Report

www.bsria.co.uk

Air Supply for Combustion Appliances

In Airtight Homes

Milestones 3 & 4 - Completion of laboratory testing and Final Technical Report

Report 53267/3

December 2009

Carried out for: Department of Communities & Local Government
Zone 2/G6
Eland House
Bressenden Place
London

Compiled by: Dr Arnold Teekaram

Total No. of pages: 44

Quality Approved: Mike Smith
Director of Engineering

BSRIA Limited
Old Bracknell Lane West, Bracknell, Berkshire RG12 7AH UK
T: +44 (0)1344 465600 **F:** +44 (0)1344 465626
E: bsria@bsria.co.uk **W:** www.bsria.co.uk

EXECUTIVE SUMMARY

The work reported here was conducted under BSRIA's contract with CLG- contract number CI/ 71/13/3 BD2799 "Air supply for combustion appliances in airtight homes". This work is in support of the impending revisions to Approved Document J of the Building Regulations, the purpose of which is to provide evidence to allow CLG and BRAC to determine whether the Approved Document J should be amended with regard to the requirement for provision of permanent ventilation for combustion of open flue appliances.

This project was therefore designed with the following objectives:

- To conduct a series of laboratory tests to determine the ventilation requirements for a small selection of gas and solid fuel open flue appliances producing secondary heating

- To conduct air permeability tests on a number of new dwellings to determine the level of adventitious ventilation available and to determine whether they would provide the minimum ventilation requirements for the appliances tested in the study. The study also aims to determine whether a dwelling with an air permeability as low as 5 $m^3/(h.m^2)$ would have adequate adventitious ventilation to enable the appliances to operate safety.

- To make recommendations in support of the impending revisions to Approved document J of the Building Regulations with regards to the ventilation requirements

The appliances tested in the study are given below.

Appliance no.	KW rating
1. ILFE (Inset living flame effect) fire –glass fronted	Input 5.5 kW (net)
2. ILFE (Inset living flame effect) fire –open fronted	Input 7.0 kW (net)
3. DFE (decorative fuel effect) fire in recess with throat	Input 7.6 kW (net)
4. DFE (decorative fuel effect) fire in recess with throat	Input 2.04 kW (net)
5. Wood burning stove	6.0 kW output
6. Wood Burning Stove	8.7 kW output

Thirty new dwellings were tested for air permeability using the ATTMA Standard TS1 "Measuring Air Permeability of Building Envelopes". Separate tests were conducted on the whole house and living room.

The main findings of the study are given below:

1. For a glass fronted inset living flame effect fire (Appliance 1) with a net input of 5.5 kW, the critical ventilation area (adventitious) required for this appliance to operate safely without spillage of the combustion products was determined to be 78.4 cm^2. The equivalent critical free area for a purpose provided vent in a room that is completely airtight was determined as 51.1 cm^2 based on a discharge coefficient of 0.89. It is not possible to make a direct comparison of the test results with the Part J requirement as the current ventilation requirement is only for appliances in excess of 7 kW input (net). There is no other published data to confirm what the adventitious ventilation is for an appliance below 7 kW input (net) to operate satisfactorily without spillage of the combustion products.

2. The critical adventitious ventilation required for an open fronted inset living flame effect fire (appliance 2) to operate without spillage of the combustion products was 167 cm^2. The appliance is rated at 7.0 kW net input. The equivalent critical free area for a purpose provided vent in a room that is completely airtight was determined as 115 cm^2 based on a discharge coefficient of 0.89. The current ventilation requirement in part J is only for appliances exceeding 7kW input (net).

3. Tests with a DFE fire with a rated input of 7.6 kW(net) showed that the critical adventitious ventilation required to operate safely without the spillage of combustion products was 132 cm^2. The equivalent critical free area for a purpose provided vent in a room that is completely airtight was determined as 90 cm^2 based on a discharge coefficient of 0.89. The current part J requirements for this particular appliance in a recess with throat is that the vent area for a purpose provided vent should be no lower than 100 cm^2. There is however no indication as to what adventitious ventilation this requirement is based upon.

4. Tests were also conducted at a lower input (net) of 2.04 kW for the DFE fire. The critical adventitious ventilation was determined as 130.0 cm^2 and 89.1 cm^2 for a purpose provided vent fitted to a room that is completely airtight.

5. No safety factor is included in the critical ventilation requirements determined in this study.

6. Tests conducted on a wood burning stove proved inconclusive. No spillage of the combustion products into the room was detected at the worst case condition that could be directly attributed to the reduced ventilation into the room. The average room pressure measured during the test was around – 11 Pa. At this pressure, it was clear that no spillage into the room was induced. The adventitious equivalent free area of the test room at this pressure was 40.6 cm^2. With an increased fuel loading, there was no evidence of spillage that could be attributed to the reduced ventilation rate into the room. Other important observations made of the appliance is that it is a "closed" appliance designed with access doors that are well sealed when closed and this would inevitably prevent the combustion gases from spilling easily into the test room.

7. The results of the air permeability tests conducted on 30 dwellings showed that all the dwellings complied with the Part L requirements of 10 $m^3/(h.m^2)$. Nine dwellings achieved an air permeability value below 5.0 $m^3/(h.m^2)$ with the remainder achieving an air permeability figure below 8.0 $m^3/(h.m^2)$

8. The air permeability tests which were conducted on the living room only showed that the adventitious ventilation available would be insufficient to meet the minimum requirements to allow the gas appliances tested in this study to operate safely in the majority of dwellings reported in this study. If however the adventitious ventilation of the whole dwelling is considered including the free area under the door to the living room, then it is more than adequate to allow all 4 gas appliances tested in this study to operate safely.

9. The results have also shown that there would be adequate adventitious ventilation in a dwelling which achieves an air permeability of 5.0 $m^3/(h.m^2)$ for all 4 types of gas appliances tested in this study. This conclusion is however based on the adventitious ventilation from the whole dwelling and not the living room. In some dwellings which achieved an air permeability of 5.0 $m^3/(h.m^2)$, the air permeability of the living room was observed to vary from dwelling to dwelling.

10. The equivalent adventitious ventilation (whole house) from a dwelling which achieved an air permeability of around 5.0 $m^3/(h.m^2)$ at 50 Pa was 902 cm^2 at a room pressure of 4.0 Pa.

The main recommendations arising from the study are given below:

1. The critical values of the ventilation rates determined during this study were conducted only on a small sample of selected gas appliances. Differences in design and the heat input rating may result in different values of the critical ventilation rate. Further tests should be conducted on more than one appliance of the same type to determine whether the ventilation requirements differ significantly before definitive recommendations can be made to Part J of the Building Regulations.

2. Tests performed on the solid fuel stove proved inconclusive. The results showed that the level of adventitious ventilation may have been adequate to prevent the spillage of the flue gases into the room. As it is not possible to reduce the adventitious ventilation of the test room, tests should be repeated on a similar appliance with a larger heat output. Tests should also be performed with the door of the appliance opened to determine if spillage of CO in particular would occur. This is particularly important in view of the high CO levels in the flue gases. Other types of solid fuel fires which may be tested could include a solid fuel open fire as this type of fire may be more prone to spillage of the flue gases. Because of the tight timescale, it was not possible to include these tests within the scope of the current project.

3. Tests should be conducted on other types of gas appliances not examined in this study to determine their ventilation requirements These include:

   - Radiant ceramic gas fires
   - Flueless gas fires
   - LPG appliances

CONTENTS

APPENDICES

TABLES

FIGURES

1 INTRODUCTION

The work reported here was conducted under BSRIA's contract with CLG- Contract number CI/ 71/13/3 BD2799 "Air supply for combustion appliances in airtight homes". This work is in support of the impending revisions to Approved Document J of the Building Regulations, the purpose of which is to provide evidence to allow CLG and BRAC to determine whether the Approved Document J should be amended with regard to the requirement for provision of permanent ventilation for combustion of open flue appliances.

This final technical report gives details of the main objectives of the study, the test programme, the test methodology and main findings.

1.1 BACKGROUND AND OBJECTIVES

All combustion appliances rely on adequate ventilation air for safe operation. Appliances that produce secondary heating such as open flue gas fires and solid fuel appliances rely mainly on the adventitious ventilation in a dwelling if the installed appliance is below a specified kW rating. Where the adventitious ventilation is not sufficient, purpose provided vents are installed to supplement the adventitious ventilation. Insufficient ventilation can lead to incomplete combustion and potentially spillage of the combustion products within the living room. In older dwellings, the adventitious ventilation available was sufficient to allow most appliances below a specified kW rating to operate satisfactorily. However, with the more stringent air permeability specification being imposed on new dwellings, the level of adventitious ventilation may not be sufficient to allow these appliances to operate safely. This project was therefore designed with the following objectives:

- To conduct a series of laboratory tests to determine the ventilation requirements for a small selection of gas and solid fuel open flue appliances producing secondary heating.

- To conduct air permeability tests on a number of new dwellings to determine the level of adventitious ventilation available and to determine whether they would provide the minimum ventilation requirements for the appliances tested in the study. The study also aims to determine whether a dwelling with an air permeability as low as 5 $m^3/(h.m^2)$ would have adequate adventitious ventilation to enable the appliances to operate safety.

- To make recommendations in support of the impending revisions to Approved Document J of the Building Regulations with regards to the ventilation requirements

A full detailed description of test programme is given in section 2. Current published ventilation requirements are given in section 3. The test methodology is described in section 4 and the test results are given in section 5. Application of the results to real buildings is given in section 6. The main findings of the study are given in section 7 and recommendations are given in Section 8.

1.2 CONSULTEES

As part of this research project the following manufacturers and organisations were consulted.

- HETAS- The Official Body of Solid Fuel Domestic Heating Appliances, Fuels and Services
- Fire and Fireplaces Ltd
- Dunbrik Flues Ltd- Domestic flues and chimneys systems
- Baxi Fires Division Ltd
- A J Wells and Sons Ltd- Solid fuel Appliance Manufacturer

2 TEST PROGRAMME

2.1 LABORATORY TESTS

The study tested a selection of appliances to determine their ventilation requirements and a description of these are given in Table 1.

Table 1 Test appliances

Appliance No.	Appliance Type.	KW rating	Notes
1	ILFE (Inset living flame effect) gas fire –glass or closed fronted	Input 5.5 kW (net)	Manufacturers nominal input
2	ILFE (Inset living flame effect) gas fire –open fronted	Input 7.0 kW (net)	Manufacturers nominal input
3	DFE (decorative fuel effect) gas fire in recess with throat	Input 7.6 kW (net)	Manufacturers nominal input
4	DFE (decorative fuel effect) gas fire in recess with throat	Input 2.04 kW (net)	The appliance was set to operate at low fire setting
5	Wood burning stove	6.0 kW output	Manufactures nominal output
6	Wood Burning Stove	8.7 kW output	The appliance heat output was increased by increasing the fuel loading

The main differences between the closed and open fronted ILFE appliances is that the flue flow characteristics differ greatly. Spillage of the combustion products is also likely to occur more readily with an open fronted appliance. DTI report GAC3407 10 November 2005 "Assessment of the size and composition of the UK gas appliance population" shows that the installation of ILFE fires remains dominant and popular over other types of fires because of their higher efficiency levels (around 60% gross) whilst the installation of open DFE fires are low in comparison, due to their poor efficiency (20% gross).

The choice of a solid fuel wood burning stove was based on the fact that due to the restrictive nature of ADL and SAP, vey few open solid fuel fires are being installed in new dwellings. HETAS returns show that the majority of installations are now for closed room –heater/stove type appliances.

2.2 DOMESTIC AIR PERMEABILITY TESTS

Thirty new dwellings were tested for air permeability using the ATTMA Standard TS1 "Measuring Air Permeability of Building Envelopes". Separate tests were conducted on the whole house and living room. A full description of the test methodology is given in Section 4.4

3 CURRENT PUBLISHED VENTILATION REQUIREMENTS

3.1 PART J SPECIFICATIONS

For most types of open flue appliances with an input less that 7 kW (net), the regulations do not require purpose provided ventilation. The table below gives the ventilation requirements for appliances with a heat input exceeding 7 kW (net)

Table 2 Part J Specification

Fire type	Part J specifications
Radiant convector	5 cm^2 per kW input (net) in excess of 7 kW (net)
DFE	For DFE fires in a recess with throat, the free vent area should be no lower than 100 cm^2 For DFE fires in fireplace with no throat, the vent area should be at least 50% of the flue cross sectional area For DFE fires with rated input up to 7 kW (net) with flue clearance rate up to 70 m^3/hr no vent is required
ILFE	5 cm^2 per kW input (net) in excess of 7 kW (net)
DFE and ILFE using LPG	As above
Flueless gas fire in a room	At least 100 cm^2 plus 55 cm^2 per kW input (net) in excess of 2.7 kW (net). Maximum appliance rated input = 0.045 kW (net) per m^3 volume of room
Multi-fuel burning stoves	For appliances rated up to 50 kW output permanent ventilation is required as below: For a stove with a flue draught stabiliser, vent area must be 3 cm^2 per kW output for the first 5 kW and 8.5 cm^2 per kW output above 5 kW. For a stove without a flue draught stabiliser, total vent area must be at least 5.5 cm^2 per kW of appliance rated output above 5 kW. Below 5 kW there is no need to provide purpose provided ventilation.
Solid fuel open fires	Permanent ventilation is required as below: For no throat, vent area must be at least 50% flue cross sectional area For throat, vent area must be at least 50% throat opening area

DFE: Decorative fuel effect
ILFE: Inset living flame effect
LPG: Liquid petroleum gas

3.2 ADVENTITIOUS VENTILATION

Research has found that the adventitious ventilation in older dwellings i.e. air entering the building through cracks around doors, windows and suspended floors and even through the fabric of the building is unlikely to be no less than an air vent having a free area of 35 cm^2 even after improvements have been made such as the introduction of double glazing and weather stripping.

For the majority of open flue gas fired appliances, the adventitious ventilation in older dwellings is adequate for appliances with a net input rating not exceeding 7.0 kW and which generates a clearance flue flow not greater than 70m^3/h under specified conditions (BS5871-2:2005). For some types of solid fuel appliances, e.g. stoves without flue draught stabiliser, (See Table 2) below 5 kW output the adventitious ventilation is also adequate. However, it is not clear whether these assumptions are based on an adventitious ventilation of 35 cm^2.

4 LABORATORY TESTS

In setting up the laboratory tests, a number of important considerations were reviewed. These are described below:

4.1 DESIGN OF FIRE PLACE AND FLUE ARRANGEMENT

In the design of the fireplace and flue arrangement for the test, the following was considered:

1. The flue should be representative of actual installations and designed to provide the correct flue draught for the appliances that are installed.
2. Consideration should be given to the correct fireplace builders recess, required chimney height and correct throat dimensions (for appliances that require a fire back).
3. Simulation of external wind conditions: The wind at the top of the chimney may have a positive or negative influence on the induced draught, depending on the wind velocity, the surroundings and the position of the chimney top in relation to the roof. The higher the wind speed, the higher the negative pressure at the flue top and the greater the additional draught in the flue. The position of the chimney top in relation to the roof could either produce excessive updraughts or downdraughts that will affect the performance of the appliance. The external wind conditions and wind directions may also have an influence on the airflow entering the air vent depending whether the vent is fitted on the side of the house which faces the prevailing wind or the leeward side in which case air could be sucked out instead of being drawn in by the appliance when its working. These effects were not simulated in this study as the flue terminated within the laboratory. In the absence of the external wind effects, it then relatively simple to quantify the effect of reducing the ventilation free area on the combustion performance of the appliance and the spillage into the room.
4. Internal/external temperature differences: A higher internal/external temperature difference and hence density difference means a higher buoyancy in the flue, resulting in increased flue draught. As the flue arrangement in this study terminated inside the laboratory, the internal/external temperature differences were not typical of those in winter conditions, where outside ambient temperatures will be below 10°C. The ambient laboratory temperature during the test period in October -November was in the region of region of 15°C. As the temperature of the flue gases at the exit of a typical DFE fire is likely to be in excess of 150°C, the temperature differences between autumn and winter conditions relative to the flue gas temperature may not be significant enough to cause marked variations between the flue draught at the two conditions

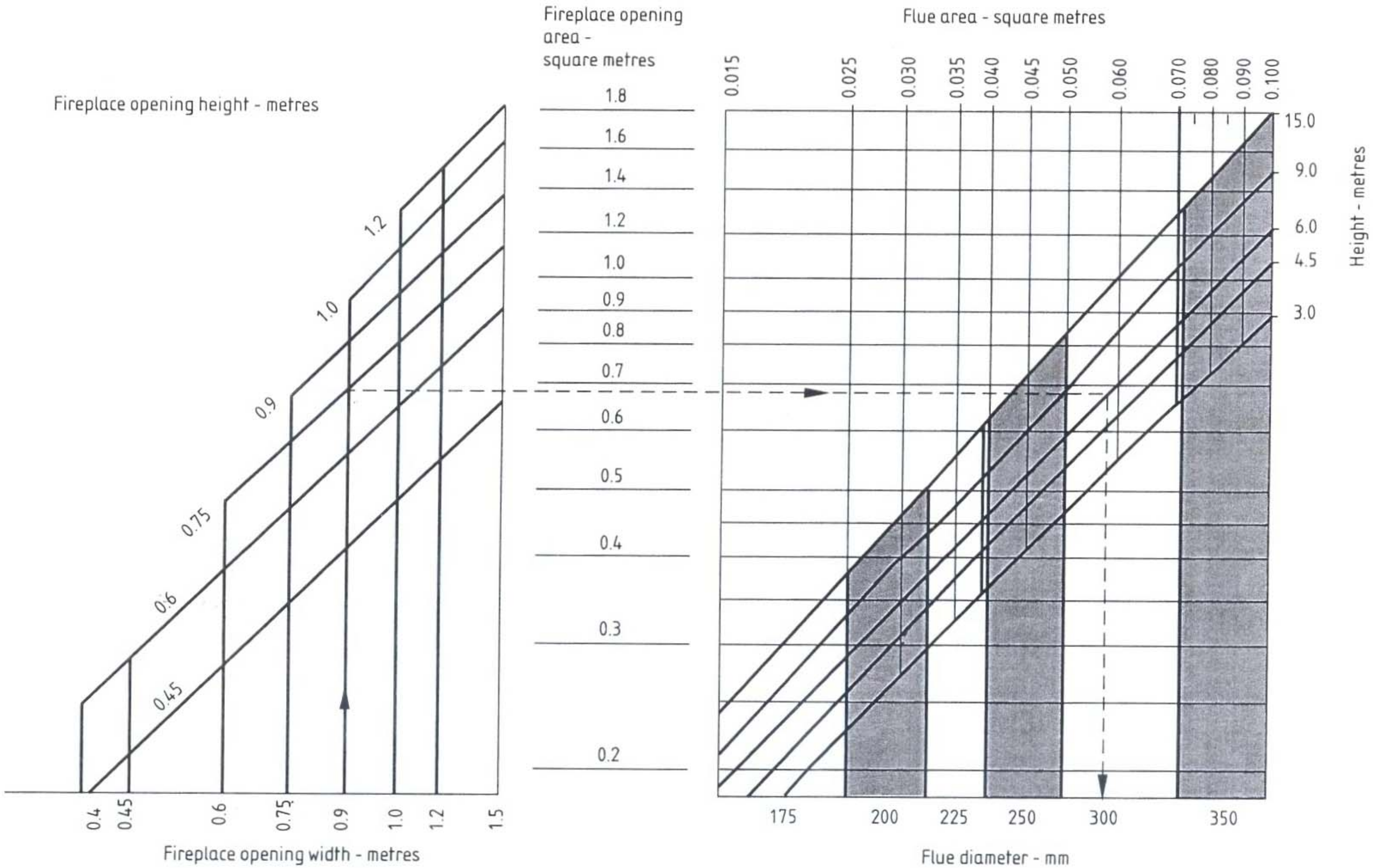
Flue Type

The general arrangement of the test facility is shown in Appendix A. A masonry flue using Dunbrik Class A1 concrete flue liners encased in LBC facing bricks was constructed for this work. The internal diameter of the flue lining was 200 mm (minimum requirement in ADJ) and will accommodate the vast majority of solid fuel burning appliances (whether or not a fireback is installed) and both Decorative and Inset Living Flame Effect gas fires as well as most domestic stoves. This flue design is used widely in new build properties and is suitable for all domestic fuels including coal and properly seasoned wood. The flue liners comply with the requirements within ADJ, BSEN 1857 for appliances using solid and gaseous fuels.

Construction of fireplace and installation of appliances

To ensure that there was no spillage from the appliance at the condition where there is adequate ventilation, the fireplace opening was sized in relation to the flue height and the flue internal diameter. See Figure 1. The fireplace was constructed with a builders maximum recess opening of 610 (H) by 600 mm (W) and reduced for individual appliances in accordance with the manufacturer’s specification. The fireplace was constructed initially without a fireback to facilitate the testing of the ILFE fire. The fireback was later installed for the DFE fire in accordance with the manufacturers instructions. In the case of the solid fuel stove, the appliance was sited outside the builders recess and connected to the flue as indicated in Figure 2.

Figure 1 Flue/fireplace sizing chart BS5871-3

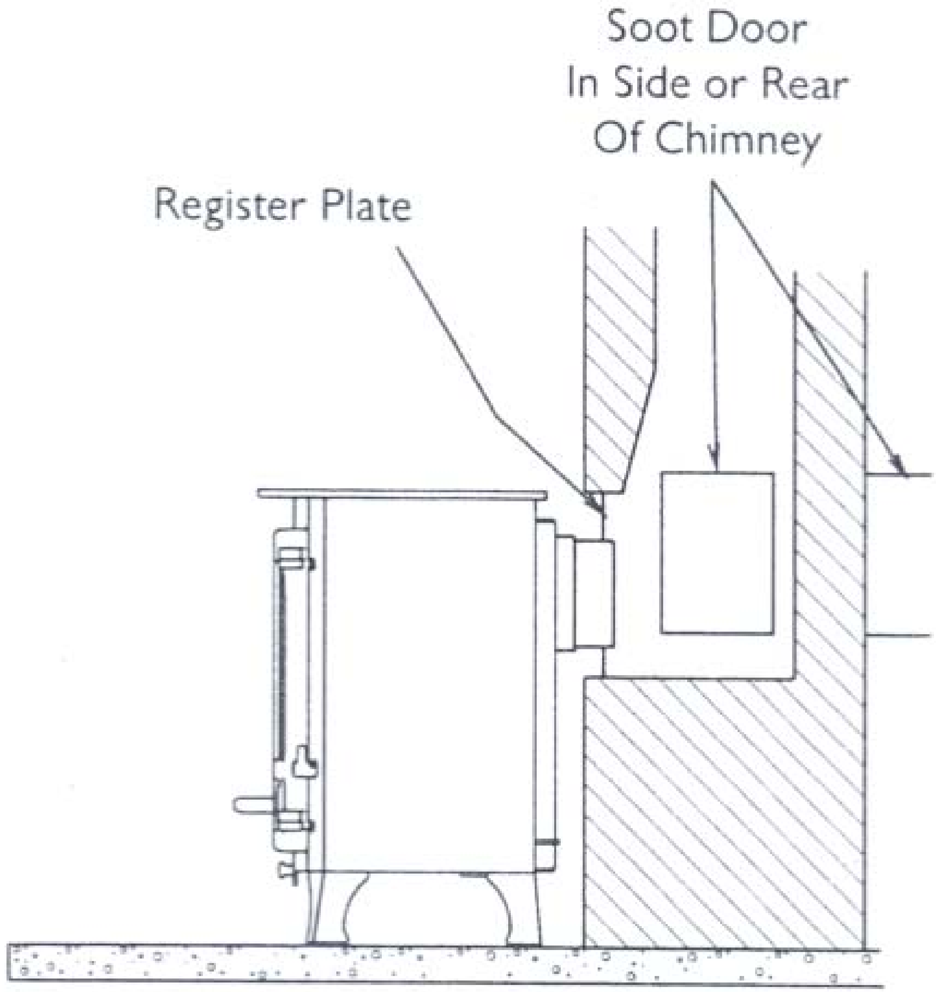


EXAMPLE Fireplace opening is 0.9 m wide × 0.75 m high = 0.68 m²
Then for flue height 6.0 m, use a 300 mm diameter flue.

NOTE 1 Where choice is possible, the smallest diameter flue should be used. Large diameter flues, particularly of short length, will be conducive to downdraught and therefore spillage.

NOTE 2 In the case of fireplace openings served by the above chart, a fireplace opening of greater width (*W*) than height (*H*) will be less likely to spill than one of width (*H*) and height (*W*), despite their having the same fireplace opening areas (*W H*).

Figure 2 **Installation of solid fuel stove**



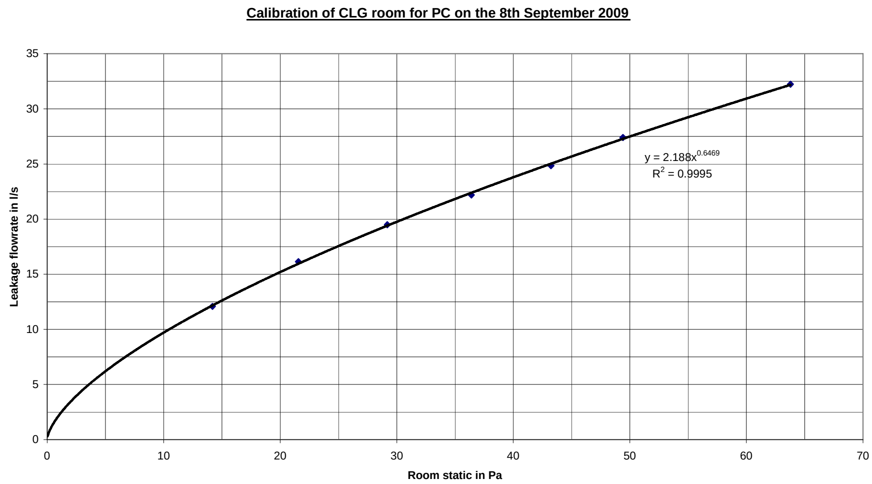
Flue height

The flue height was constructed to 4.5 m. This is the minimum requirement in Approved document J. See Appendix A. The static pressure in the flue was measured for each appliance installed to ensure that the correct flue draught was achieved at the commencement of the test.

4.2 AIR LEAKAGE OF THE TEST ROOM

Tests were carried out to establish the air leakage rate of the test chamber with the flue sealed in order to establish the adventitious ventilation, which remained uncontrolled during the appliance testing. The target air permeability figure aimed for was $1m^3/(h.m^2)$ at 50 Pa as this is representative of most cold rooms. This equates to a target leakage rate of 24.82 litres/sec at 50 Pa based on an envelope area of 89.36 m^2 which also includes the concrete floor. The actual air leakage rate achieved during the test was 27.84 litres /sec @ 50 Pa (equivalent to 1.12 $m^3/(h.m^2)$). See Figure 3. This is approximately 10 times better than the air permeability requirement of 10 $m^3/(h.m^2)$ at 50 Pa for new dwellings. For comparison, the results of the air permeability test of two dwellings, for the living room with the vents and fireplace sealed were 1.54 $m^3/(h.m^2)$ and 2.07 $m^3/(h.m^2)$ respectively.

Figure 3 Room calibration curve



The air permeability test results of the test room were obtained by pressuring the room to over 60 Pa. The air permeability test was also repeated by depressurising the room to –50 Pa. There was no significant discrepancy between the two curves.

The adventitious ventilation of the test room in terms of the equivalent free area as a function of the room static pressure relative to outside the room is shown in Figure 4. The effective adventitious free area is obtained from the relation

$$Q = A\, C_d\, (2\Delta P/\rho)^{0.5}$$

Where

- C_d = Discharge coefficient
- A = Effective free area
- ΔP = Pressure differential between inside and outside of the test room
- ρ = density of air

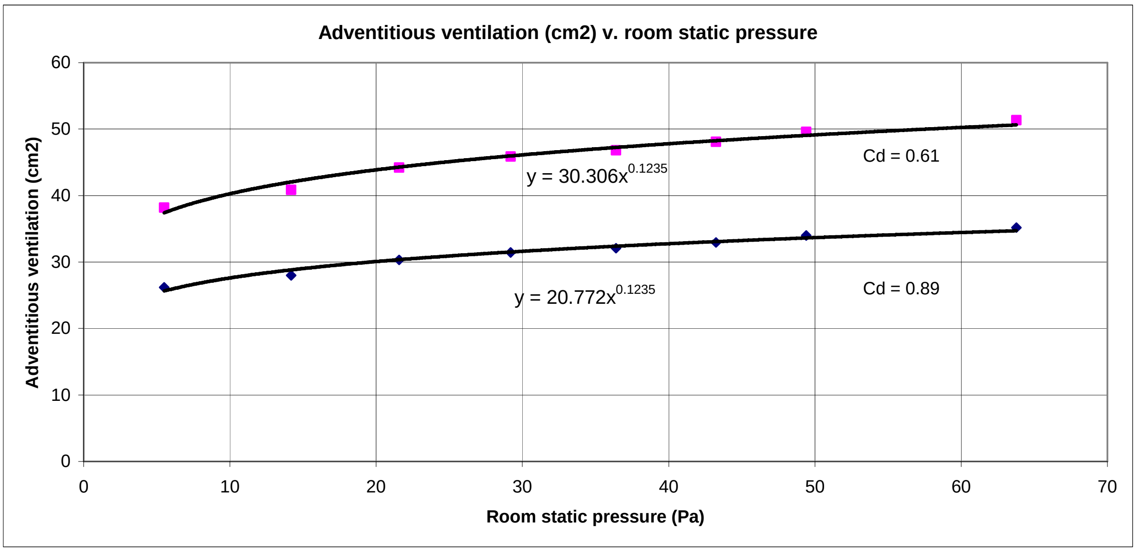
Two values of the discharge coefficient are used to illustrate the effect on the adventitious free vent area.

For the purposes of this study a discharge coefficient of 0.61 will be used to determine the adventitious free area of the test room and dwellings that were tested for air permeability as part of this study.

The value of 0.61 is that used in the ATTMA standard TS1 "Measuring Air Permeability of Building Envelopes".

The results show that the adventitious ventilation free area is markedly dependant on the value of the discharge coefficient used. See Figure 4.

Figure 4 Adventitious ventilation versus Room static pressure



The test results described in this report were obtained by supplying the ventilation air by means of a fan connected to an air distribution system (50 mm diameter sparge pipe) located within the perforated ceiling in the test room. This method was chosen as the preferred methodology as the tests were conducted in a more controlled manner compared to allowing the appliance to operate under induced draught conditions only. These are described below.

4.3 TEST METHODOLOGY

The method adopted to determine the ventilation requirements employed the use of a blower fan and laminar flow element to introduce a known volume of air into the room through a 50 mm diameter sparge pipe located in the perforated ceiling. The tests commenced with a high flow rate and reducing it gradually until spillage occurred. At each ventilation rate which comprised of the mechanical ventilation and adventitious ventilation, the concentration of CO_2 spilled from the fire was measured at the sampling sparge bar placed against the fire front. See Figure 5

Figure 5 ILFE Fire showing position of sampling sparge bar

The background CO_2 concentration in the room was also measured. The test room was purged between each ventilation rate when necessary to avoid the build up of CO_2 from the previous tests. Readings were recorded over a period of 10 minutes for each ventilation rate and the time-averaged values computed.

In the tests only the CO_2 was used to determine the onset of spillage as this was easily detected. Though concentrations of NOx and CO were also measured, these gases were not detectable over the test period.

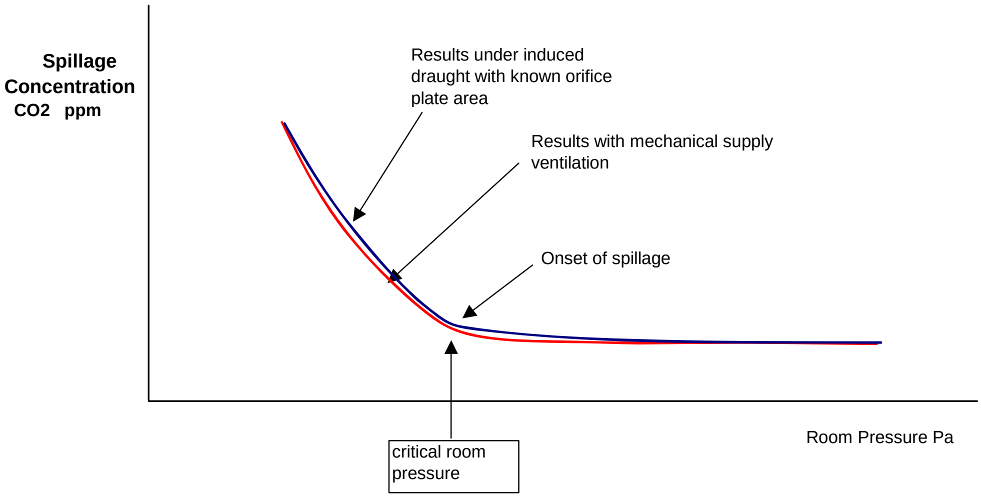
The tests were conducted after the chimney was allowed to warm up from a cold start. The pre-test heating up period was approximately 2 hours. During this time, the door to the test room was opened to allow sufficient ventilation to prevent any spillage occurring. The background CO_2 levels in the room was constantly monitored and compared with that outside the room.

The differential room pressure ΔP between the inside and outside of the room was measured for given ventilation rates.

Figure 6 shows an illustration of the methodology. As the ventilation to the room is reduced, a value of the critical pressure ($P_{Critical}$) and ventilation rate ($Q_{critical}$) within the room will be reached at which spillage of CO_2 will begin to occur.

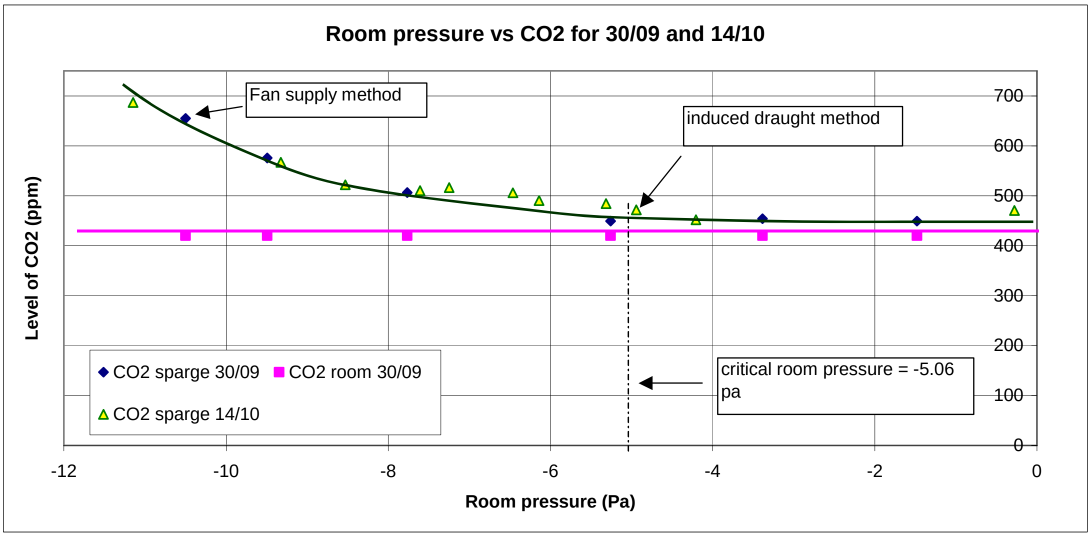
From the relation $Q_{critical} = C_d A_{Critical} \sqrt{(2 \Delta P_{Critical} / \rho)}$, the critical ventilation free area $A_{Critical}$ corresponding to the critical flow rate and critical pressure can be determined. To determine the adventitious critical free vent area, a discharge coefficient of 0.61 is used in the calculation. To determine the free ventilation open area for a purpose provided vent, a discharge coefficient of 0.89 is used.

Figure 6 Illustration of methodology



To determine the validity of the above method, a second test was conducted, this time by allowing the appliance to operate under induced draught conditions only. The ventilation rate to the room was reduced by using a series of purpose made vents (hole in a plate). The differential room pressure between the inside and outside of the room and CO_2 spilled from the fire was monitored as in the previous test. Repeatability of the two sets of results would only be possible if the fluid dynamics of the air flow in the room is similar in the two experiments. See Figure 6. Figure 7 does demonstrate that this is the case and shows actual experimental data using both methods to establish the critical room pressure at which spillage occurs. In general, the critical room pressure is around -5.0 Pa using both methods. It was decided to use the fan supply method to determine the ventilation air requirements for appliances as the tests are performed in a more controlled manner.

Figure 7 Comparison of the results using fan supply and induced draught methods



In analysing the test results, the following calculations were carried out.

Calculation of the mechanical ventilation rate

The mechanical ventilation rate into the room provided by the fan was calculated from the calibration of the laminar flow element:

$Q = (\Delta P / 70.39) * 2000$ L/m

Where ΔP is the pressure drop across the laminar flow element

Calculation of the adventitious ventilation rate

The adventitious ventilation rate at various room pressures obtained during the test was determined from test room air permeability curve.

Calculation of the total ventilation rate

When the room is under negative pressure:

The total ventilation rate = mechanical ventilation rate + adventitious ventilation rate
See Figure 8.

When the room is under positive pressure:

The total ventilation rate = mechanical ventilation rate - adventitious ventilation rate
See Figure 9.

Figure 8 Room under negative pressure

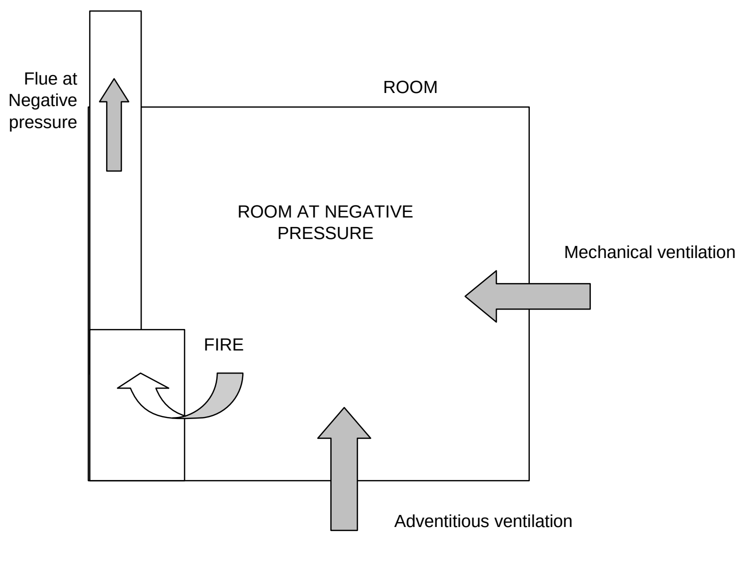
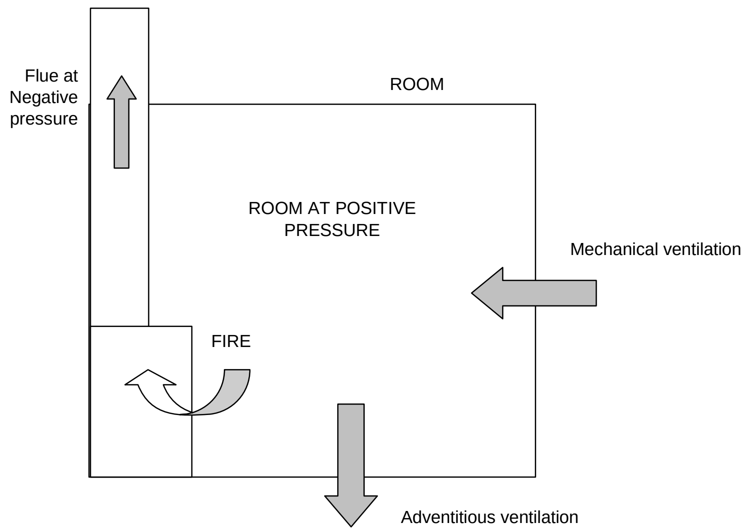


Figure 9 Room under positive pressure



4.4 BUILDING AIR PERMEABILITY TESTS

The methodology used to establish the air leakage tests is described below.

Whole dwelling air leakage tests

The dwellings were tested in the normal way in accordance with the ATTMA Technical Standard 1, Issue 2 compliant. This required all open flued heating appliances to be switched off, the flue sealed and the associated make-up air vent sealed.

Living room air leakage test

To determine the air leakage rate in the room where an appliance was installed, the following methodology was employed.

1. With the appliance switched off, flue sealed and associated make-up vent sealed, the air permeability test was performed at the same test condition as for the whole dwelling. All doors to the room were closed but not sealed.
2. The above test was repeated with the associated make-up air vent unsealed
3. The room size was determined from actual measurements or from drawings.
4. With the blower door removed, the undercut of the door(s) was measured with a BSRIA calibrated door wedge. Measurements were also taken of the width of the door between jambs and a note made as to whether the final finished floor covering has been laid. The commissioning of dwellings for Part F of the proposed new 2010 Building Regulations requires the undercut of all internal doors to be a minimum of 10 mm, if the final flooring has been laid or a minimum of 20 mm, if the final finish flooring has not been laid.

From the selection of dwellings tested, the majority had no fireplace. For these dwellings, the air permeability test was conducted on the living room in order to establish the air leakage rate. It is not expected that there would be significant differences in the air leakage rate between a living room with and without a fire as the adventitious ventilation would be primarily from windows, external doors and cracks in the building fabric.
Figures 10 and 11 shows an example of the air permeability data and test results at 50 Pa for the whole house and living room. In order to compare the critical free adventitious ventilation area from the laboratory results with that adventitious ventilation available from the dwellings tested, it is necessary to recalculate the TSI leakage area at the critical pressures

measured during the laboratory test. The TSI leakage area for the example shown for the whole house is 1090 cm^2 at 50 Pa. At 7 Pa, the effective leakage area is 888 cm^2 using the same value of the discharge coefficient of 0.61. The variation is therefore approximately 18% for the example shown.

Note: Even though the air permeability data of the dwelling shown was produced within the pressure range 25-70 Pa, the correlation coefficient is quite good and in most cases around 0.9996. It would therefore be a reasonable approximation to use the extrapolated values of the building leakage rate at the lower pressures achieved during the test to re-calculate the effective hole area. The advantage of this is that in practice, the effective free whole area calculated is more representative of that in a real building at the lower room pressures created by the fire rather than at 50 Pa, which would never occur.

Figure 10 Building air permeability test for dwelling no. 25- Whole House

Test Results at 50 Pascals

Measured Air Permeability ($m^3/(h.m^2)$):	7.87	Q_{50}: Airflow (m^3/h):	2186
		Design Air Permeability ($m^3/(h.m^2)$):	8.00
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	YES		

Building Leakage Curve

Air Flow Coefficient (C_{env}):	293.9	Air Leakage Coefficient (C_L):	300.1
Exponent (n):	0.51	Correlation Coefficient (r^2):	0.9996

Test Information

		TS1 Leakage Area (m^2):	0.109
Type of Test:	Depressurisation	Test Method:	B
Test Standard:	TS1	Regulation Complied With:	ADL1A

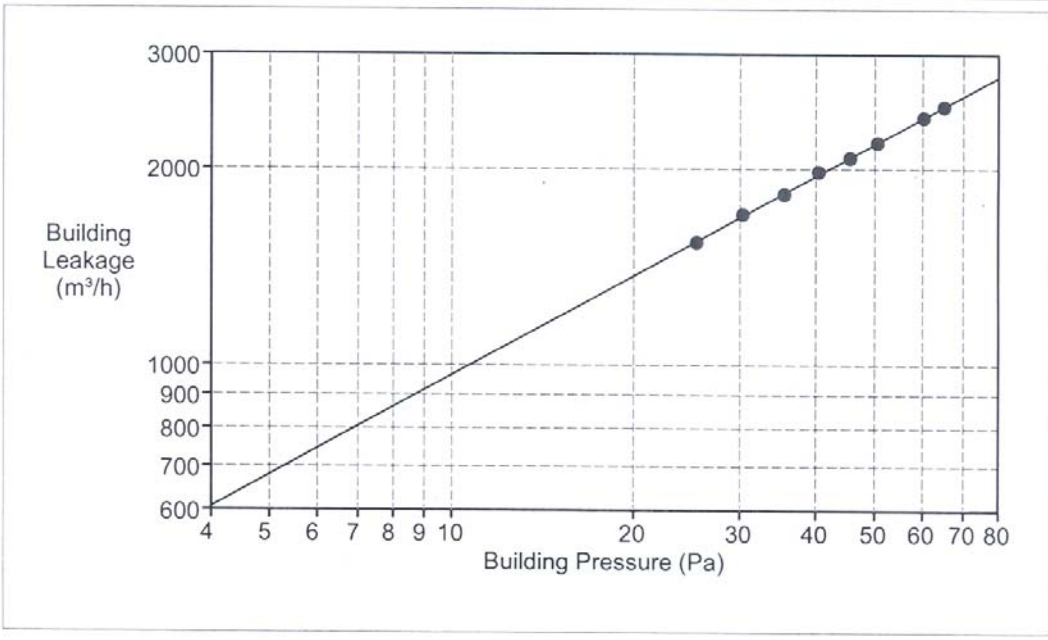


Figure 11 Building air permeability test for dwelling no. 25- Living Room

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	312
Measured Air Permeability (m³/(h.m²)):	3.16	Design Air Permeability (m³/(h.m²)):	8.00

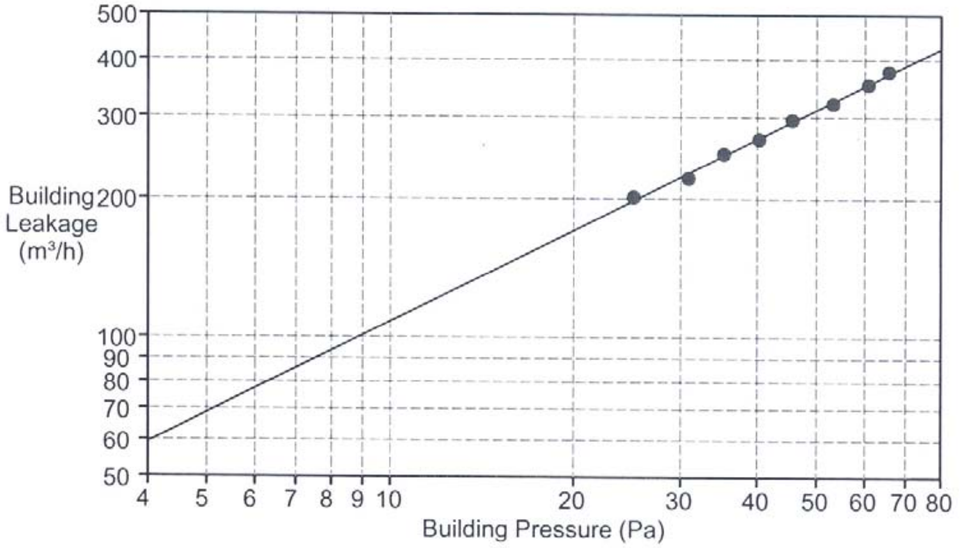
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	YES

Building Leakage Curve

Air Flow Coefficient (C_{env}):	23.7	Air Leakage Coefficient (C_L):	23.8
Exponent (n):	0.66	Correlation Coefficient (r²):	0.9980

Test Information

		TS1 Leakage Area (m²):	0.016
Type of Test:	Depressurisation	Test Method:	B
Test Standard:	TS1	Regulation Complied With:	ADL1A



5 TEST RESULTS

5.1 GAS FIRES

A summary of the laboratory results is given in table 3 and these are graphically illustrated in figures 12 to 23. For each appliance, the critical pressure and flow rate at which spillage occurs are given. The corresponding values of the critical ventilation area based on the adventitious ventilation and for a purpose provided vent are also shown.

Table 3 Summary of critical ventilation requirements

Appliance No	Critical Pressure (Pa)	Critical Flow Rate m^3/h	Critical Vent area cm^2 (adventitious C_d= 0.61)	Critical Vent area cm^2 (purpose provided vent Cd =0.89)
1	-5.06	50.0	78.4	51.1
2	+4.0	94.93	167.4	114.7
3	-13.31	136.0	131.7	90.3
4	-6.55	94.36	130.0	89.1

Notes :

1. The critical pressure and corresponding flow rate are the particular values at which the onset on spillage occurs.

2. The critical free vent area (adventitious) is calculated based on a discharge coefficient of 0.61 and presents the minimum adventitious ventilation required for that particular appliance for a dwelling that is completely airtight.

3. The critical free vent area for purpose provided vent is shown for comparison and is calculated based on a discharge coefficient of 0.89 and represents the minimum ventilation area required for that particular appliance for a building that is completely airtight.

ILFE Results (Inset living flame effect) fire –glass fronted- Input 5.5 kW net

Figure 12 Room pressure vs CO_2

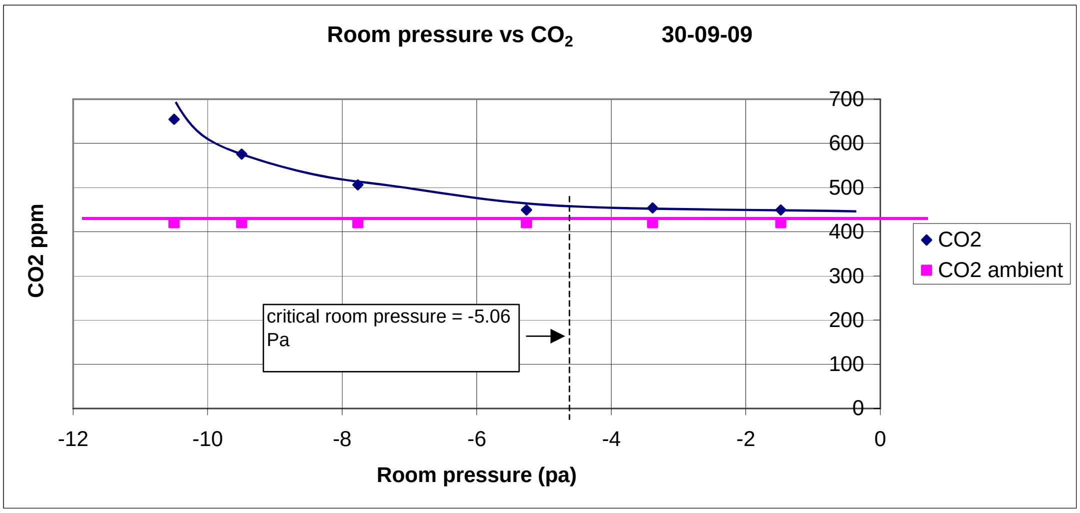


Figure 13 Room Ventilation vs room pressure

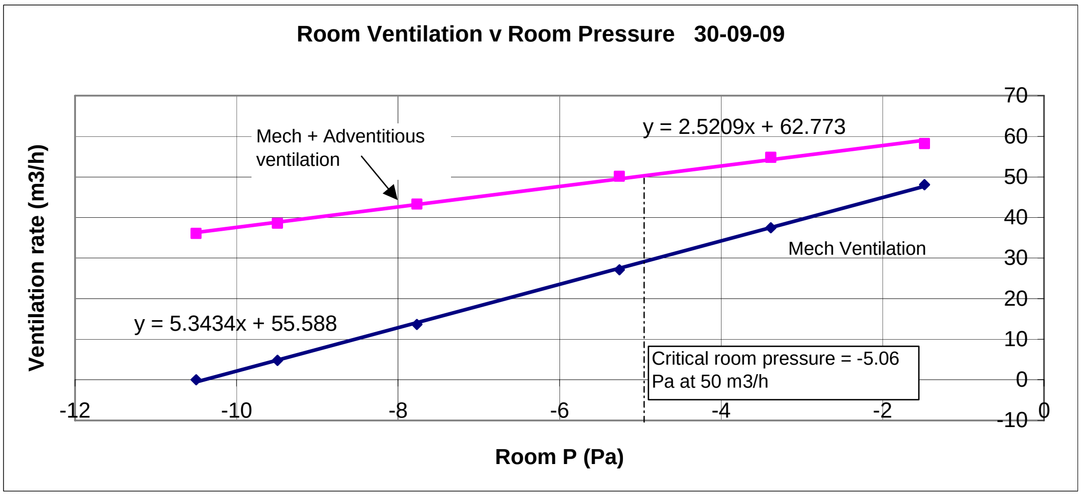
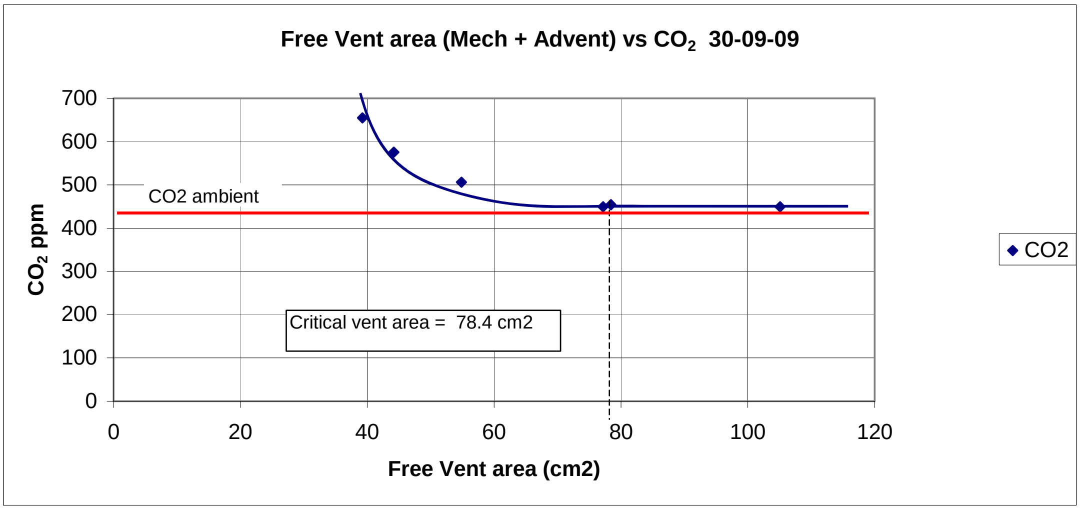


Figure 14 CO_2 vs free vent area



ILFE Results (Inset living flame effect) fire –open fronted Input 7.0 kW (net)

Figure 15 CO_2 vs room pressure

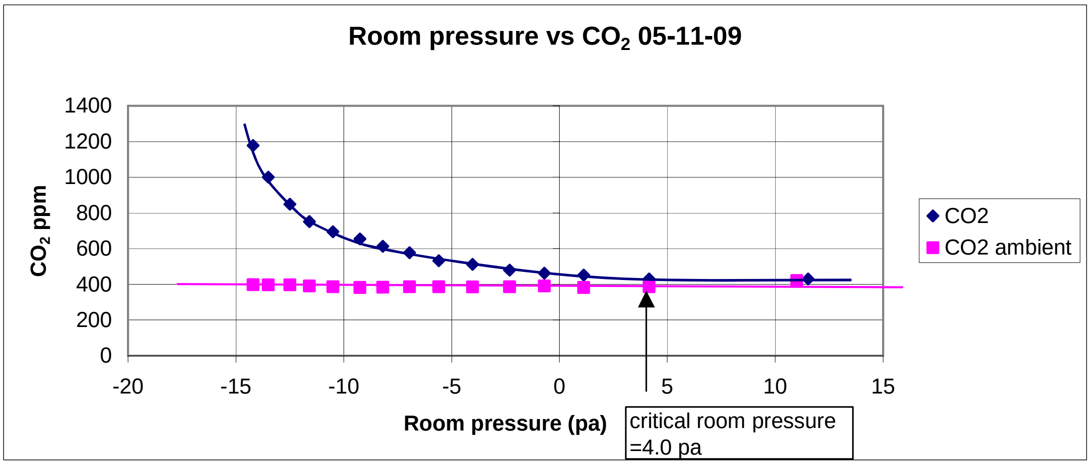


Figure 16 Room ventilation vs room pressure

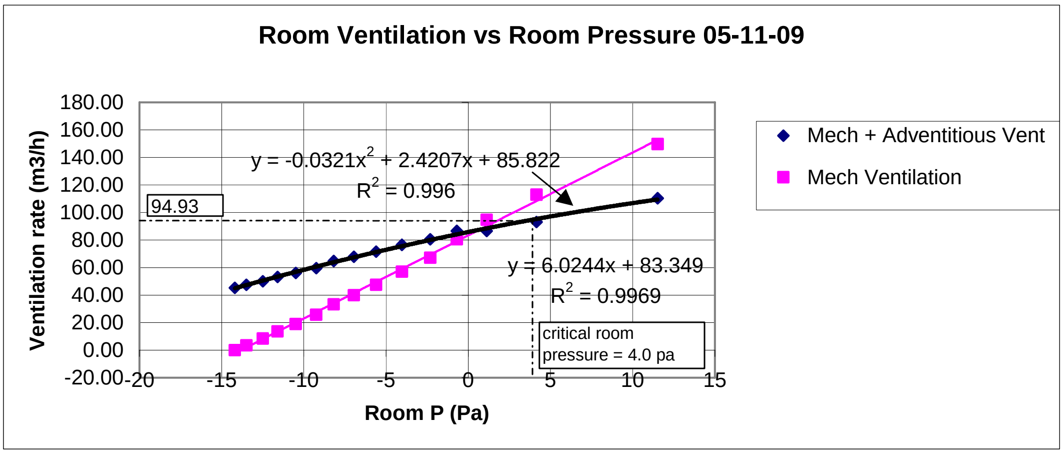
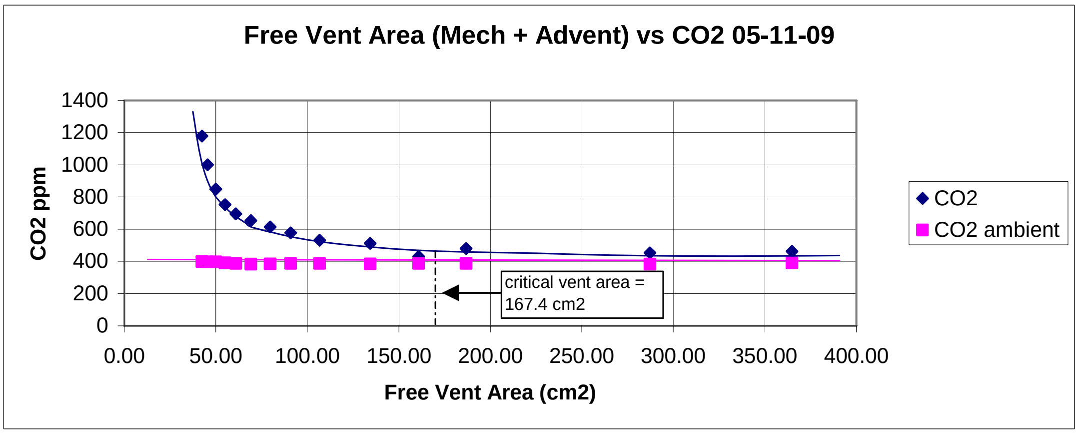


Figure 17 CO_2 vs free vent area



DFE Results (decorative fuel effect) fire in recess with throat - Input 7.6 kW (net)

Figure 18 CO_2 vs room pressure

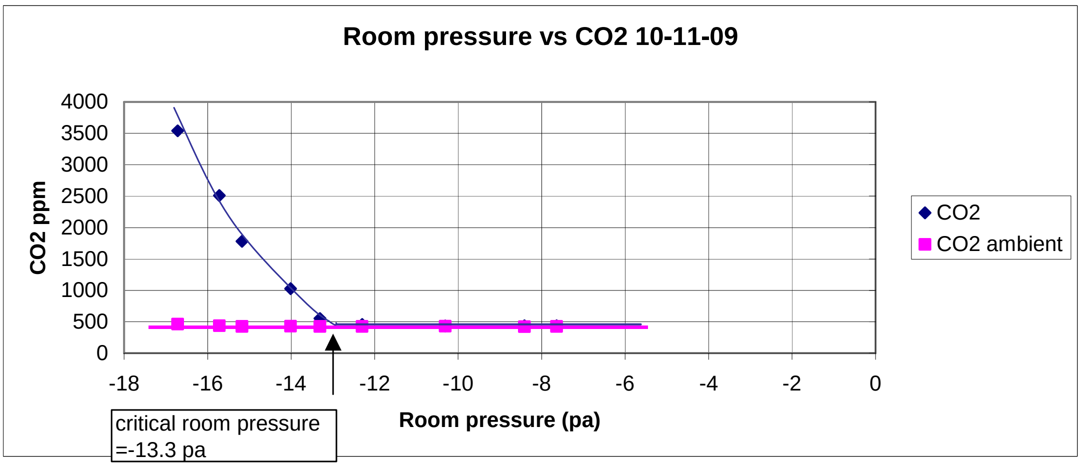


Figure 19 Room ventilation vs room pressure

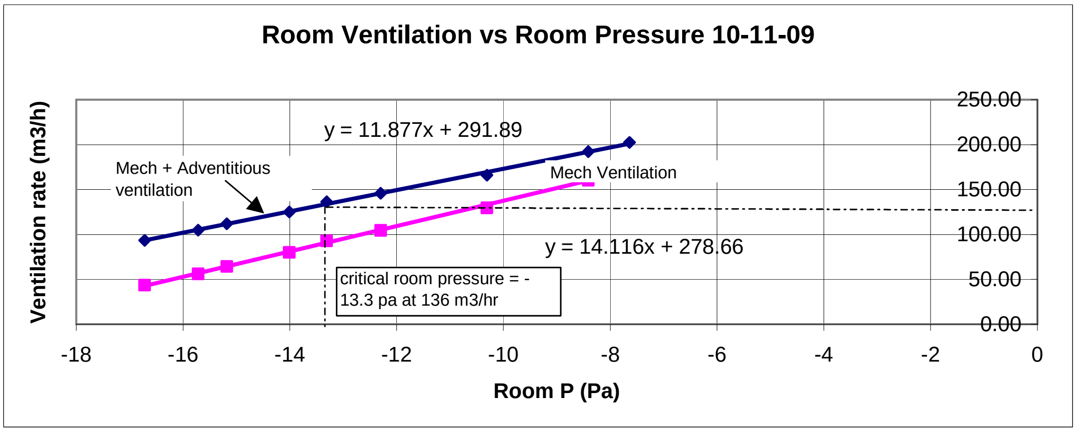
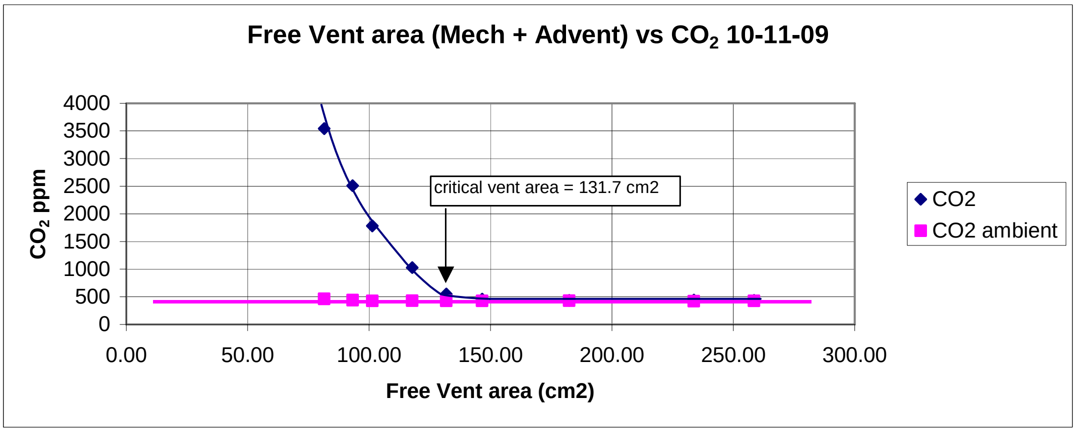


Figure 20 CO_2 vs free vent area



DFE Results (decorative fuel effect) fire in recess with throat - Input 2.04 kW (net)

Figure 21 Room Pressure vs CO_2

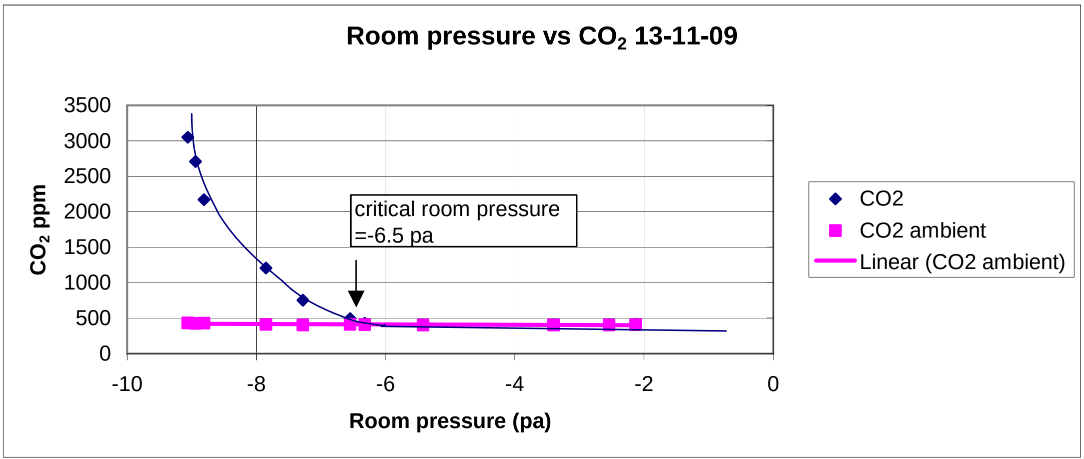


Figure 22 Room ventilation vs room pressure

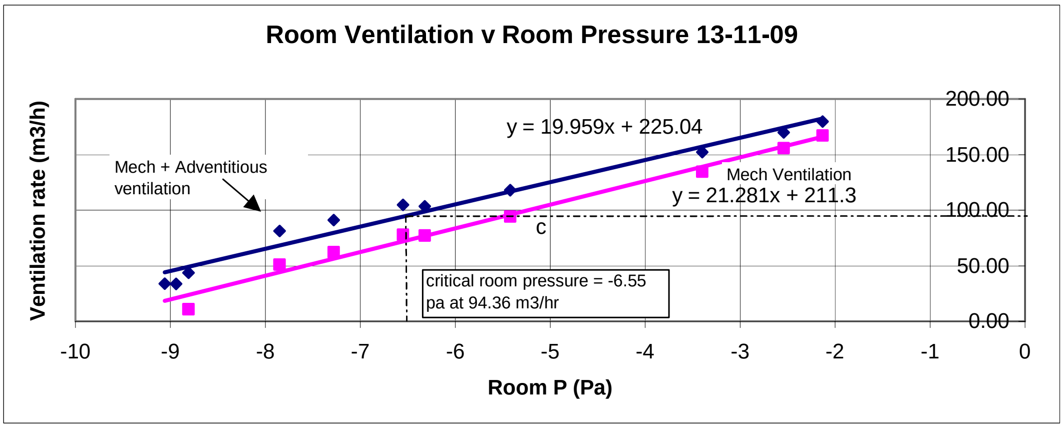
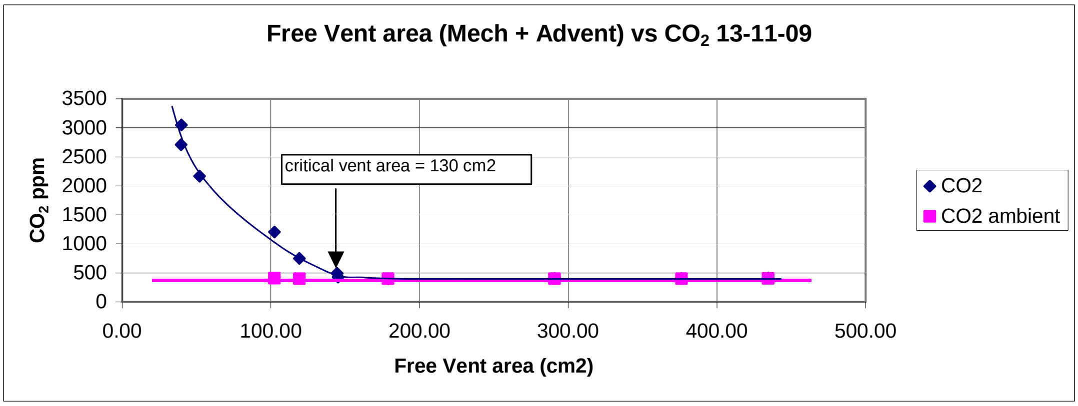


Figure 23 CO_2 vs free vent area



5.2 WOOD BURNING STOVE

Tests were also conducted to determine the ventilation requirements for a wood burning stove using beech as the solid fuel at two test conditions.

1. With adequate ventilation, i.e. above the minimum ventilation requirement of 5.5 cm^2 per kW of appliance rated output above 5 kW (Part J requirement). The purpose of this test was to establish a base line for comparing the spillage into the room when the ventilation rate was reduced.

2. With reduced ventilation. This test was conducted at the worst-case condition with the test room door closed such that the only ventilation to the appliance was the adventitious ventilation through the room. The purpose of this test was to determine whether any spillage into the test room would occur.

The appliance is rated at 6.0 kW nominal output. The fuel load to achieve this output was calculated in accordance with BSEN 13240:2001.

The variation of CO_2 emitted into the room measured at the sparge bar is shown Figure 24. The test was conducted with the door to the test room fully opened. This test represents the appliance operating under normal conditions with adequate ventilation. The average ambient room CO_2 level was approximately 405 ppm before the fire bed was lit after which the CO_2 increased to around 430 ppm. The maximum CO_2 spilled into the room during the test was recorded around 440 ppm after the fuel was loaded on to the fire. The increase in CO_2 within the room is attributed to the fact that the doors to the appliance were opened when the fire bed was lit and when the fuel was loaded allowing flue gases to spill into the room. Over the remainder of the test period, the CO_2 decayed to a constant value around 390 ppm

The variation of CO_2 spilled into the room over the test period with the appliance operating with adventitious ventilation only is shown in figure 25. The average CO_2 within the room prior to lighting the firebed was around 410 ppm. With the fuel loaded, the maximum CO_2 recorded was in the region of 430 ppm. Over the remainder of the test, there is no evidence of spillage that can be attributed to the reduced ventilation, as the CO_2 levels were similar to the base line test. The room pressure measured during the test was around – 11 Pa (see Figure 26). At this pressure, it is clear that no spillage into the room was induced. The adventitious equivalent free area of the test room at this pressure was 40.6 cm^2. Other important observations made of the appliance is that it is a "closed" appliance designed with access doors that are well sealed when closed and this would inevitably prevent the combustion gases from spilling easily into the test room.

The variation of the CO within the flue is shown in Figures 27 and 28. It is clear that there is no marked increase in the CO with the ventilation reduced when compared with the base line test results.

It is therefore possible that the adventitious ventilation into the room with an equivalent free area of 40.06 cm^2 is adequate to enable the appliance to operate satisfactorily without undue spillage and increases in the CO within the flue which one would normally expect as the combustion air requirement is reduced.

The test was repeated by increasing the fuel load to give an output of 8.7 kW and operating the appliance only on the adventitious ventilation into the room. There was no spillage of CO_2 into the room that could be directly attributed to the reduced ventilation rate.

Figure 24 **Variation of CO_2 (sparge) with test room door opened**

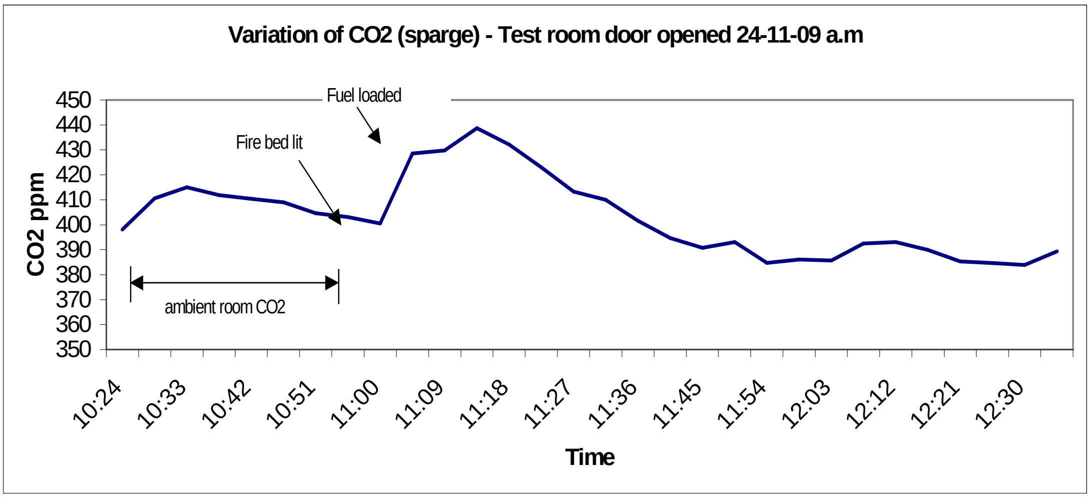


Figure 25 Variation of CO_2 (sparge)- Adventitious ventilation only

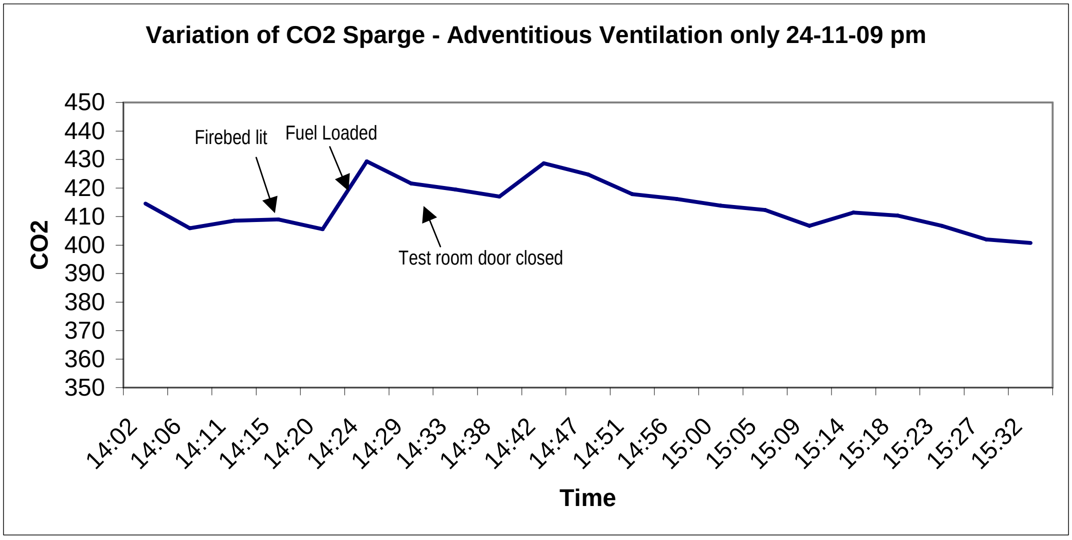


Figure 26 Variation of room pressure

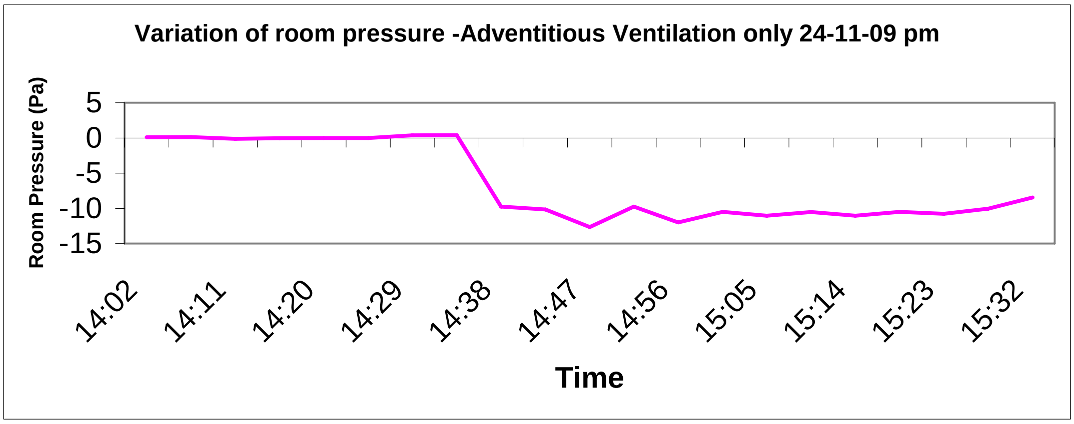


Figure 27 Variation of CO within the flue- base line test results

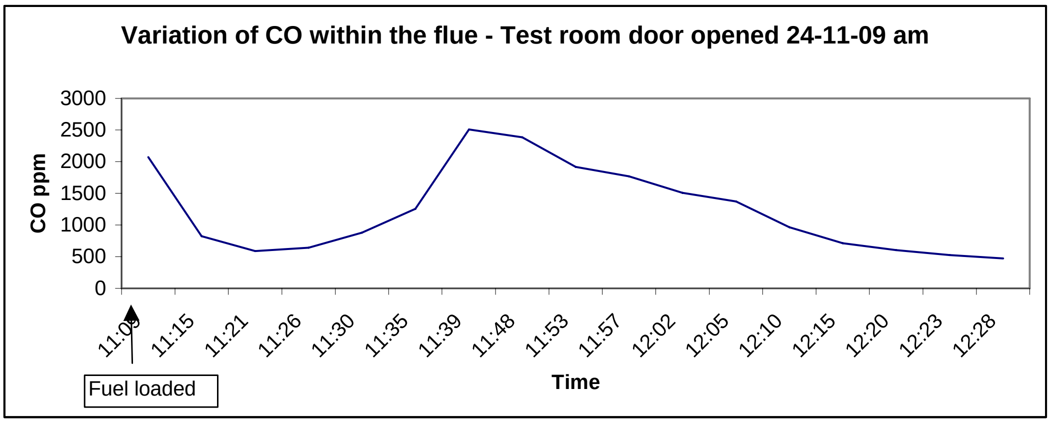
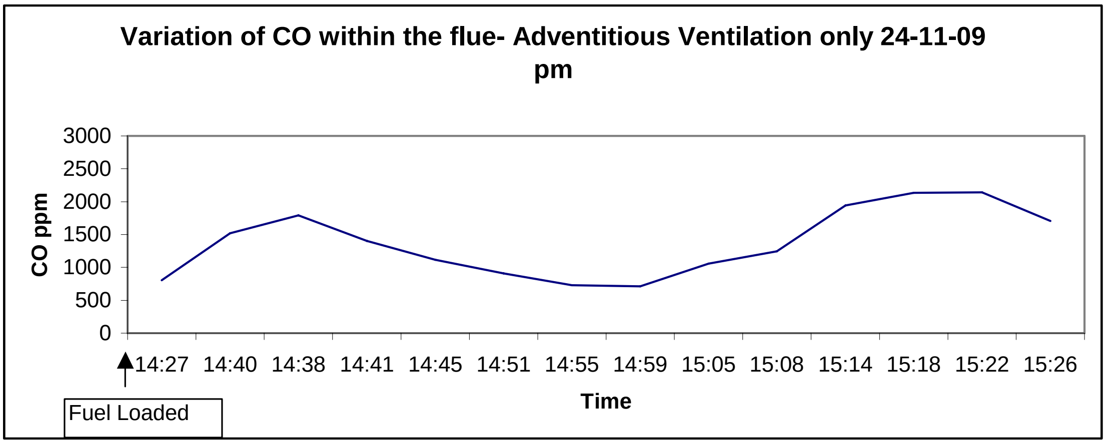


Figure 28 Variation of CO within the flue- adventitious ventilation only



6 APPLICATION OF THE TEST RESULTS TO DWELLINGS

Air permeability data for 30 dwellings measured during this study is shown in figure 29. This represents the air permeability for the whole dwelling. Air permeability data for the living room only is shown in figures 30 to 33. Out of the batch of 30 dwellings, only two had fireplaces and these are indicated by dwellings number 29 and 30.

With reference to Figure 29, all of the dwellings met the requirement of Part L and achieved an air-tightness between 4 and 8 $m^3/(h.m^2)$ at 50 Pa.

Figure 29 Air leakage rate of complete houses

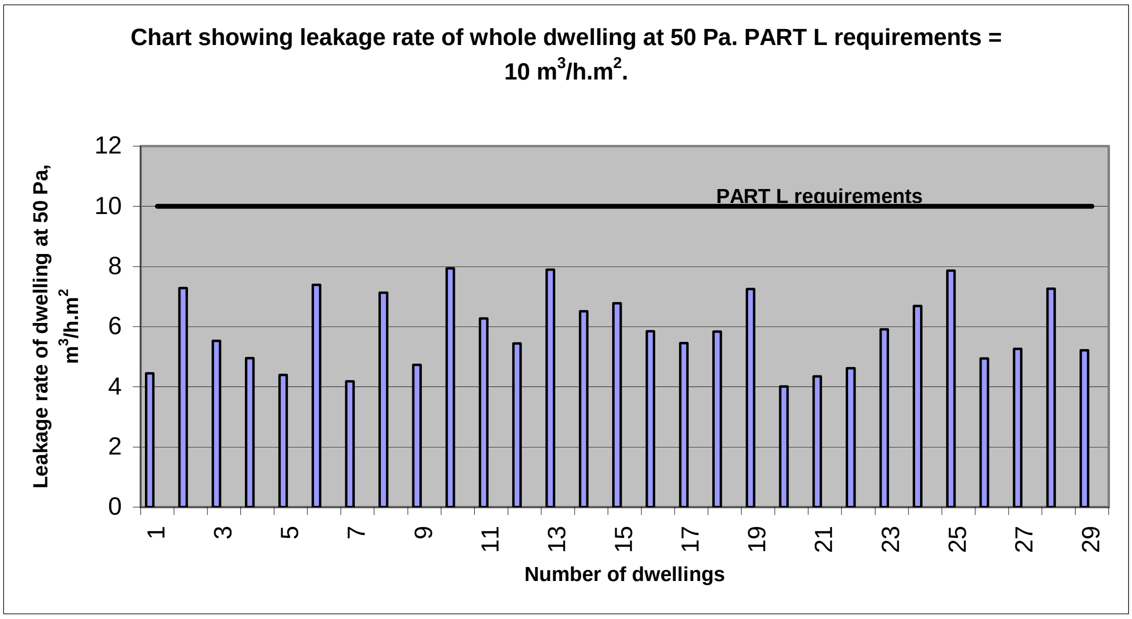


Figure 30 Adventitious ventilation area of living rooms at Pc = 5.06 Pa

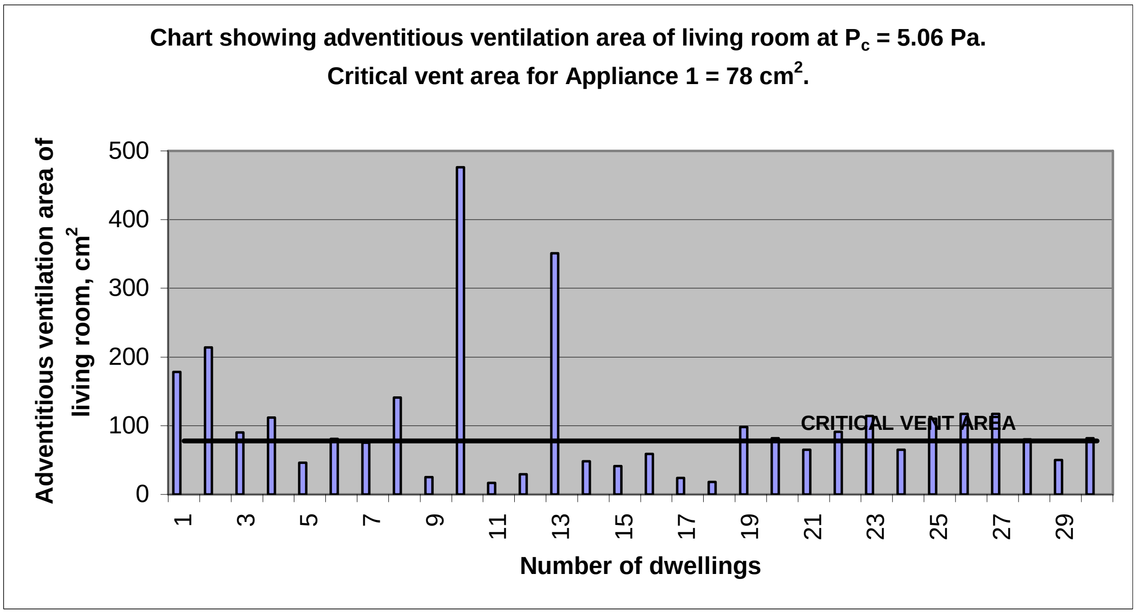


Figure 31 Adventitious ventilation area of living rooms at Pc = 4.0 Pa

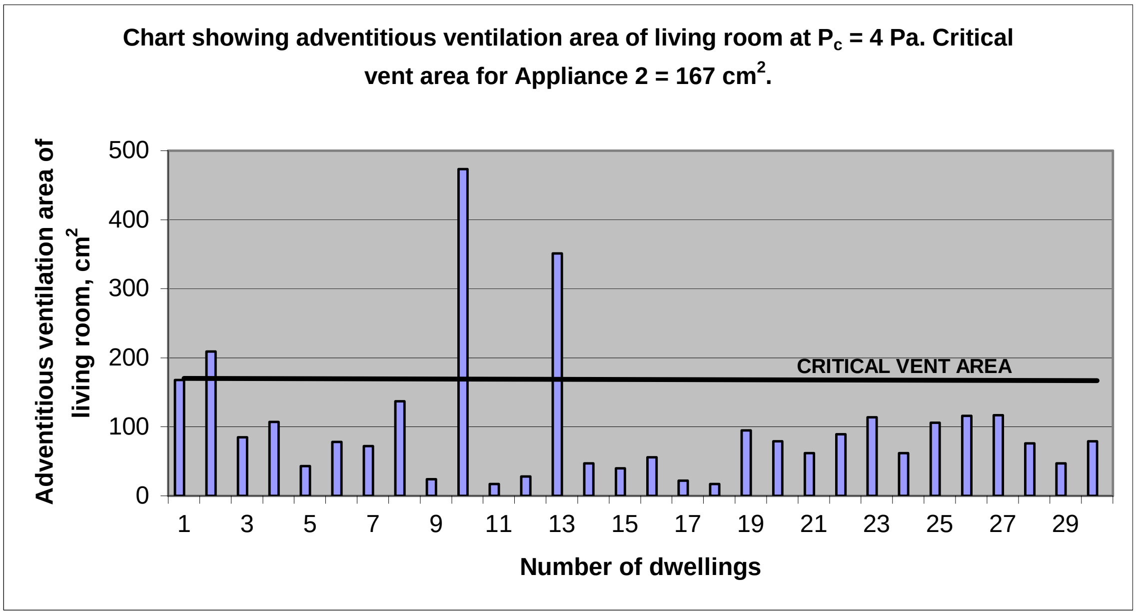


Figure 32 Adventitious ventilation area of living rooms at Pc = 13.31 Pa

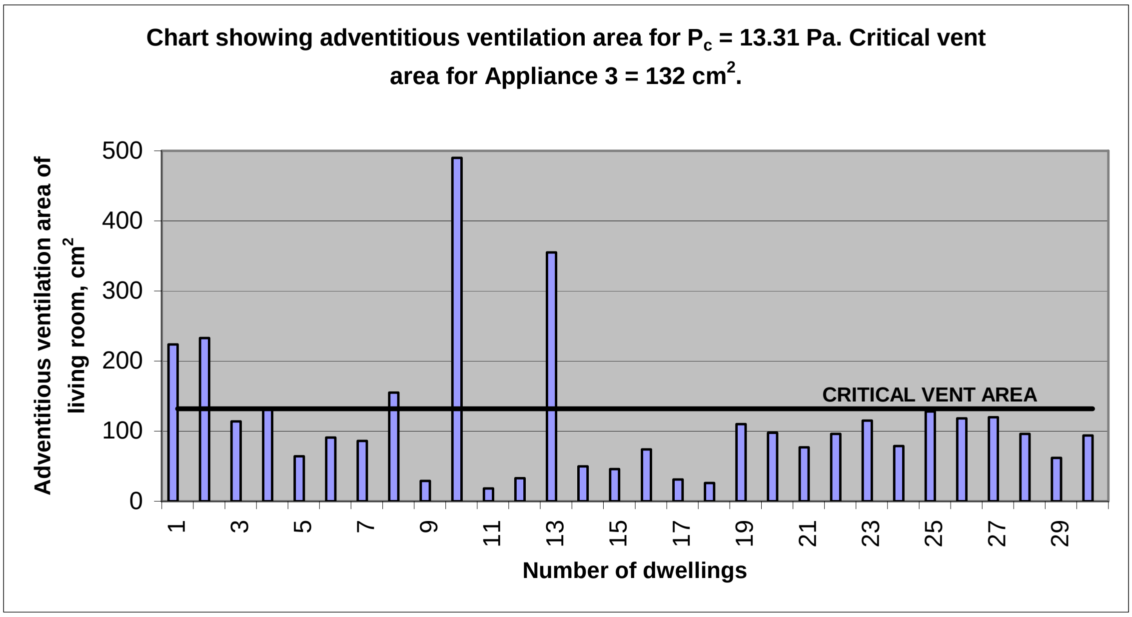
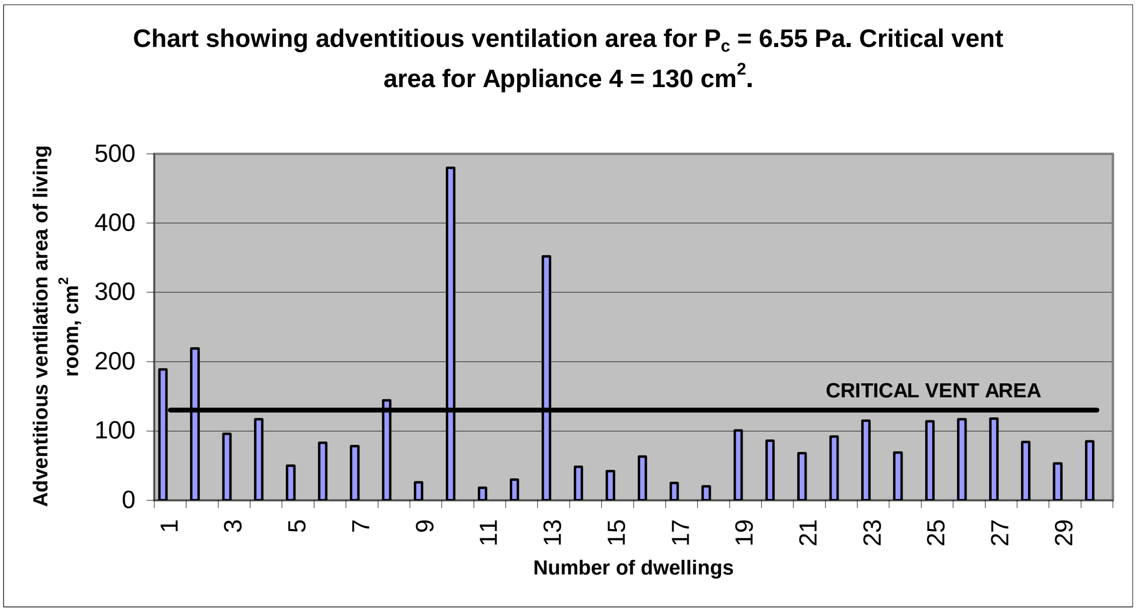


Figure 33 Adventitious ventilation area of living rooms at Pc = 6.55 Pa



Figures 30 to 33 show the adventitious ventilation of the living room which is calculated in terms of the free leakage area at the critical room pressures achieved during the laboratory tests for each appliance. This is to enable a comparison of the critical ventilation area determined from the laboratory test with the amount of adventitious ventilation available from the living room only. The adventitious ventilation excludes the free area under the door to the living room. It is evident from figures that if the free vent area under the door to the living room is not included, then the adventitious ventilation for the majority of dwellings expressed in terms of the free leakage area is well below the critical value that will allow the appliances to operate safely.

The effect of including the free area under the door is to increase the adventitious ventilation to the living room. This is illustrated in Figures 34-37 and shows that in all of the dwellings with the exception of dwelling nos. 4, 11, 19 and 20 in Figure 35 the adventitious ventilation including the contribution from the free area under the door exceeds the critical ventilation requirement for all 4 appliances. It is important to note that the adventitious ventilation under the door to the living room in terms of the free area and its contribution to meeting the minimum ventilation requirements depends also on the adventitious ventilation of the whole house excluding the living room. If we take for example dwelling number 7 which has the lowest air leakage rate of around 4.0 $m^3/(h.m^2)$, (see Figure 29), the adventitious ventilation of the whole house excluding the living room is around 280 cm^2 at critical pressure of 4.0 Pa compared to the free area under the living room door is 212 cm^2. i.e. the whole house ventilation (cm^2) excluding the living room, exceeds that of the free area under the door.

Figure 34 Adventitious ventilation area of living rooms + effective free area under doors at Pc = 5.06 Pa

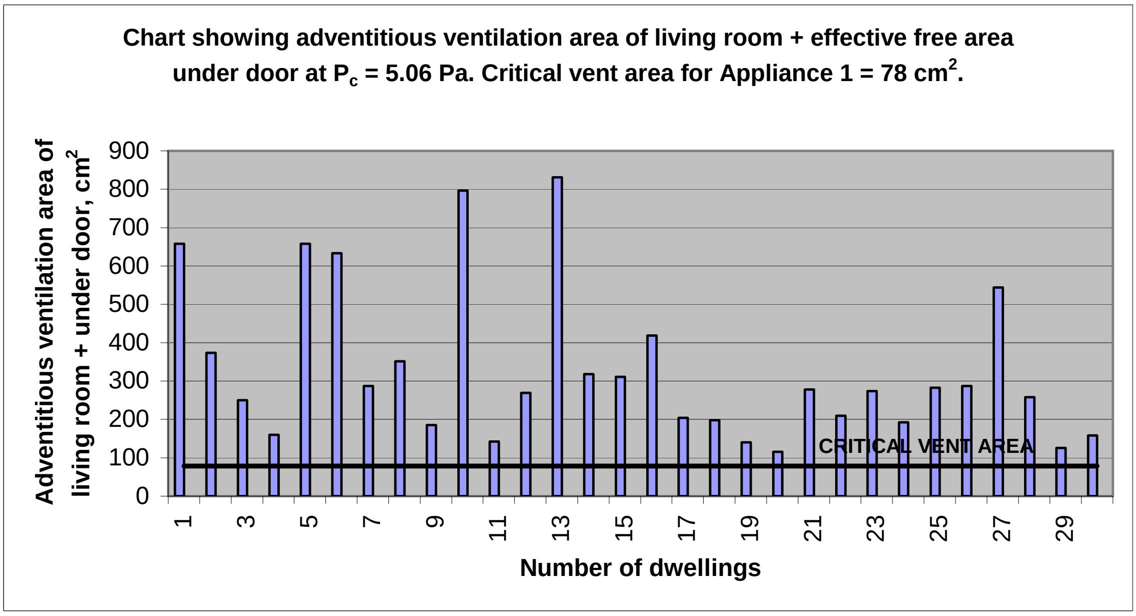


Figure 35 Adventitious ventilation area of living rooms + effective free area under doors at Pc = 4.0 Pa

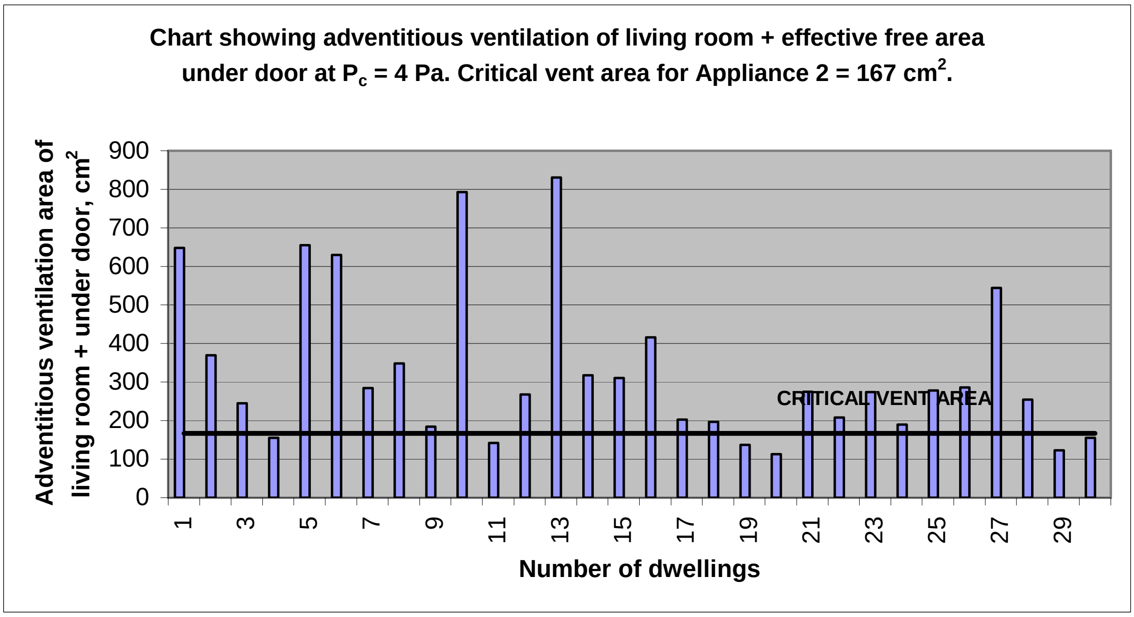


Figure 36 Adventitious ventilation area of living rooms + effective free area under doors at Pc = 13.31 Pa

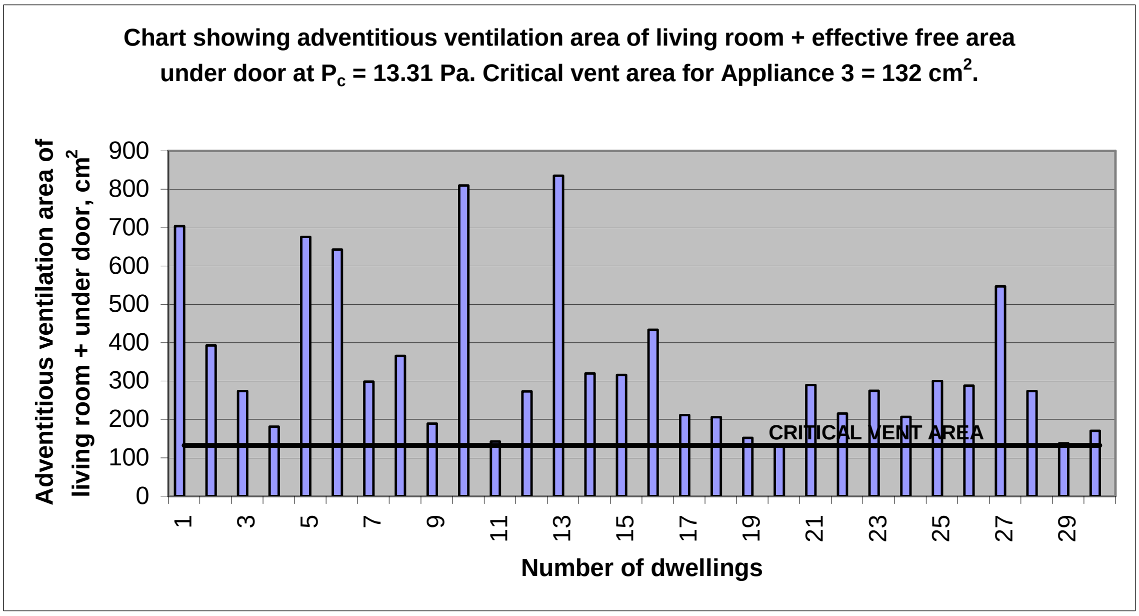
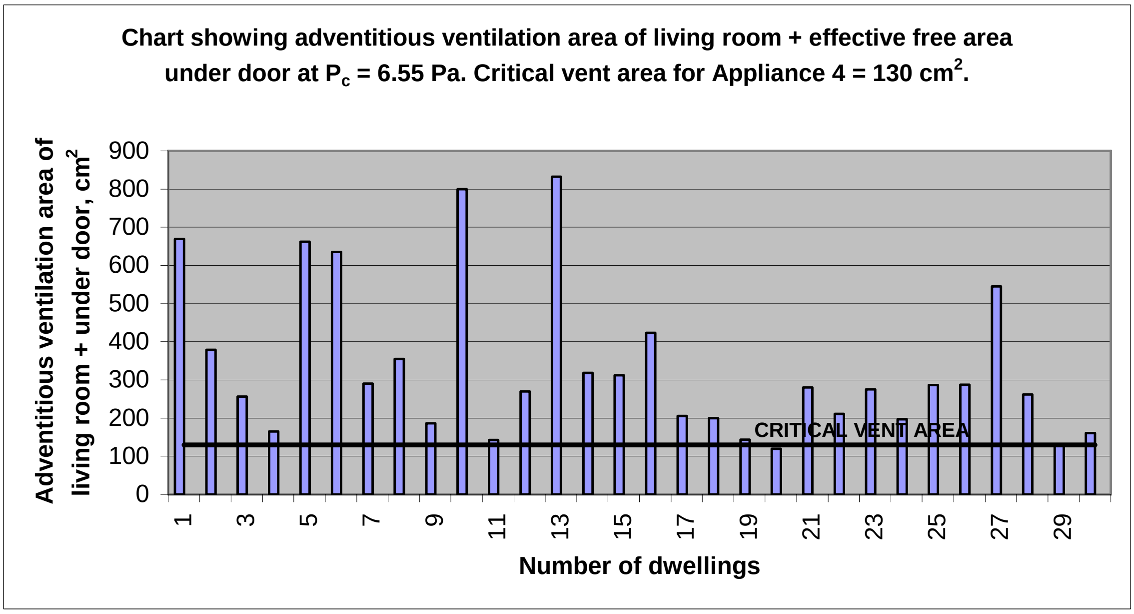


Figure 37 Adventitious ventilation area of living rooms + effective free area under doors at Pc = 6.55 Pa



In all of the dwellings tested, examination of the air permeability data for the whole house shows that the contribution of the adventitious ventilation from the whole house is adequate to meet the minimum ventilation requirements for the appliances tested in this study. See Figures 38 41.

Figure 38 Adventitious ventilation area (Whole House) vs ventilation requirement for Appliance 1

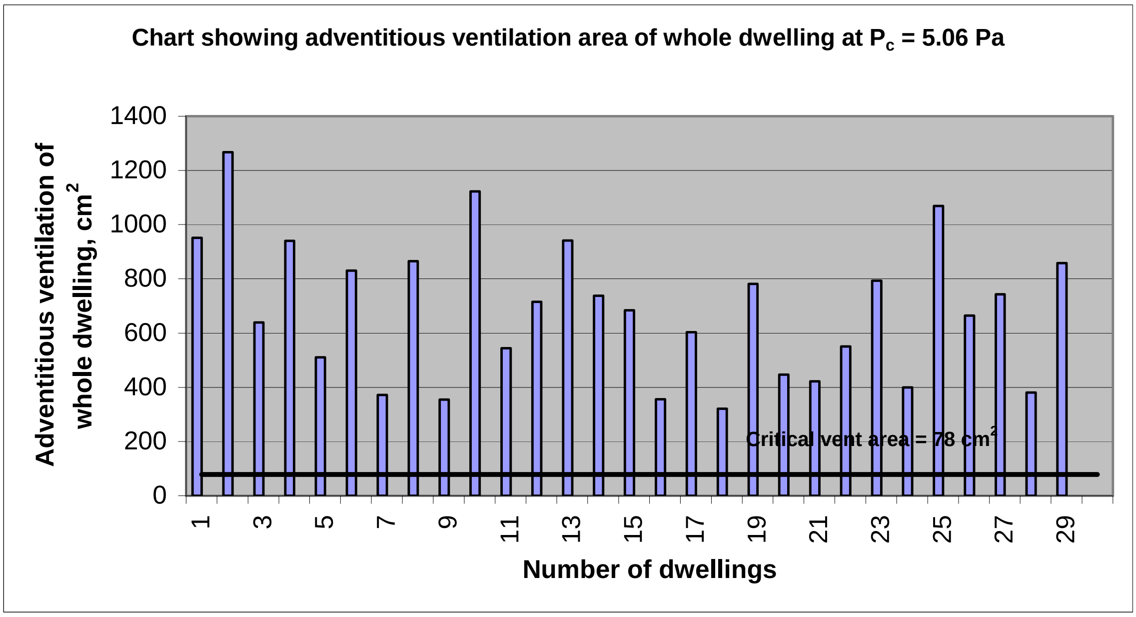


Figure 39 Adventitious ventilation area (Whole House) vs ventilation requirement for Appliance 2

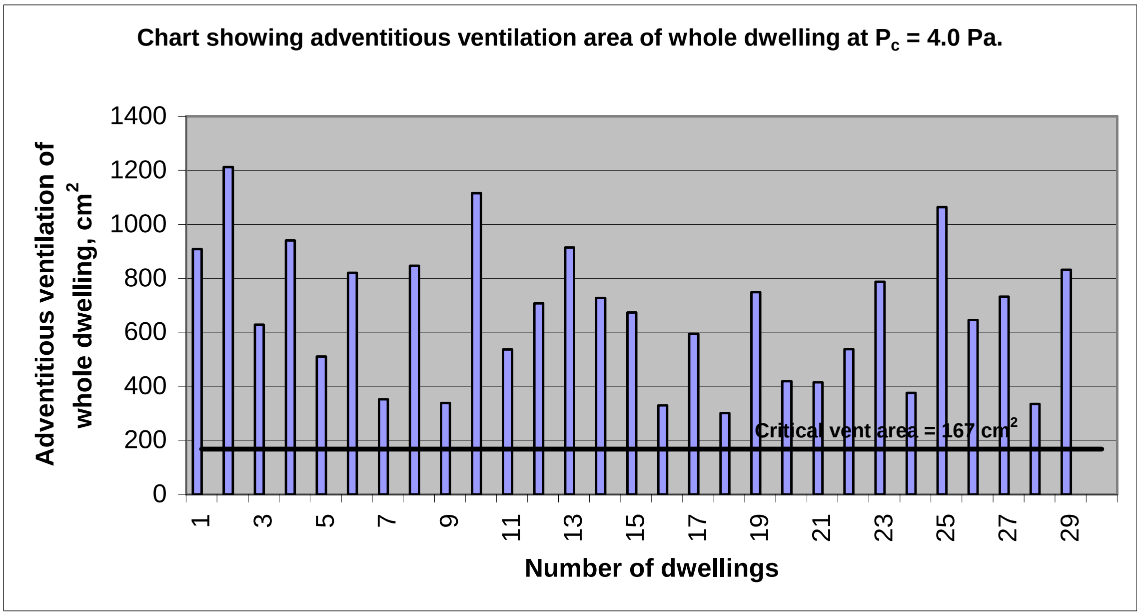


Figure 40 Adventitious ventilation area (Whole House) vs ventilation requirement for Appliance 3

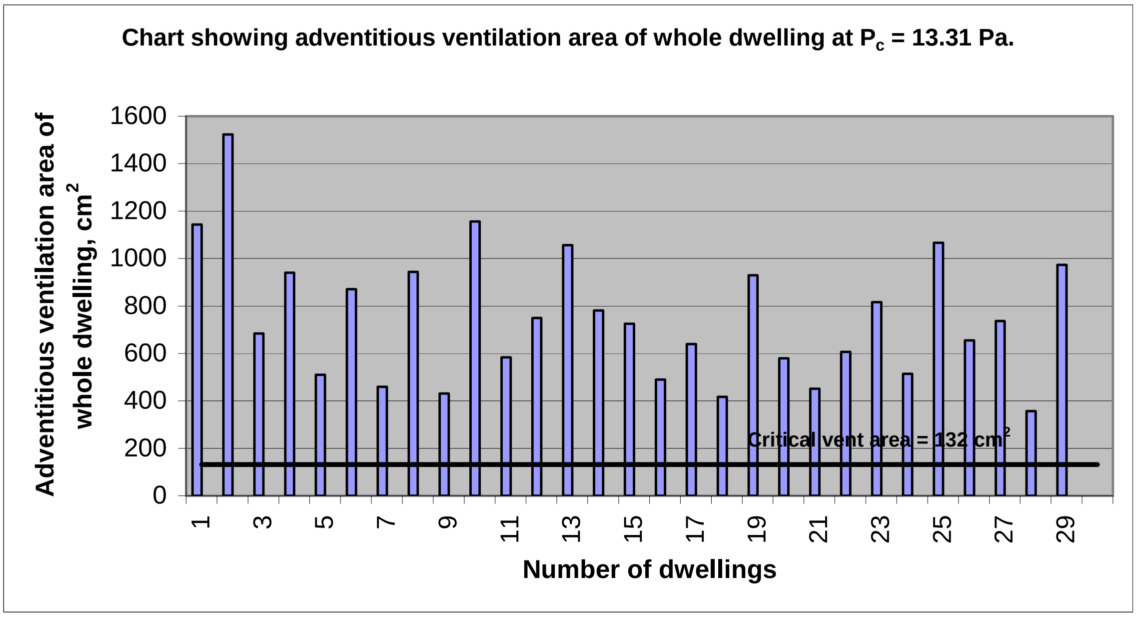
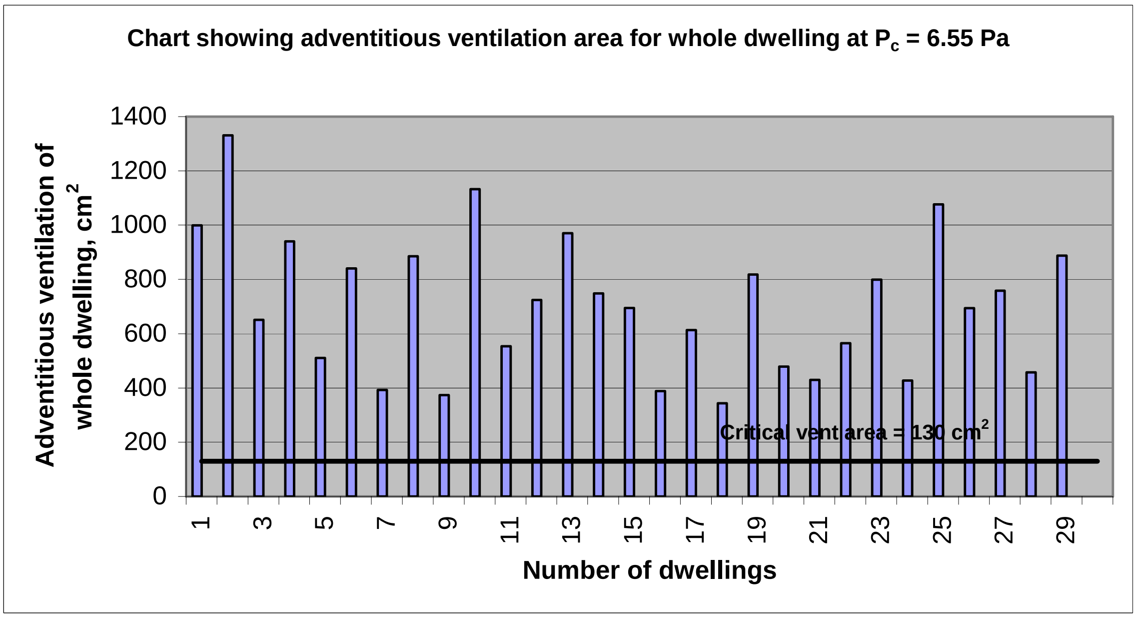


Figure 41 Adventitious ventilation area (Whole House) vs ventilation requirement for Appliance 4



One general observation resulting from the air permeability field results is that whilst the air permeability for more that one dwelling is the same, the air permeability of the living rooms can vary significantly from dwelling to dwelling. For example dwellings no 4 and 9 both achieved an air permeability of 4.95 and 4.73 $m^3/(h.m^2)$ @ 50 Pa. The corresponding air permeability of the individual living rooms were respectively 3.36 and 1.01 $m^3/(h.m^2)$ @ 50 Pa. Other observations noted were; the whole dwelling may have a high leakage rate but achieves a better air permeability result on the living room. For e.g. dwelling no. 11 achieved an air permeability of 6.27 $m^3/(h.m^2)$ @ 50 Pa with the living room achieving a corresponding air permeability figure of 0.48 $m^3/(h.m^2)$ @ 50 Pa.

Figure 42 shows the ventilation requirements (adventitious) for all 4 gas appliances plotted against the adventitious ventilation available from a dwelling (whole house) that achieved an air permeability figure of 4.95 $m^3/(h.m^2)$ @ 50 Pa. The equivalent adventitious ventilation (whole house) at the critical pressure of 4 Pa was calculated at 902 cm^2 and this is shown on the graph for comparison. It is evident that for appliance 2, which has the largest ventilation requirement of 167 cm^2, the ventilation from the whole house is approximately 5 times more than the critical value required. Note the critical value of the room pressure of 4 Pa was chosen for this comparison as this is the minimum value of the critical room pressure from the range of appliances tested in this study.

Figure 42 Adventitious ventilation for a dwelling with an air leakage of 4.95 $m^3/(h.m^2)$ at 50 Pa

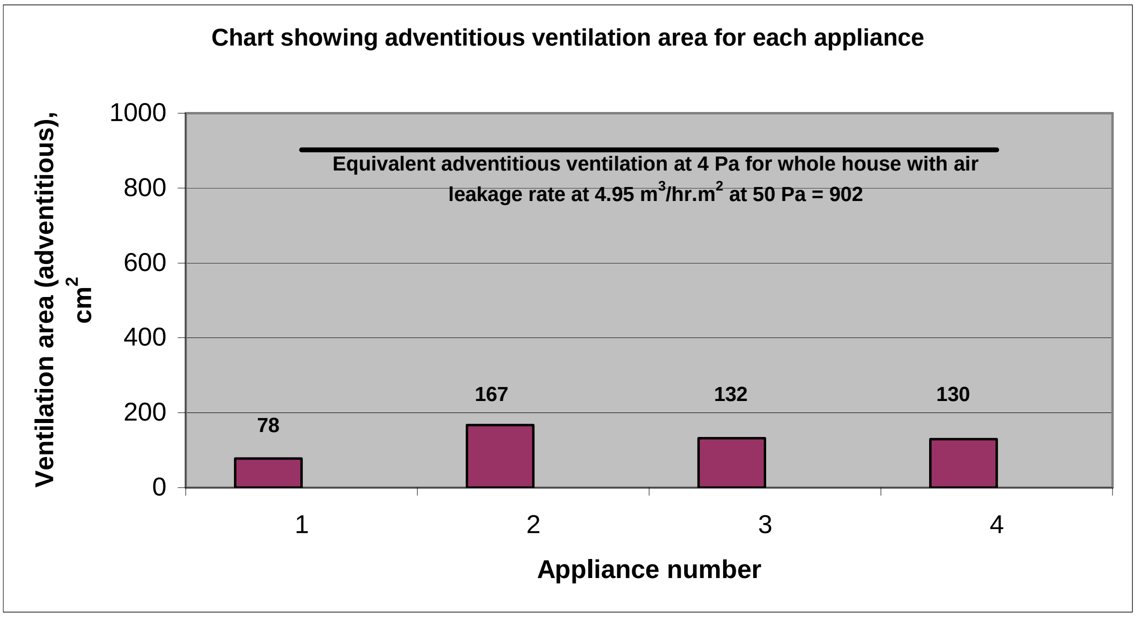


Figure 43 shows the measured air permeability of the living rooms for the dwellings tested in this study. The air permeability excludes the free area under the doors to the living rooms. With the exception of dwellings 19 and 13, the air permeability varies between 1 and 6 $m^3/(h.m^2)$.

If the air permeability of the living room is considered on its own (excluding the free area under the living room door), it was shown in Figures 30 to 33 that the adventitious ventilation available would not be sufficient to meet the minimum ventilation requirements of the gas appliances tested in this study. Figures 44 to 47 shows the supplementary ventilation that would therefore be required from a purpose provided vent to meet the critical ventilation rate for each appliance. Only those dwellings that require supplementary ventilation are shown on the charts. A discharge coefficient of 0.89 is used to determine the ventilation area for the purpose provided vent. The free area of the purpose provided vent was calculated from the critical ventilation flow rate for each appliance and the measured air permeability of the living room.

In general, the supplementary free ventilation area required from a purpose provided vent depends on measured air permeability of the living room and the appliance type. Table 4 summarizes the minimum air permeability of the living room excluding the free area under the door below which purpose provided ventilation is required.

Table 4 Minimum air permeability values for living room only excluding free area under living room door

Appliance no	Minimum air permeability of living room ^{3}/(h.m^2) @ 50 Pa
1	2.88
2	5.76
3	3.36
4	3.36

Figure 43 Measured air permeability of living rooms excluding free area under the living room door

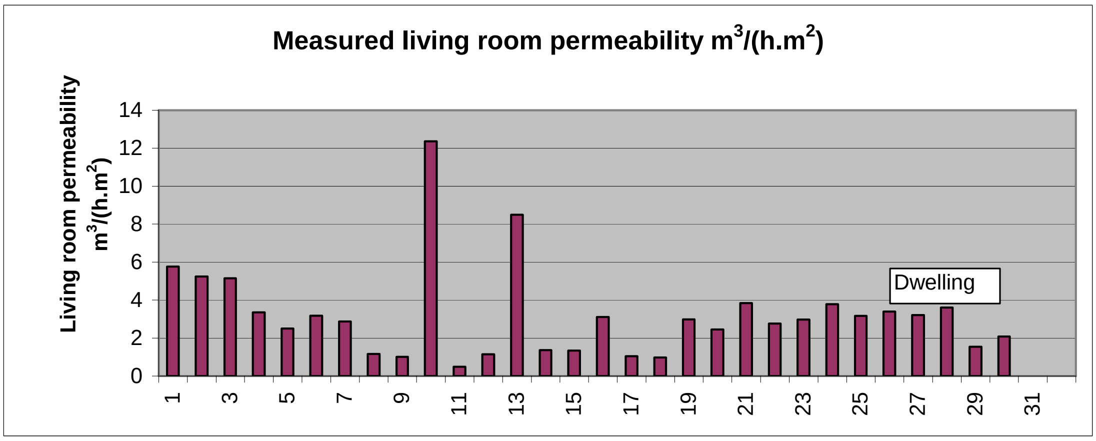


Figure 44 Supplementary ventilation required for living room excluding free area under door

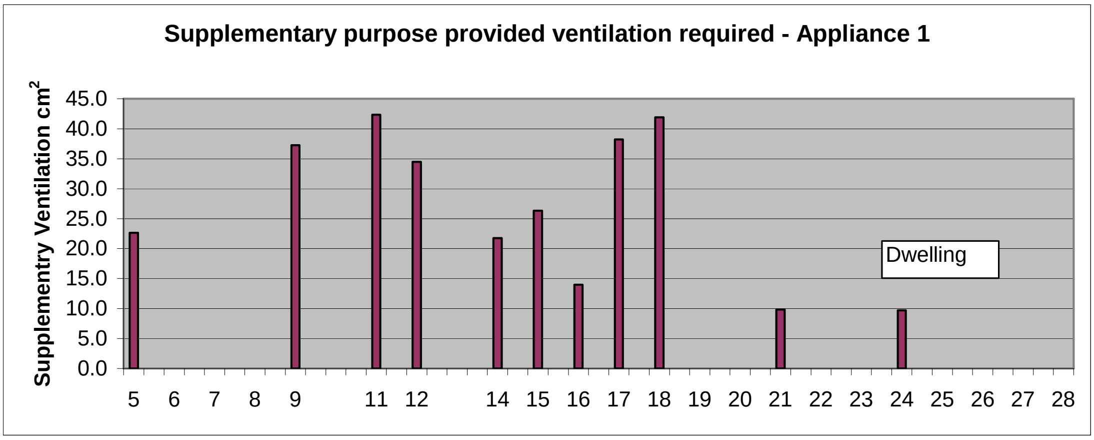


Figure 45 **Supplementary ventilation required for living room excluding free area under door**

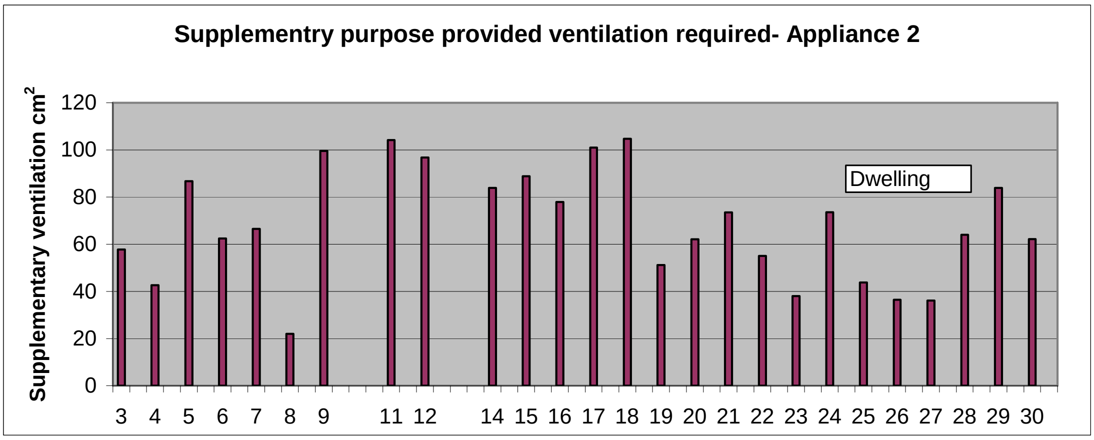


Figure 46 **Supplementary ventilation required for living room excluding free area under door**

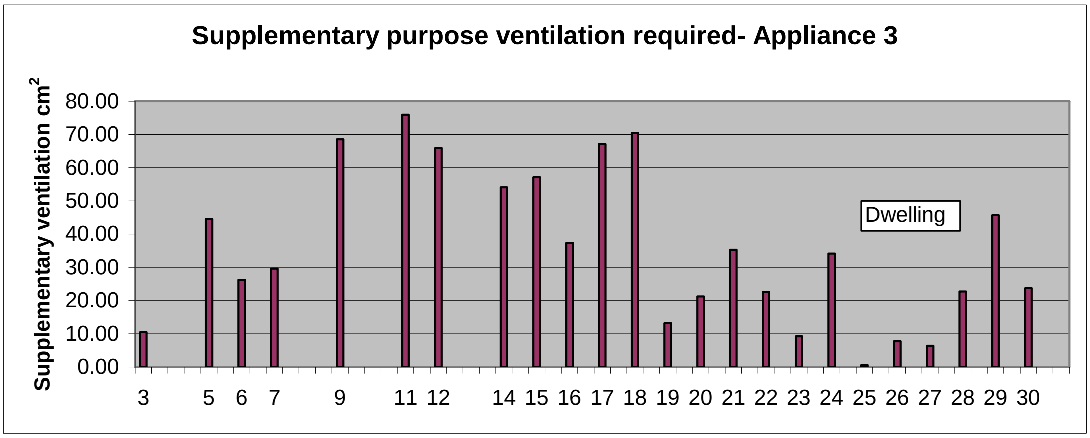
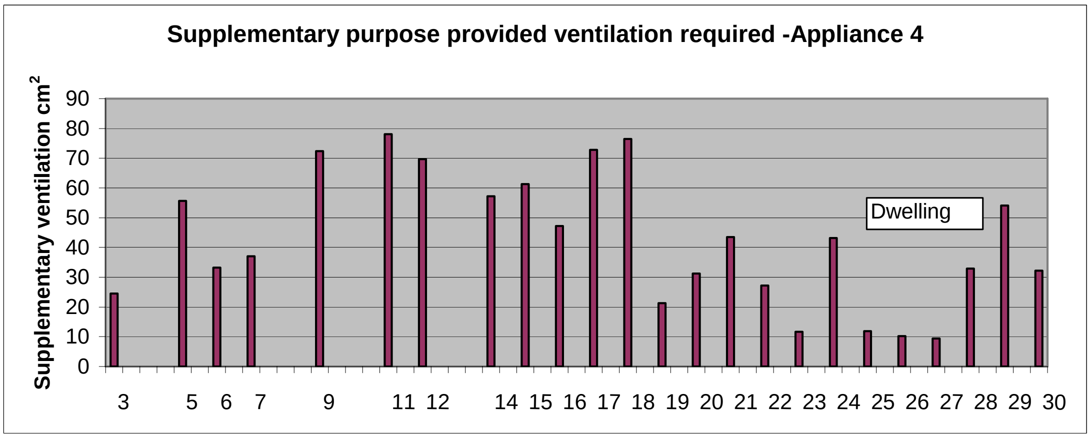


Figure 47 **Supplementary ventilation required for living room excluding free area under door**



7 CONCLUSIONS

Laboratory tests were carried out on 4 gas fires and 1 wood burning stove to determine the minimum ventilation requirements for each appliance to achieve safe combustion without the spillage of the combustion products within the enclosed living space. Air permeability tests were also carried out on 30 new dwellings to determine whether the adventitious ventilation available would be sufficient to meet the minimum ventilation requirements for the appliances tested in the study. The main findings are given below:

1. For a glass fronted inset living flame effect fire (Appliance 1) with a net input of 5.5 kW, the critical ventilation area (adventitious) required for this appliance to operate safely without spillage of the combustion products was determined to be 78.4 cm^2. The equivalent critical free area for a purpose provided vent in a room that is completely airtight was determined as 51.1 cm^2 based on a discharge coefficient of 0.89. It is not possible to make a direct comparison of the test results with the Part J requirement as the current ventilation requirement is only for appliances in excess of 7 kW input (net). There is no other published data to confirm what the adventitious ventilation is for an appliance below 7 kW input (net) to operate satisfactorily without spillage of the combustion products.

2. The critical adventitious ventilation required for an open fronted inset living flame effect fire (appliance 2) to operate without spillage of the combustion products was 167 cm^2. The appliance is rated at 7.0 kW net input. The equivalent critical free area for a purpose provided vent in a room that is completely airtight was determined as 115 cm^2 based on a discharge coefficient of 0.89. The current ventilation requirement in part J is only for appliances exceeding 7 kW input (net).

3. Tests with a DFE fire with a rated input of 7.6 kW (net) showed that the critical adventitious ventilation required to operate safely without the spillage of combustion products was 132 cm^2. The equivalent critical free area for a purpose provided vent in a room that is completely airtight was determined as 90 cm^2 based on a discharge coefficient of 0.89. The current part J requirements for this particular appliance in a recess with throat is that the vent area for a purpose provided vent should be no lower than 100 cm^2. There is however no indication as to what adventitious ventilation this requirement is based upon.

4. Tests were also conducted at a lower input (net) of 2.04 kW for the DFE fire. The critical adventitious ventilation was determined as 130.0 cm^2 and 89.1 cm^2 for a purpose provided vent fitted to a room that is completely airtight.

5. No safety factor is included in the critical ventilation requirements determined in this study.

6. Tests conducted on a wood burning stove proved inconclusive. No spillage of the combustion products into the room was detected at the worst-case condition that could be directly attributed to the reduced ventilation into the room. The average room pressure measured during the test was around – 11 Pa. At this pressure, it was clear that no spillage into the room was induced. The adventitious equivalent free area of the test room at this pressure was 40.6 cm^2. With an increased fuel loading, there was no evidence of spillage that could be attributed to the reduced ventilation rate into the room. Other important observations made of the appliance is that it is a “closed” appliance designed with access doors that are well sealed when closed and this would inevitably prevent the combustion gases from spilling easily into the test room.

7. The results of the air permeability tests conducted on 30 dwellings showed that all the dwellings complied with the Part L requirements of 10 $m^3/(h.m^2)$. Nine dwellings achieved an air permeability value below 5.0 $m^3/(h.m^2)$ with the remainder achieving an air permeability figure below 8.0 $m^3/(h.m^2)$.

8. The air permeability tests which were conducted on the living room only showed that the adventitious ventilation available would be insufficient to meet the minimum requirements to allow the gas appliances tested in this study to operate safely in the majority of dwellings reported in this study. If however the adventitious ventilation of the whole dwelling is considered including the free area under the door to the living room, then it is more than adequate to allow all 4 gas appliances tested in this study to operate safely.

9. The results have also shown that there would be adequate adventitious ventilation in a dwelling which achieves an air permeability of 5.0 $m^3/(h.m^2)$ for all 4 types of gas appliances tested in this study. This conclusion is however based on the adventitious ventilation from the whole dwelling and not the living room. In some dwellings which achieved an air permeability of 5.0 $m^3/(h.m^2)$, the air permeability of the living room was observed to vary from dwelling to dwelling.

10. The equivalent adventitious ventilation (whole house) from a dwelling which achieved an air permeability of around 5.0 $m^3/(h.m^2)$ at 50 Pa was 902 cm^2 at a room pressure of 4.0 Pa.

8 RECOMMENDATIONS

1. The critical values of the ventilation rates determined during this study were conducted only on a small sample of selected gas appliances. Differences in design and the heat input rating may result in different values of the critical ventilation rate. Further tests should be conducted on more than one appliance of the same type to determine whether the ventilation requirements differ significantly before definitive recommendations can be made to Part J of the Building Regulations.

2. Tests performed on the solid fuel stove proved inconclusive. The results showed that the level of adventitious ventilation may have been adequate to prevent the spillage of the flue gases into the room. As it is not possible to reduce the adventitious ventilation of the test room, tests should be repeated on a similar appliance with a larger heat output. Tests should also be performed with the door of the appliance opened to determine if spillage of CO in particular would occur. This is particularly important in view of the high CO levels in the flue gases. Other types of solid fuel fires which may be tested could include a solid fuel open fire as this type of fire may be more prone to spillage of the flue gases. Because of the tight timescale, it was not possible to include these tests within the scope of the current project.

3. Tests should be conducted on other types of gas appliances not examined in this study to determine their ventilation requirements. These include:

    - Radiant ceramic gas fires
    - Flueless gas fires
    - LPG appliances

APPENDICES

Appendix: A Ventilation Test Facility at BSRIA