling to 980</td>
<td>falling to 1</td>
<td>rising to 19.2</td>
<td>437</td>
<td>0.14</td>
<td>0.41</td>
<td>1.321</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>2</td>
<td>17.6</td>
<td>211</td>
<td>0.06</td>
<td>1.34</td>
<td>3.818</td>
<td>0.57</td>
</tr>
<tr>
<td>6</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<td>–</td>
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<tr>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>7a</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>8</td>
<td>more than 5000</td>
<td>3.1</td>
<td>15</td>
<td>1801</td>
<td>0.487</td>
<td>1.18</td>
<td>3.189</td>
<td>1.93</td>
</tr>
<tr>
<td>9</td>
<td>falling to 50</td>
<td>0.35</td>
<td>20.4</td>
<td>130</td>
<td>0.023</td>
<td>0.37</td>
<td>0.641</td>
<td>0.13</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>0.3</td>
<td>20.5</td>
<td>36</td>
<td>0.007</td>
<td>0.33</td>
<td>0.664</td>
<td>0.1</td>
</tr>
<tr>
<td>10</td>
<td>falling to 40</td>
<td>rising to 0.55</td>
<td>20.1</td>
<td>98</td>
<td>0.02</td>
<td>0.38</td>
<td>0.761</td>
<td>0.2</td>
</tr>
<tr>
<td>10</td>
<td>About 40</td>
<td>0.4</td>
<td>20.4</td>
<td>84</td>
<td>0.021</td>
<td>0.34</td>
<td>0.854</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Figure 8: Concentration profiles in Bedroom 2 for Tests 1 and 4
Figure 9 Concentration at top of Bedroom 2 for Tests 1 and 4
Table 8  Temperatures

<table>
<thead>
<tr>
<th>Test No</th>
<th>Temperature rise during test in Bedroom 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>top</td>
</tr>
<tr>
<td>1</td>
<td>6.0</td>
</tr>
<tr>
<td>1†</td>
<td>6.3</td>
</tr>
<tr>
<td>4‡</td>
<td>12.3</td>
</tr>
<tr>
<td>4†‡</td>
<td>9.0</td>
</tr>
<tr>
<td>5</td>
<td>16.3</td>
</tr>
<tr>
<td>8‡</td>
<td>22.6</td>
</tr>
<tr>
<td>9†</td>
<td>19.3</td>
</tr>
<tr>
<td>9‡</td>
<td>27.0</td>
</tr>
<tr>
<td>10‡</td>
<td>26.3</td>
</tr>
<tr>
<td>10†‡</td>
<td>31.4</td>
</tr>
</tbody>
</table>

†  Higher extract rate  
‡  Low height extract  

5.2 COMBI BOILER

When the extract and the boiler were in the same room it was found that an extract rate of 160 – 200$m^3$/hr was sufficient to maintain flue reversal for a short period. The rate of extraction determined above was not sufficient to maintain flue reversal during the steady state phase of the test, and rates of 270 - 290$m^3$/hr were used. The extraction rates measured in each test are shown in Table 6.

Carbon monoxide and carbon dioxide spilled into the room as soon as the flue was reversed. The profiles after 26 minutes for tests 5 and 8 are shown in Figure 10, and the concentrations at the highest sample point on the stand are shown in Figure 11. A summary of the concentrations of carbon monoxide, carbon dioxide, and oxygen measured is shown in Table 7. As can be seen, much more carbon monoxide was produced in the test where the extract was at a low height rather than mounted through the window.

The spillage of the combustion products also raised the temperature in the room. The rise in temperature measured during each test (see Section 5.1) is shown in Table 8, and is defined as: -

\[
\text{temperature at end of steady state period} - \text{temperature at start of test}
\]

In the final part of the test, the external ventilator area was increased until the flue started to pull normally. The results obtained are given in Table 6.

When the boiler and extract were in different rooms (Tests 6, 7, and 7a) it did not prove possible to reverse (and maintain) the flow in the flow in the flue, even at the highest extract rates available (~350$m^3$/hr).
Figure 10 Concentration profiles in Bedroom 2 for Tests 5 and 8
Figure 11: Concentration at top of Bedroom 2 for Tests 5 and 8
5.3 GAS FIRE

The extraction rate needed to reverse the flue tended to be similar to that required by the Central Heating Boiler, as shown by the values of extraction rate shown in Table 6.

Carbon monoxide and carbon dioxide spilled into the room as soon as the flue was reversed although the low power rating of the appliance (6.6 kW) resulted in a slow build up of combustion products. However, the initial period where the concentrations of carbon monoxide and carbon dioxide altered significantly was less than 1 hour in all tests. The profiles for tests 9 and 10 are shown in Figure 12, and the concentrations at the highest sample point on the stand are shown in Figure 13. A summary of the concentrations of carbon monoxide, carbon dioxide, and oxygen measured is shown in Table 7. The amount of carbon monoxide produced by the Gas Fire was significantly less than produced by the Combi Boiler.

The spillage of combustion products also raised the temperature in the room. The rise in temperature measured during each test (see Section 5.1) is given in Table 8.

In the final part of the test, the external ventilator area was increased until the flue started to pull normally. The results obtained are given in Table 6.
Figure 12  Concentration profiles in Bedroom 2 for Tests 9 and 10
Figure 13 Concentration at top of Bedroom 2 for Tests 9 and 10
6 DISCUSSION

6.1 COMBUSTION PRODUCTS

When the flow in the flue was fully reversed, all of the combustion products entered the room containing the appliance. Thus, the concentrations of carbon monoxide and carbon dioxide in the volume around the appliance tended to increase until the rate at which they were being produced is equal to the rate at which they were being removed. This is known as “steady state” conditions. The net effect of convection, ventilation, and extraction processes in the room produces the profile recorded during each test.

Figure 14, Figure 15 and Figure 16 show the concentration of carbon monoxide and carbon dioxide in the Bedroom 2 for the three gas appliances used. The concentration of carbon dioxide fell as the extraction rate increased, while the concentration of carbon monoxide appeared to rise at the higher flow rates. The change in position of the extract caused a noticeable effect on the concentration of carbon dioxide with all three appliances, although the effect on the concentration of carbon monoxide varied between the appliances. This is discussed in more detail in Section 6.1.3 The effect of extract flow rate on the production of combustion products cannot be seen clearly in these plots. However, by assuming that all the combustion products are taken into the extraction system, a value for the quantities produced by the gas appliance can be calculated by the equation:

\[
\text{Rate of combustion product production} = \frac{\text{Concentration of combustion product in extract system}}{\text{Flow rate in extraction system}}
\]

![Figure 14](image-url) Concentration in Bedroom 2 with the Central Heating Boiler

\[
\begin{align*}
\text{Central heating boiler} & : \\
\text{Central heating boiler, higher extract rate} & : \\
\text{Central heating boiler, low height extract} & : \\
\text{Central heating boiler, low height extract, higher extract rate} & :
\end{align*}
\]
Figure 15 Concentration in Bedroom 2 with the Combi Boiler

Figure 16 Concentration in Bedroom 2 with the Gas Fire
Figure 17, Figure 18 and Figure 19 show the rate of carbon monoxide and carbon dioxide production plotted against extraction rate. The effect of the changes (flow rate and extract position) can now be seen much more clearly. The rate of carbon dioxide production by the appliance, based on its power rating, is also shown on the chart. The experimental measurements are close to these predicted values.

Figure 17 Quantity of carbon monoxide and dioxide produced by the Central Heating Boiler
Figure 18  Quantity of carbon monoxide and dioxide produced by the Combi Boiler

Figure 19  Quantity of carbon monoxide and dioxide produced by the Gas Fire
6.1.1 Low extract rates

A Low Extract Rate is enough to maintain flow reversal in the flue and the values used are shown in Table 6.

Previous work\(^3\) showed that the Combi Boiler spilled significant amounts of carbon monoxide when the flue was partially blocked, even if the air supply to the boiler was not vitiated. This was attributed to the design of the draught diverter allowing combustion products to re-circulate within the boiler case when the flue was restricted or blocked. Thus, when the flow in the flue is reversed by an extraction fan, the air supplied to the burner is a combination of air from the room and combustion products from the draught diverter. Hence, a higher concentration of carbon monoxide will be produced than expected from the vitiation of the room air and, because the flow in the flue is reversed, this will enter the room. The Central Heating Boiler and the Gas Fire produced only small quantities of carbon monoxide at low extract rates. The concentrations and quantities of carbon monoxide and carbon dioxide produced are shown on Figures 14 – 16 and Table 7.

6.1.2 High extract rates

With both the Central Heating Boiler and the Gas Fire, the test started with “low” extraction rate, which was increased later in the test. The values used are shown in Table 6. Again, the concentrations of carbon monoxide and carbon dioxide measured are shown on Figures 14 – 16 and Table 7. The quantity of carbon monoxide produced increased for the Central Heating Boiler, but not for the Gas Fire. The higher extract rate caused changes in the concentration / height profiles of the carbon monoxide, carbon dioxide and oxygen which caused some difference in the composition of the combustion air supply, as shown in Table 9. The increased extraction rate caused a decrease in the concentration of carbon dioxide in the combustion air in three of the four that can be compared, yet the rate of production of carbon monoxide increased in both tests involving the Central Heating Boiler, but was little changed in the Gas Fire tests. The difference in response between the two appliances may have been due, for example, to the design of the draught diverters and burners.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>1(\dagger)</td>
<td>300</td>
</tr>
<tr>
<td>4(\ddagger)</td>
<td>740</td>
</tr>
<tr>
<td>4(\dagger\dagger)</td>
<td>1000</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>8(\ddagger)</td>
<td>3000</td>
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<td>9</td>
<td>20</td>
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<tr>
<td>9(\dagger)</td>
<td>10</td>
</tr>
<tr>
<td>10(\ddagger)</td>
<td>40</td>
</tr>
<tr>
<td>10(\dagger\dagger)</td>
<td>20</td>
</tr>
</tbody>
</table>

\(\dagger\) Higher extract rate
\(\ddagger\) Low height extract
6.1.3 Change in position of the extract

The extract opening was either positioned in the upper part of one of the windows (to represent a window mounted extraction fan), or much closer to floor level (to represent a fan inside an appliance such as a tumble drier). Details of the positions are in Section 2.1 and Figure 3.

With the Central Heating Boiler, the amount of carbon monoxide produced was increased (and carbon dioxide reduced) when the lower position of extract was used compared with the higher position. The height / concentration profiles also showed differences, with considerably higher concentrations of both carbon monoxide and carbon dioxide in the upper half of the room but smaller increases lower down, as shown in Figure 8.

With the Combi Boiler, the amount of carbon monoxide produced was increased (and carbon dioxide reduced) when the lower position of extract was used compared with the higher position. The height / concentration profiles also showed differences, with considerably higher concentrations of both carbon monoxide and carbon dioxide in the room, as shown in Figure 10.

The Gas Fire showed little change in the overall output of carbon monoxide and carbon dioxide, although the height / concentration profiles were different, as shown in Figure 12.

The changes in the concentration / height profiles resulted in the air supplied to the burner being contaminated by a higher concentration of combustion products (and lower concentration of oxygen) where the extract was at low down for both boilers. This is shown in Table 9. However, the air supply for the Gas Fire is taken from just above the floor and this was almost unaffected by contamination with combustion products.

6.2 TEMPERATURES

6.2.1 Temperature Rise

Temperatures were measured at 3 heights on the central stand in Bedroom 2 as described in Section 2.5.2. The heat given off by the appliances in normal operation raised the temperature in the room, and values for this (for the Gas Fire only) are shown in Table 10. The temperature rise recorded during the flue reversal phase of the test in the centre of Bedroom 2 is shown on Figure 20, Figure 21, and Figure 22. The temperature rise was most noticeable when using the Gas Fire because all the heat produced went into the room, rather than a large proportion being removed by the water circulating through the boilers. In addition, the Gas Fire was located just above the floor and the temperature rise was seen at all 3 measurement heights in the room. The two boilers were mounted at a height of 1.02m (the Central Heating Boiler) and 1.12m (the Combi Boiler) above the floor. Consequently, the warm combustion products were ejected at a higher level and would tend to rise because of their buoyancy the temperature rise was much smaller at floor level than near the ceiling. This difference was accentuated when the high level extract was used, rather than the lower position where the warm combustion products tended to be pulled down. Assuming that a person in the room would be aware of a temperature rise of five degrees Celsius, the Gas Fire and Combi Boiler faults are likely to be detected, but the Central Heating Boiler malfunction would only be detected with the lower height extract.

<table>
<thead>
<tr>
<th>Table 10</th>
<th>Temperature rise when appliance operated normally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appliance</td>
<td>Temperature rise - Celsius</td>
</tr>
<tr>
<td></td>
<td>Ceiling</td>
</tr>
<tr>
<td>Gas Fire</td>
<td>2</td>
</tr>
</tbody>
</table>
Figure 20  Temperature rise at top of Bedroom 2

Figure 21  Temperature rise in middle of Bedroom 2

Figure 22  Temperature rise near floor of Bedroom 2
6.2.2 Temperatures in the draught diverter and flue

These measurements were used to check for the direction of flow in the flue. During normal flow in the flue, the hot flue gases rapidly heated the flue. Flue reversal produced a rapid drop towards atmospheric ambient temperature. The temperature in the draught diverter was affected by the proximity of the hot gas appliance, and also by dilution of the flue gases by fresh air during flue reversal. However, an indication of the direction of flow in the flue could be inferred from these two measurements.

The measurements from Test 9 are shown in Figure 23.

![Figure 23](image-url)

### Time (minutes) vs. Event

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30</td>
<td>Boiler lit</td>
</tr>
<tr>
<td>-28</td>
<td>Extract flow reduced until</td>
</tr>
<tr>
<td>-22</td>
<td>Flue pulling</td>
</tr>
<tr>
<td>-16</td>
<td>Boiler turned off</td>
</tr>
<tr>
<td>-14</td>
<td>Extract re-started</td>
</tr>
<tr>
<td>0</td>
<td>Boiler re-lit, extract set for experimental conditions</td>
</tr>
<tr>
<td>48</td>
<td>Extract rate increased</td>
</tr>
<tr>
<td>95</td>
<td>Ventilator area increased</td>
</tr>
<tr>
<td>103</td>
<td>Max vent. area, extract rate reduced</td>
</tr>
<tr>
<td>109</td>
<td>Flue pulling</td>
</tr>
</tbody>
</table>

**Figure 23** Differential Pressures and Flue Temperatures for Test 9
6.3 DIFFERENTIAL PRESSURES

Differential pressures were measured as described in Section 2.5.3 and those measured in the extract system were used to determine the flow rates. The differential pressures in the flue were used to measure qualitatively the flow in the flue. The flow measurements were found to be in good agreement with the measurements described in Section 6.2.1, as shown on Figure 23.

The measurements of differential pressure between the room and the flue, and between the room and the outside, are also presented in Figure 23.

6.4 EXTRA VENTILATOR AREA REQUIRED

The final stage of each test involved increasing the ventilator area into the volume containing the gas appliance and the extract until the flue started to flow normally. As the extract system pulled from the flue, the ventilators, and any other available opening, increasing the ventilator area reduced the tendency for the flow in the flue to remain reversed. The reduction of flow down the flue resulted in a lower dilution of the hot combustion products by cool air, and this resulted in an increase in the temperature recorded at the draught diverter. This can be seen in Figure 23, between 95 and 109 minutes. However once the change to the normal direction of flow in the flue occurred, the differential pressure due to flow in the flue indicated that almost normal flow rates were produced almost immediately. The change was thus observed as a gradual reduction in flow down the flue as the ventilator area was increased, and then a sudden reversal and rapid increase in flow up the flue without any further increase in ventilator area being needed.

The first stage of a test involved determining the extract flow to reverse a cold flue. To maintain reversal in the flue during the experiment a higher extraction rate was needed (see Section 4). In some tests, the extraction rate was increased part way through a test, sometimes after the flue had started to pull spontaneously. Thus, a range of extraction flow rates was used in these tests. The extra ventilator area needed depended on such things as the characteristics of the particular gas appliance, the characteristics of the flue in the prevailing weather conditions, the ventilation available (both adventitious and specifically provided) and the suction from the extraction system. The extra ventilator area found necessary to make the flue flow normally is shown in Figure 24.

As in the previous tests, the “excess flow” was plotted against the extra ventilator area required, as shown in Figure 25. The results indicate that larger excess flows may require larger ventilators to ensure that the flue pulls normally. However has not been possible to derive any definitive values from this small number of tests.

6.5 TESTS WHERE IT WAS NOT POSSIBLE TO MAINTAIN A REVERSED FLUE

In several tests (2, 3, 3a, 6, 7, and 7a), the gas appliance was located in Bedroom 2 and the extract opening in Bedroom 1. The state of the intervening doors (i.e. open or closed) was as detailed in Table 5. Even with the extraction system operating at its maximum rate (about 350m³/hr), it did not prove possible to maintain a reversed flow in the flue for more than a few seconds. The design and construction of the test house used would appear to produce sufficient adventitious ventilation available to prevent an extract in Bedroom 1 causing flue reversal in the gas appliances used in these tests in Bedroom 2.
Figure 24 Extra ventilator area required to cause normal flow in the flue vs. flowrate in the extraction system

Figure 25 Extra ventilator area required to cause normal flow in the flue vs. excess flowrate in the extraction system
7 COMPARISON WITH THE FIRST PHASE TESTS

The two houses used were constructed differently, and also more thorough measures were used to seal gaps and reduce adventitious ventilation in the first series of tests at Fauld. The lengths of flue used were shorter in the second series of tests, because of the location of the appliances. However, both situations probably represent conditions that can be expected to be found in the domestic environment.

7.1 EXTRACTION REQUIRED TO REVERSE FLUE

Table 11 and Table 12 show the values of extraction rate to just reverse the flue, and to maintain reversal during an experiment.

<table>
<thead>
<tr>
<th>Table 11</th>
<th>Comparison of extraction rates, extract and appliance in same room</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 11</td>
</tr>
<tr>
<td></td>
<td>Just reverse</td>
</tr>
<tr>
<td>C/H Boiler</td>
<td>40 - 85</td>
</tr>
<tr>
<td>Combi Boiler</td>
<td>60 - 120</td>
</tr>
<tr>
<td>Gas Fire</td>
<td>40</td>
</tr>
</tbody>
</table>

Values in m$^3$/hr

<table>
<thead>
<tr>
<th>Table 12</th>
<th>Comparison of extraction rates, extract and appliance in different rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 1$^1$</td>
</tr>
<tr>
<td></td>
<td>Just reverse</td>
</tr>
<tr>
<td>C/H Boiler</td>
<td>95</td>
</tr>
<tr>
<td>Combi Boiler</td>
<td>140 - 180</td>
</tr>
<tr>
<td>Gas Fire</td>
<td>100</td>
</tr>
</tbody>
</table>

Values in m$^3$/hr

$\S$ Flue reversal not possible

7.2 EXTRA VENTILATOR AREA NEEDED TO MAKE FLUE PULL NORMALLY

Figure 26 shows the results of combining the results of tests from the First Phase$^1$ with those from the present work. Trend lines drawn on Figure 26 show the results from the First Phase as dashed lines, and a combination of First and Second Phase tests as solid lines. The present work does not appear to have significantly altered the conclusions based on the First Phase of work.
7.3 DIFFERENT EXTRACT LOCATIONS

In Phase 2, a low level extract was used during some tests. The concentrations and profiles were very different compared with high level extract with both the Central Heating and Combi Boilers. A similar situation existed in the First Phase of tests when the boiler was located in one room and the extract in the adjacent room but with a closed door between the two rooms. The similarity between Test 14 in the previous test series and Test 8 in the current series is clearly shown in Figure 27. The extraction system was far less effective at removing combustion products, and consequently a higher concentration of carbon dioxide and lower concentration of oxygen was present in the release room. Thus, the air supply to the appliance burners was more vitiated, and more carbon monoxide was produced. This situation rapidly produced significant concentrations of carbon monoxide (~1500ppm in 11 minutes) compared to a steady state concentration of about 300ppm where the extract was at high level.

7.4 TEMPERATURE RISE

A slightly larger temperature rise was seen in the Current Phase, compared to the previous tests. Although the house was better insulated, the majority of the heat loss was through the extract, rather than through the structure of the building.
Figure 27 Comparison of Test 14 from First Phase and Test 8 from Current Phase
8 CONCLUSIONS FROM THE CURRENT TESTS

a) Flue reversal can be obtained in some appliances with extract rates of less than 100m$^3$/hr.

b) The rate of production of carbon monoxide was dependent on the appliance, the extraction rate and the location of the extract. The Central Heating Boiler at low extraction rates produced little carbon monoxide. Larger quantities were produced at higher (>300m$^3$/hr) extraction rates. Increased amounts were produced in both cases when a low height (rather than located in the top of the window) extract was used. The Combi Boiler, even at the lowest extraction rates used produced much more carbon monoxide. Again, a low height extract increased the quantity of carbon monoxide produced. The quantity produced by the Gas Fire was small during each test.

c) The temperature rise alone, compared to normal operation of the appliances, may warn an occupant of a developing toxic atmosphere.

d) Many of the conclusions from the previous work\(^1\) were found to be valid in this phase, even though the houses in which the tests were performed were quite different. The recommendations (on the next page) are based on both phases of work.
9 RECOMMENDATIONS

a) An additional 50cm$^2$ has been found to be inappropriate in many situations. Consequently, it is recommended that the guidance:

“50cm$^2$ additional ventilation will generally be sufficient”

should be removed from both BS5440-2$^4$ and the CORGI handbook$^5$, and replaced by the phrase:

“The additional ventilation required can be determined during a spillage test by partially opening a window and measuring the free area of the opening at a point when spillage is no longer evident during the test. The spillage test must be repeated with a cold appliance and flue when the additional permanent ventilation has been fitted.”

Similar wording should be added to BS5440-1$^6$

b) Increase public and gas installers awareness of the potential for cooker hoods, room extract fans, tumble driers and similar appliances with fans, to cause spillage. Electrical installers must be made aware of the potential problems. Instructions for such appliances must include a suitable warning.

c) The spillage test is currently the best method available to a service engineer for determining conflicts with air extraction equipment.
10 BIBLIOGRAPHY

2. BS5440-2: 2000 (Specification for the installation and maintenance of ventilation for gas appliances), Section 5.2.1
4. BS5440-2: 2000 (Specification for the installation and maintenance of ventilation for gas appliances), Section 6.1
6. BS5440-1: 2000 (Specification for the installation and maintenance of flues), Section 5.3.2.3
7. APPENDIX A  EXTRA FIGURES FOR TESTS 1 TO 10, WHERE # IS THE TEST NUMBER

Figure A#(a)
Test #, Concentration profiles in Bedroom 2

Figure A#(b)
Test #, Concentration in the extract system

Figure A#(c)
Test #, Concentration in the combustion air supply, and in the draught diverter

Figure A#(d)
Test #, Wind speed and direction
Figure A1(a)
Test 1, Concentration profiles in Bedroom 2
Figure A1(b)  
Test 1, Concentration in the extract system
Figure A1(c)

Test 1. Concentration in the combustion air supply, and in the draught diverter
Figure A1(d)

Test 1. Wind speed and direction
Figure A2(a)
Test 2, Concentration profiles in Bedroom 2

Figure A2(b)
Test 2, Concentration in the extract system

Figure A2(c)
Test 2, Concentration in the combustion air supply, and in the draught diverter

Figure A2(d)
Test 2, Wind speed and direction

Unable to reverse flue.

Figure A3(a)
Test 3, Concentration profiles in Bedroom 2

Figure A3(b)
Test 3, Concentration in the extract system

Figure A3(c)
Test 3, Concentration in the combustion air supply, and in the draught diverter

Figure A3(d)
Test 3, Wind speed and direction

Unable to reverse flue.
Figure A3a(a)
Test 3a, Concentration profiles in Bedroom 2

Figure A3a(b)
Test 3a, Concentration in the extract system

Figure A3a(c)
Test 3a, Concentration in the combustion air supply, and in the draught diverter

Figure A3a(d)
Test 3a, Wind speed and direction

Unable to reverse flue.
Figure A4(a)
Test 4. Concentration profiles in Bedroom 2
Figure A4(b)
Test 4, Concentration in the extract system
**Figure A4(c)**

Test 4, Concentration in the combustion air supply, and in the draught diverter
Figure A4(d)
Test 4, Wind speed and direction
Figure A5(a)
Test 5, Concentration profiles in Bedroom 2
Figure A5(b)
Test 5. Concentration in the extract system
Figure A5(c)
Test 5, Concentration in the combustion air supply, and in the draught diverter
Figure A5(d)
Test 5. Wind speed and direction
Figure A6(a)  
Test 6, Concentration profiles in Bedroom 2

Figure A6(b)  
Test 6, Concentration in the extract system

Figure A6(c)  
Test 6, Concentration in the combustion air supply, and in the draught diverter

Figure A6(d)  
Test 6, Wind speed and direction

Unable to reverse flue.

Figure A7(a)  
Test 7, Concentration profiles in Bedroom 2

Figure A7(b)  
Test 7, Concentration in the extract system

Figure A7(c)  
Test 7, Concentration in the combustion air supply, and in the draught diverter

Figure A7(d)  
Test 7, Wind speed and direction

Unable to reverse flue.
Figure A7a(a)
Test 7a, Concentration profiles in Bedroom 2

Figure A7a(b)
Test 7a, Concentration in the extract system

Figure A7a(c)
Test 7a, Concentration in the combustion air supply, and in the draught diverter

Figure A7a(d)
Test 7a, Wind speed and direction

Unable to reverse flue.
Figure A8(a)
Test 8, Concentration profiles in Bedroom 2
Figure A8(b)
Test 8. Concentration in the extract system
Test 8, Concentration in the combustion air supply, and in the draught diverter

Figure A8(c)
Figure A8(d)
Test 8, Wind speed and direction
Figure A9(a)
Test 9, Concentration profiles in Bedroom 2
Figure A9(b)
Test 9. Concentration in the extract system
Figure A9(c)

Test 9. Concentration in the combustion air supply, and in the draught diverter
Figure A9(d)
Test 9. Wind speed and direction
Figure A10(a)
Test 10, Concentration profiles in Bedroom 2
Test 10, Concentration in the extract system

Figure A10(b)
Figure A10(c)
Test 10, Concentration in the combustion air supply, and in the draught diverter
Figure A10(d)
Test 10. Wind speed and direction